III SESSIONE
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GEO - ARCHEOLOGIA
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Chairman: A. ARNOLDUS-HUYZENDVELD

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Problems of conservation of geological-archaeological sites in the eastern Ukraine

Problemi di conservazione dei siti geologico-archeologici nell'Ucraina orientale

GERASIMENKO N. (*)

ABSTRACT – The category of geo-archaeological site as a protected object is proposed and substantiated for the first time in Ukraine. The geo-archaeological sites are important for determination of geological age of the material cultures, for understanding of causative linkages within the system "environment - society". The evidences of environmental impact on migrations and collapses in the Old Cultures history are available in Ukraine as well as those of the human impact on environment.
The program of selection, preservation and geological studies of the geo-archaeological sites are presented in the paper. The objects of protection from the soil-geological view-point are determined at the geo-archaeological sites. The list of selected geo-archaeological sites for different periods are proposed for the Eastern Ukraine.

KEY WORDS – Geological-archaeological site, Pleistocene, Holocene.

RIASSUNTO – La categoria del sito geo-archeologico come oggetto protetto viene proposta e validata per la prima volta in Ucraina. I siti geo-archeologici sono importanti per la determinazione dell'età delle principali culture e per la comprensione dei legami di causalità nel sistema «ambiente-società». Le evidenze dell'impatto ambientale sulle migrazioni e sui crolli sociali nella storia delle Culture Antiche sono disponibili in Ucraina così come quelle dell'impatto umano sull'ambiente.
Il programma di selezione, la conservazione e gli studi geologici dei siti geo-archeologici sono presentati nell'articolo. Gli oggetti di protezione dal punto di vista pedo-geologico sono determinati sui siti geo-archeologici. Viene presentata la lista dei siti geo-archeologici per i diversi periodi per l'Ucraina orientale.

PAROLE CHIAVE – Sito geologico-archeologico, Pleistocene, Olocene.

1. – INTRODUCTION

The problem of preservation of geo-archaeological localities is of great importance for Ukraine. The famous multi-layered Auchelian - Mousterian - Late Paleolithic sites in Ukraine are characterized by well subdivided complete Pleistocene sequences. But none of such localitiesis is geologically protected. The very category of geo-archaeological site is absent in the existing list of geological sites (KOROTENKO *et alii*, 1987). Since the Mesolith, archaeological sites are related to the Holocene deposits. The last ones in some cases are of great thickness and clearly stratified into the horizons of different genesis containing the cultural layers of different age. The factors of an appearance and upset of the Old Cultures can be studied at such objects. But none of the Holocene sites is regarded as protected soil-geological monuments.

The valuable archaeological sites in Ukraine are protected at state, regional and local range. But with the exception of the world-famous Paleolithic monuments studied by natural sciences methods (the Korolevo, Dobranichevka, Mezhirich sites, so on), they are preserved not from the soil-geological view-point. So, most valuable stratigraphical sequences at the localities can be desroyed. Especially critical conditions for conservation of geo-archaeological sites exist in the Eastern Ukraine. There are no sites protected at the state range here. For example, the Bronze age settlement Bezymenne have been half-destroyed by locals

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just before its arrangement as some kind of geo-archaeological museum. To prevent such tragic accidents the national and regional strategy of geo-archaeological protection should be elaborated and realized.

The Eastern Ukraine is a natural transitional region between the forest-steppe and steppe zones. So, its nature is very sensitive and vulnerable to climatic changes. In the archaeological context, it is a crossroads between the Old Cultures migration flows. Nomadic or husbandry settlement systems change one another during the last six millennia there. So the Eastern Ukraine is a quite appropriate important region to elucidate the cause and effect relationships within the system "environment-society".

2. – THE PROGRAM OF GEOTOP STUDIES AND PRESERVATION AT THE GEO-ARCHAEOLOGICAL SITES

At present, the program of the inventory of the Ukrainian archaeological sites ought to be carried out. We propose that soil-archaeological investigation should be the integral part of this program. Soil-geological signs must to be taken in account for the determination of the range of the site protection. Some sites are not of great significance by their own archaeology but unique in respect of continuous sequences, and so of importance value for another sites. The correlation of archaeological and geochronological dating at the same sites can be used for the working of the local calibration scales. It also approves that geology and archaeology of the sites are of great mutual importance and ought to be studied and protected together. We proposed to distinguish the sites valuable for both scientific areas as special type of protection objects - geo-archaeological ones represented in the lists of both types of sites.

The objectives of geotop investigations at the archaeological sites should include:

1. To determine the geological age of cultural layers by stratigraphical and geochronological methods
2. To reconstruct the palaeoecological setting of ancient men by the multi-disciplinary complex of lithological-palaeogeographical methods
3. To explain the selection of the site (settlement) locations and, finally, to explain the settlement pattern for every period
4. To reveal the impact of the settlement subsistense activity on the environment (local or regional one, with short or long-term consequences)
5. To estimate the natural conditions of the investigated period against the background of those of wider chronological interval (the Pleistocene, the Holocene)
6. To correlate the data obtained from the different sites. Judging from the last objective, to realize the program at all geo-archaeological sites is essentially important.

The complex of lithological-palaeogeographical methods includes lithological namely, palaeogeomorphological, palaeopedological, palynological, malacological ones. The other palaeoenvironmental indicators (microvertebrates, mammals, paleobotanical macrofossils) should be used whether they are preserved in the sites.

The accurate determination of right stratigraphical position of a cultural layer is a primary task of investigation. The problem is that the consequent soil-geomorphic processes can destort the real position of a cultural layer. For example, very slow hillwash processes along gentle slope can involve artifacts and transfer them somewhere down almost imperceptibly for archaeologists regarded them as a cultural layer "in situ". Plant roots, desiccation (or frost) fissures and especially pedofauna are the other potent factors of perversion of primary position of a cultural layer. At last, some types of soils are characterized by a deep downward reworking of the solum with embedded artifacts. To avoid mistakes, lithological-palaeogeographical studies need vast excavations allowing to trace the cultural layer extent along the soil catena and palaeorelief profile. The more number of sections located at different elements of relief has been excavated, the better for palaeoecological reconstruction. So, the complex of sites located hereabouts is always preferable to be regarded as geo-archaeological site than a single locality. The top surface pollen samples should be analysed to make correct interpretation of palaeoenvironment based on the comparison with the present environmental conditions at the site locality.

The objects of protection at the archaeological sites from the soil-geological point of view should include the preservation of the most complete soil-geological sequences (in some cases even without cultural layers, dated by geochronology only), the sequence with the cultural layers in their primary undistorted stratigraphical position and those with their typical position (for the demonstration of postsedimentary processes), the sequences with cultural layers in household structures: pits, dwelling deep floor, so on (for the illustration of different sedimentation rates) and, at last, standard natural sequences located at some reasonable distance from the site. This allows to estimate the human disturbance of the environment.

3. – GEO-ARCHAEOLOGICAL SITES PROPOSED FOR PROTECTION IN THE EASTERN UKRAINE

The task of a scientist-geoprotectionist is to provide the scientific subsumption for the selection and conservation of valuable objects. For many years, the Author studies the natural sequences of the Eastern Ukraine and co-works with archaeologists in the pollen and soil-stratigraphical investigations of some sites of Mousterian, Late and Final Palaeolithic, Mesolithic, Neolithic, Bronze Age, Scythian and Medieval cultures. The stratigraphical basis for the studies of the Palaeolithic is the Ukrainian Stratigraphical Scheme of the Pleistocene (VEKLICH *et alii*, 1993). Stratigraphical basis for studies of the Holocene is the Blytt - Sernander scheme in the modification of HOTINSKY (1977). More than 20 environmental oscillations have been recognized (GERASIMENKO, 1995) from the Holocene deposits (fig.1). The reconstruction of ecotones for each stage of the Late Pleistocene have been revealed as well as the dynamics of their complicated fluctuations within every stage. The chronological (and stratigraphical) units of both schemes have been related to the stages of material cultures development. Of course, both schemes should be further elaborated and probably corrected in details. But some interesting conclusions for archaeology can be drown from the diagrams just now. For example, direct relations between arid climatic events and collapses of husbandry or sedentary subsistence system (1800-1700 BC, 1000-700 BC, 200 AD). In order to elucidate the geological age and peculiarites of the development of the material cultures, such geo-archaeological sites are proposed to be protected in the Eastern Ukraine (fig. 2).

3.1. – THE DONETSK REGION

3.1.1. – *Paleolithic*

Korniyiv Yar (excavation by KOLESNIK, 1986) - 1 - a single stratigraphically subdivided section with the Acheulian artifacts.

Zvanivka (excavation by KOLESNIK, 1977-1981) - 2 - demonstrates the Mousterian cultural layer related to the 5b isotopic substage.

Bilokuz'mynivka (excavation by TSVEYBEL', 1966-1970, by KOLESNIK, 1986) - 15 - the multi-layered Mousterian complex related to the 5c, 5a and 4 isotopic stage.

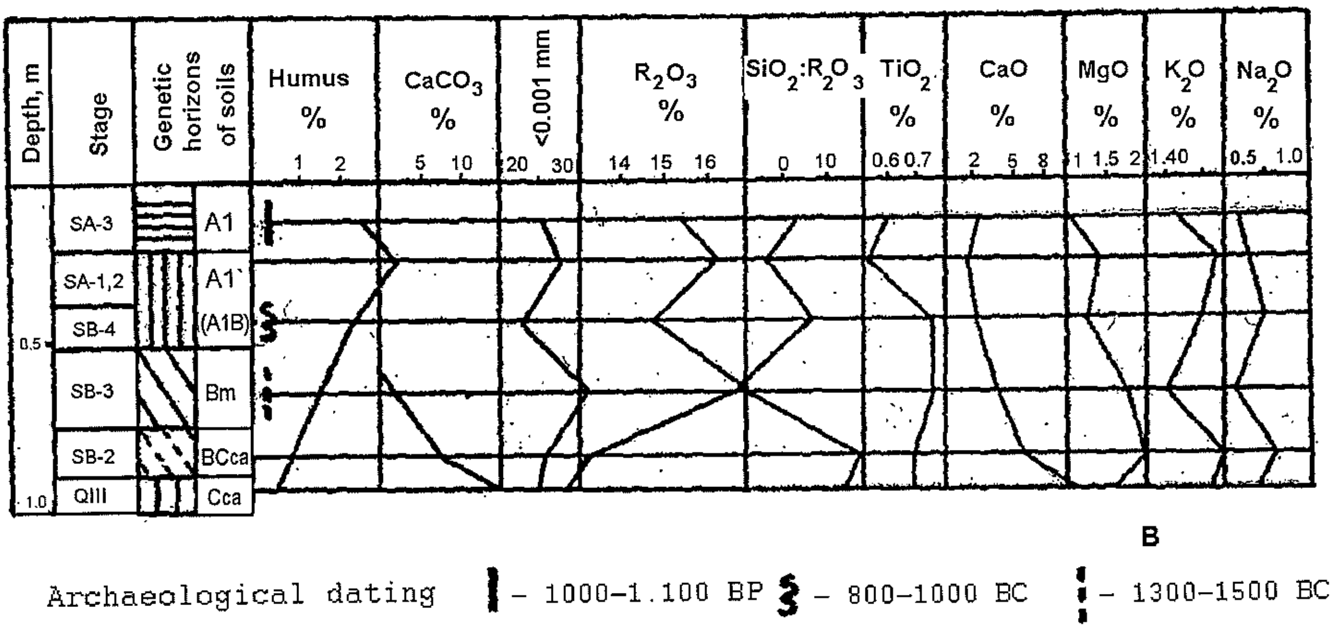

Fig. 1. – Diagram of the stages of vegetation dynamics in the Holocene and their relations to the stages of the material culture development for the South-Eastern Ukraine. The comparison with the stages of the Kaidaky temperate interval of the Pleistocene (isotopic subtage 5e): prognostic aspects.

– Diagramma degli strati della dinamica della vegetazione nell'Olocene e delle loro relazioni con gli strati dello sviluppo delle colture principali per l'Ucraina Sud-Orientale. Il confronto con gli strati dell'intervallo temperato di Kaidaky del Pleistocene (substage isotopico 5e): aspetti rivelatori.

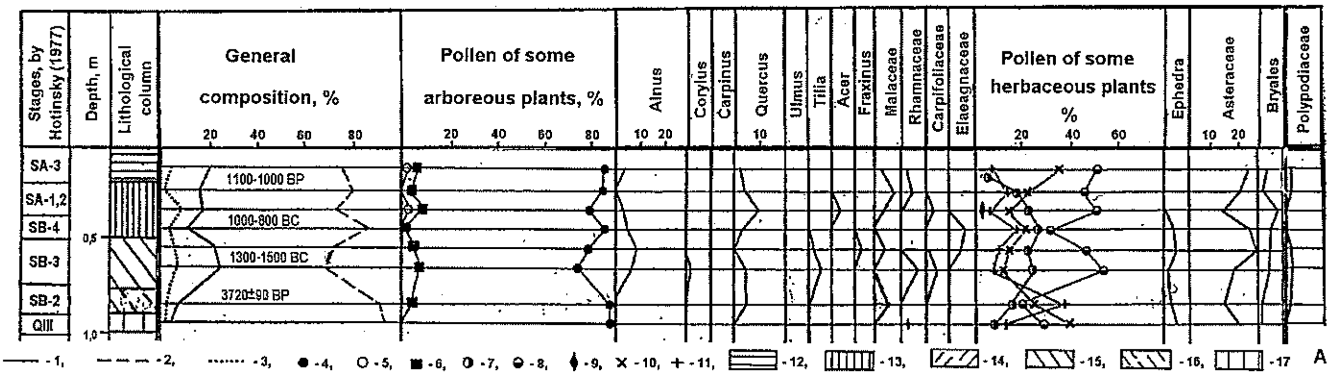

Fig. 2. – Map of archaeological localities in the Eastern Ukraine proposed to be preserved as geoarchaeological sites. A - Auchelian, B. - Mousterian, C - Late Paleolithic, D - Final Paleolithic, E - Mesolithic, F - Neolithic, G - Bronze Age, I - Scythian, K - Medieval sites. The names of localities: 1 - Korniyiv Yar, 2 - Zvanivka, 3 - Pidgorivka, 4 - Starobil'sk, 5 -Shevchenko, 6 - Peredil'sk, 7 - Rogalyk, 8 - Synychyne, 9 - Sloboda, 10 -Novoselivka, 11 - Illichivka, 12 - Glyboke Ozero, 13 - Ol'khova, 14 - Sydorove, 15 - Bilokuz'mynivka, 16 - Kurdyumivka, 17 - Bila Gora, 18 - Sabivka, 19 - Minchekur, 20 - Zymivnyky, 21 - Igren', 22 - Stari Kaydaky, 23 - Kamyanka - Dnieprovs'ka, 24 - Amvrosievka, 25 - Novoklynivka, 26 - Bezymenne, 27 - Lyapina Balka, 28 - Kamyshuvata - Buyluvata, 29 - Chokrak, 30 - Kitey, 31 - Sary-Kaya, 32 - Kabazi, 33 - Grotto Skalisty

– Mappa delle località archeologiche nell'Ucraina Orientale proposte per essere conservate come siti geoarcheologici. A - Auchelian, B - Mousterian, C - Late Paleolithic, D - Final Paleolithic, E - Mesolithic, F - Neolithic, G - Bronze Age, I - Scythian, K - Medieval sites. The names of localities: 1 - Korniyiv Yar, 2 - Zvanivka, 3 - Pidgorivka, 4 - Starobil'sk, 5 -Shevchenko, 6 - Peredil'sk, 7 - Rogalyk, 8 - Synychyne, 9 - Sloboda, 10 -Novoselivka, 11 - Illichivka, 12 - Glyboke Ozero, 13 - Ol'khova, 14 - Sydorove, 15 - Bilokuz'mynivka, 16 - Kurdyumivka, 17 - Bila Gora, 18 - Sabivka, 19 - Minchekur, 20 - Zymivnyky, 21 - Igren', 22 - Stari Kaydaky, 23 - Kamyanka - Dnieprovs'ka, 24 - Amvrosievka, 25 - Novoklynivka, 26 - Bezymenne, 27 - Lyapina Balka, 28 - Kamyshuvata - Buyluvata, 29 - Chokrak, 30 - Kitey, 31 - Sary-Kaya, 32 - Kabazi, 33 - Grotto Skalisty

Kurdyumivka (excavation by KOLESNIK, 1987-1992) - 16 - the most complete and thick Upper Pleistocene section among the Mousterian localities of the region.

Bila Gora (excavation by KOLESNIK, 1988) - 17 - demonstrates the Upper Paleolithic cultural layer related to the 3 isotopic stage.

Synychyne (excavation by SNEZHKO, 1989,1995) - 8 - demonstrates the Late Paleolithic cultural layer related to the 2 isotopic stage.

Sydorove (excavation by KOLESNIK, 1993-1996) - 14 - demostrates the Final Paleolithic cultural layer related to the Late Glacial deposits (located in the valley).

Peredils'k (excavation by GORELIK, 1988-1994) - 6 - the complex of the Final Paleolithic sites (located at a plato).

Rogalyk (excavation by GORELIK, 1981-1984, 1988-1994) - 7 - the complex of Final Paleolithic sites located at slope. The most complete Holocene sequence in the region Pidgorivka (excavation by GURIN, 1987-1991) - 3 - the multi-layered Final Paleolithic and Eneolithic site with well stratified sequence.

3.1.2. – *Mesolithic*

Khutor Shevchenko (excavation by GORELIK, 1981-1984) - 5 - demonstrates the Mesolithic cultural layer related to the Preboreal 2 deposits.

Sabivka (excavation by GORELIK, 1988-1994) - 18 - demonstrates the Mesolithic cultural layer related to the Preboreal 1 deposits.

Zymivnyky (excavation by GORELIK, 1981-1984) - 20 - the complex of Mesolithic sites related to the Preboreal, Boreal and the beginning of Atlantic period.

3.1.3 – *Neolithic*

Minchekur (excavation by GORELIK, 1988) - 19 - demonstrates the Neolithic layer related to the AT 1 deposits.

Illichivka - 11 - the stratified complex of the Neolithic and Bronze Age sites (excavation by DEGERMENGY, 1992-1993, by TSYMYDANOV).

Ol'khova (excavation by GORELIK, 1981-1984) - 13 - the Late Neolithic cultural layer related to the AT 2 deposits.

Starobil'sk (excavation by GURIN, 1987-1989) - 4 - the most complete and thick sequence at the Eneolithic site (the AT 3 deposits).

3.1.4. – *Bronze and Medieval Ages*

Novoselivka (excavation by ZIMIDANOV, 1988-1989) - 10 - the stratified complex of multi-layered Bronze age and Medieval localities at the sand terrace dunes.

Glyboke Ozero (excavation by GERSHKOVICH,1991) - 13 - the stratigraphical subdivision of different stages of the Late Bronze and Scythian cultures. The most complete section of the Subboreal deposits in the region.

Sloboda (excavation by SHVETSOV, 1995-1996) - 9 - the most complete stratigraphically subdivided sequence of the Medieval localities in the region.

3.2. – THE PRYAZOVA (NEAR THE SEA OF AZOV REGION)

3.2.1 – *Paleolithic*

Amvrosievka (excavation by BORISKOVSKY and PIDOPLICHKO, 1948-1950, by KROTOVA, 1978-1994) - 24 - the Late Paleolithic complex: a base camp and a bison kill site related to the isotopic stage 3 - 2 boundary.

Novoklynivka (excavation by KOVAL, 1995-1996) - 25 - the Final Palaeolithic site related to the Late Glacial deposits.

3.2.2 – *Bronze and Medieval Ages*

Bezymenne (excavation by GORBOV, 1990-1995) - 26 - demonstrates the stratigraphical subdivision of different stages of the Late Bronze cultures. The most complete section of the Holocene in the region.

Lyapina Balka (excavation by GORBOV, 1993-1994) - 27 - the Late Bronze settlement related to the specific deposits of a depression.

Kamyshuvata - Buylovata (excavation by GORBOV, 1992) - 28 - the complex of localities of different stages of the Bronze Age demonstrated the changes of subsistence system patterns according to the environmental changes.

3.3. – THE MIDDLE DNIEPER AND CRIMEAN REGIONS

3.3.1 - *Palaeolithic*

Kabazi (excavation by KOLOSOV, CHABAY, 1985-1995) - 32 - the complex of multi-layered Mousterian sites related to the isotopic stage 5, 4, 3.

Stari Kaidaky (excavation by GROMOV,1946-1947, by VEKLICH, 1955) - 22 - demonstrates the Mousterian site related to the isotopic stage 5.

Sary-Kaya (excavation by KOLOSOV, 1977-1986, KOLOSOV & CHABAY, 1992) - 31 - the Late Paleolithtic site related to the isotopic stage 3.

Grotto Skalisty (excavation by KOEN, 1992-1993) - 33 - the Final Palaeolithic site related to the Late Glacial.

3.3.2 – *Neolith - Medieval Cultures*

Igren' (excavation by DOBROVOL'SKY, 1949, by TELEGIN, 1954-1957) - 21 - stratified multi-layered complex of Mesolithic, Neolithic, Bronze Age sites.

Kamyanka-Dnieprovs'ka (excavation by HAVRYLUK, 1989-1991) - 23 -the most complete sequence of the Late Holocene at the Scythian site.

Chokrak (excavation by MASLENNIKOV, 1977-1996) - 29 - the different phases of existence of the Antique town and the medieval findings related to SA 1-3.

Kitey (excavation by BESSONOVA,1970, by MOLOV, 1974) - 30 - sequence of the Antique town related to SA 2 deposits.

At the present, some of the sites have been subjected to the multi-disciplinary studies according to the above-mentioned program. For example, at the Final Palaeolithic complex of sites Rogalyk (7), some dozen of sections have been inspected. Palaeogeomorphological, palaeozoological, palaeopedological, palynological, radiocarbon, thermoluminescence and palaeomagnetic studies have been carried out. This site as well as the Amvrosievka site (27) for the Upper Palaeolith, the Glyboke Ozero (13), Bezymenne (26) settlements for the Bronze Age can be regarded as the key geo-archaeological sites. Some of sites have not been investigated in detail yet. But all of them provide the prospective possibilities for future investigation and should be protected thoroughly.

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Monuments as "Geotopes": volcanic building stones from the roman area used to construct ancient Roma

Monumenti come «Geotopi»: materiali vulcanici da costruzione dell'area romana utilizzati per edificare l'antica Roma

DE RITA D. (*) & GIAMPAOLO C. (*)

ABSTRACT – We studied building stones from the most representative monuments built between the Archaic and Imperial Ages (1000 BC to 300 AD) and we localized the source excavation areas for these stones. From these data, some general inferences can be made about: 1) the roman civilization's excavation technologies through the ages, which allowed it to use rock types with progressively better physical-mechanical characteristics; 2) the increasing size of the empire which permitted increased access to different raw materials, and 3) the increasingly improved network of roads that connected the city with the surrounding countryside.
Many of the sites that the Romans used as building-stone quarries are still recognizable today and we believe that these cultural heritage sites must be protected in the future as "twins" of the ancient monuments for three main reasons. First, the study of these sites can provide extensive information regarding the sociological-environmental interconnection described above. Second, more pragmatically, these old quarries can be used as a source of restoration material for the monuments. Third, these sites provide a unique educational opportunity for the public to learn about the processes and products of explosive volcanism, both within the ancient monuments of the city and within their natural settings. In the past, the protection of historical monuments has been obvious in human culture; the protection of the natural "Geotopo" and public education for the importance of this protection is still an idea which must be promoted.

KEY WORDS – Colli Albani, Monti Sabatini, Building stones, Monuments, Archeology, Geotopo.

RIASSUNTO – In questa nota gli Autori, attraverso il riconoscimento e la catalogazione delle pietre di origine vulcanica utilizzate nell'edificazione dei principali monumenti storici di Roma, ricostruiscono i trascorsi dell'uomo nel suo paesaggio naturale. A partire dall'età arcaica fino a quella imperiale, vengono indicate le pietre di origine vulcanica maggiormente impiegate nell'edificazione dei monumenti. Per ogni pietra viene indicata l'area originale di cavatura, in modo da ripercorrere, per grandi linee, un itinerario temporale, contenente informazioni sia sulla capacità tecnologica di cavare ed utilizzare pietre con caratteristiche fisico-meccaniche via via migliori, sia sull'ampliamento del territorio che poteva essere utilizzato a scopi pratici e sulle vie di collegamento tra la città e la campagna circostante. Molti dei siti romani utilizzati come cave di approvvigionamento delle pietre da costruzione sono tutt'oggi riconoscibili e questi dovrebbero essere tutelati come beni culturali da gemellare ai monumenti. La protezione del monumento storico è ovvia nella cultura dell'uomo, mentre quella del «Geotopo» naturale lo è molto meno. La difesa del Geotopo naturale sotto i suoi molteplici aspetti è ancora una conquista che necessita l'evidenzazione dell'opportunità della protezione culturale. I siti naturali gemelli dei monumenti romani, dovranno rappresentare la documentazione naturale delle caratteristiche litologiche delle unità piroclastiche da cui derivano, nonchè delle modalità di trasporto e di deposizione della nuvola eruttiva che originò il deposito, della sua collocazione nel paesaggio e delle relazioni tra paleomorfologia e deposito.

PAROLA-CHIAVE – Colli Albani, Monti Sabatini, Pietre da costruzione, Monumenti, Archeologia, Geotopo.

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1. – INTRODUCTION

The ancient monuments and architectural heritage conserved in Roma over the last few thousand years are important resources in terms of their aesthetic and historical values. In addition, their building stones give important information on society's daily needs and its ability to use natural resources from the roman region to resolve these difficulties. As is well known, ancient Roma developed in a geologically favorable region with immense resources. The city of Roma is situated between two recently active volcanic districts, Sabatini volcanic district to the north and Colli Albani volcanic district to the south, whose predominantly explosive products dominate the landscape of Roma (fig. 1). Besides the excellent hydrological resources, used as both potable water and as a mode of transportation, and fertile soil, resulting from the breakdown of volcanic material, the volcanic stones, used to build the infrastructure of the burgeoning city of Roma, cannot be considered of secondary importance. The historical use of building stones for shelter, defense and ornamentation is tangible evidence of the evolution of the roman civilization. The stones provide a record of the region's history in terms of the fundamental elements of human habitat and, of the evolution of human technological capacity to derive necessary materials from the geological environment.

In this note we identify the volcanic rocks used in the principle historical monuments of Roma and show how the use of different volcanic building stones traces man's changing interaction with his environment through time. We studied building stones from the most representative monuments built between the Archaic and Imperial Ages (1000 BC to 300 AD) and we localized the source excavation areas for these stones. From these data, some general inferences can be made about: 1) the roman civilization's excavation technologies through the ages, which allowed it to use rock types with progressively better physical-mechanical characteristics; 2) the increasing size of the empire which permitted increased access to different raw materials, and 3) the increasingly improved network of roads that connected the city with the surrounding countryside.

Many of the sites that the Romans used as building-stone quarries are still recognizable today and we believe that these cultural heritage sites must be protected in the future as "twins" of the ancient monuments for three main reasons. First, the study of these sites can provide extensive information regarding the sociological-environmental interconnection described above. Second, more pragmatically, these old quarries can be used as a source of restoration material for the monuments. Third, these sites provide a unique educational opportunity for the public to learn about the processes and products of explosive volcanism, both within the ancient monuments of the city and within their natural settings. In the past, the protection of historical monuments has been obvious in human culture; the protection of the natural "Geotopo" and public education for the importance of this protection is still an idea which must be promoted.

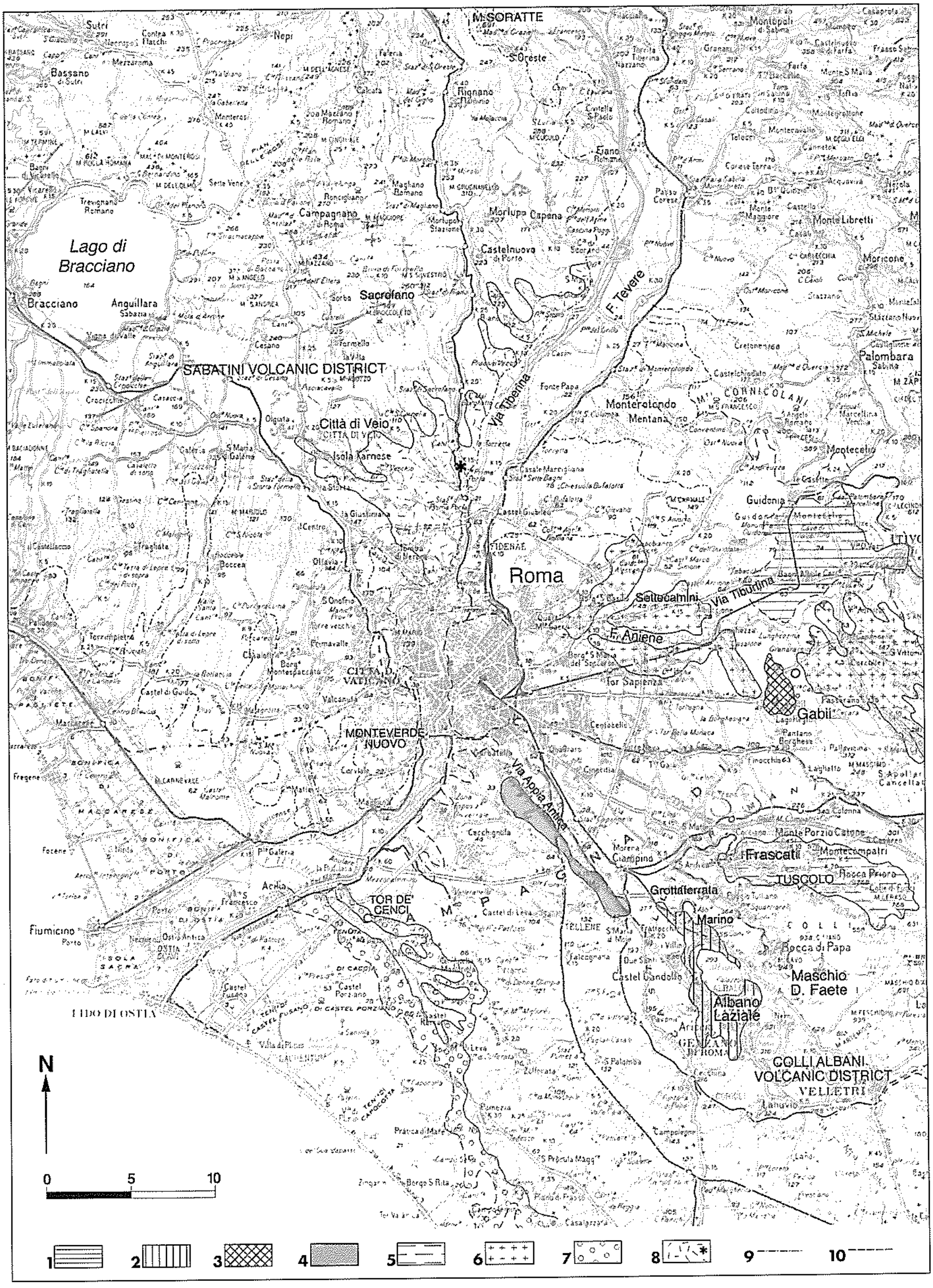
2. – THE VOLCANIC ROCKS USED BY THE ROMAN CIVILIZATION

2.1. – The "pisolithic tuff" or "cappellaccio"

In the most ancient parts of Roma the most commonly used building stone was the so called "pisolithic tuff" (or "cappellaccio"), a unit that outcrops within the area which immediately surrounded the slowly developing city. Because of the limited excavation and transport capabilities of the most ancient Romans, the

Fig. 1. – Location of Roma city between two recently active volcanic districts: Sabatini volcano to the north and Colli Albani to the south, whose predominantly explosive products dominate the landscape of Roma. 1 - Distribution of the yellow "Via Tiberina" tuff along Tevere River course. Star symbol indicates the Grotta Oscura locality. 2 - Distribution of the "pisolithic tuff" in the Tor de' Cenci - Fosso di Malafede area. 3 - "Lionato tuff" distribution along the Aniene River course, where most of historical quarries are located. 4 - Distribution of the "sperone" at the north-eastern margin of Tuscolano-Artemisio caldera rim. 5 - Extension of the Capo di Bove lava flow. 6 - Distribution of the peperino around Gabii crater. 7 - Distribution of the peperino around Albano crater. 8 - Travertine. 9 - Limits of the Colli Albani volcanic district. 10 - Limits of the Sabatini volcanic district.

– Posizione della città di Roma tra due distretti vulcanici attivi ancora in tempi recenti: i vulcani Sabatini a nord e i Colli Albani a sud, i cui prodotti prevalentemente esplosivi dominano il territorio di Roma. 1 - Distribuzione del tufo giallo «Via Tiberina» lungo il corso del Fiume Tevere. L'asterisco indica la località Grotta Oscura. 2 - Distribuzione del «tufo pisolitico» nell'area Tor de' Cenci - Fosso di Malafede. 3 - Distribuzione del «Tufo Lionato»lungo il corso del Fiume Aniene, dove è localizzata la maggior parte delle cave storiche. 4 - Distribuzione dello «sperone» al margine nord-orientale del bordo della caldera Tuscolano-Artemisio. 7 - Distribuzione del peperino intorno al cratere di Albano. 8 - Travertino. 9 - Limiti del distretto vulcanico dei Colli Albani. 10 - Limiti del distretto vulcanico dei Sabatini.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SABATINI VOLCANIC DISTRICT
Città di Veio
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Via Tiberina
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Settecamini
Via Tiburtina
F. Aniene
Gabii
MONTEVERDE
NUOVO
Via Appia Antica
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Fig. 2. – Rupe Tarpea. Outcrop of the "pisolithic tuff" and of the "lionato tuff" in the Campidoglio area in the center of Roma. The deepening of the base of the "Lionato tuff" indicates the location of the ancient valley filled by the tuffs.

– *Rupe Tarpea. Affioramento del «tufo pisolitico» e del «tufo lionato» nell'area del Campidoglio nel centro di Roma. L'incupirsi della base del «tufo lionato» indica la posizione dell'antica valle riempita dai tufi.*

areas of supply and habitation were similar; the size and geometry of the blocks were at approximation rock, linked to the action of weathering and, finally, the structures were elementary and simple. Although the physical-mechanical characteristics of the "pisolithic tuff" are definitely inferior to those of subsequently used building stones (see Tab. 1) the ease of excavation and limited amount of transport made this material an efficient choice in the Archaic period. The "pisolithic tuff" is not a single unit, however, but rather consists of different pyroclastic flows emitted during the oldest activity of the central area of the Colli Albani volcanic district, around 500,000 years B.P. (DE RITA *et al.*, 1988; 1995; ROSA, 1995). The high degree of fragmentation of the pumice ash matrix and the presence of accretionary lapilli in this rock, indicate that the eruption involved the interaction with water. The erupted products extend across the central area of the district, reaching as far as its periphery, located 30-40 km from the volcanic source (DE RITA *et al.*, 1992; 1995). The "pisolithic tuff" outcrops both in parts of the southern section of the city and within its central historical area; for example, exposure of the tuff can be clearly seen at the foot of Campidoglio Hill where it forms the base of the Rupe Tarpea (fig. 2). The reconstructed paleomorphology of the Campidoglio area indicates that the pyroclastic flow was channeled along an ancient drainage and eventually attained a maximum thickness of about 10 m (DE RITA *et al.*, 1992; 1995). The "pisolithic tuff" pyroclastic flows were also channeled along the once-great Velabro Valley (today completely obliterated by urbanization). As early Roma began to development in this area - at the confluence of the Tevere and Velabro Rivers, at the base of the Palatino and Aventino Hills and in front of Tiberina Island - it is not surprising that the "pisolithic tuff" became the first building stone used in the city. The use of the "pisolithic tuff" in the first roman monuments can be observed in the oldest parts of the Serviane Walls (LUGLI, 1957; COARELLI, 1974 and bibliography therein) (fig. 3A). Some of the quarries that supplied building stone for

TAB. I – Main physical-mechanical characteristics of volcanic rock types mainly used as building stones in the ancient roman monuments

– *Principali caratteristiche fisico-meccaniche dei tipi di rocce vulcaniche usati come materiali da costruzione*

	weight per unit of volume Kg/m^3	compression breaking load Kg/cm^2	compression breaking load after imbibition Kg/cm^2	imbibition coefficient weight %
pisolithic tuff	1300 ÷ 1500	90 ÷ 100	–	–
lionato tuff	1460 ÷ 1850	52 ÷ 115	59 ÷	6 ÷ 14
yellow "Via Tiberina" tuff	1340 ÷ 1710	70 ÷ 127	55 ÷ 171	5.0
sperone	not available	not available	not available	not available
lapis gabinus	not available	not available	not available	not available
lapis albanus	1540 ÷ 2180	55 ÷ 130	58 ÷ 145	6.3 ÷ 4.0
travertine	2424	572	657	1.4
leucitite	2810	2856	-	0.73

A

B

Fig. 3. – A) Serviane Walls, built with blocks from the "pisolithic tuff", present in Via Salandra, close to Termini railway station. B) Natural outcrops of the "pisolithic tuff" in the Tor de' Cenci area, south of Roma.

– *A) Mura Serviane, costruite con blocchi di «tufo pisolitico», presenti in Via Salandra, vicino alla stazione ferroviaria Termini. B) Affioramenti naturali del «tufo pisolitico» nell'area di Tor de' Cenci, nella zona sud di Roma.*

the Walls are still recognizable in archaeological excavations below Termini railway Station. Beyond representing a historical and archaeological monument of incalculable value, the Serviane Walls can thus also be considered as "Geotopo", documenting human use of a natural resource and the relationship established, to varying degrees through time, between natural resources and human technology. Many other works of the Archaic period, preserved near the Foro di Cesare, were made with this stone; for example an Archaic cistern was excavated in the tuff and its walls were recovered by small blocks of the same material. In addition, the earliest hut village at the top of the Palatino Hill is constructed of "pisolithic tuff".

The corresponding natural "Geotopo" is much more difficult to define because most of the ancient quarries have by now been destroyed or obliterated, whereas the more recent ones are besieged by urbanization or have been used for refuse disposal. One locality which still preserves a "pisolithic tuff" outcrop with characteristics analogous to those found in the tuff blocks of roman constructions, is located at Tor de' Cenci - Fosso di Malafede, an area, already protected because of the important information it contains on the natural environment. We propose the Tor de' Cenci area as a "Geotopo" twinned with the "Geotopo" of the Serviane Wall (fig. 3B). An educational program should be developed so that Tor de' Cenci may also document the lithological characteristics of the "pisolithic tuff", the transport and depositional mechanisms acting on the ash cloud that formed the deposit, the deposit's spatial distribution and the relationship between preexisting paleomorphology and the volcanic deposit. Because the Tor de'

A

B

Fig. 4. – A) Aventino. Serviane Walls restored with blocks of the yellow "Via Tiberina tuff". B) Natural outcrops of the yellow "Via Tiberina tuff" along Via Tiberina, north of Roma.

– A) Aventino. Mura Serviane restaurate con blocchi del «tufo di Via Tiberina» giallo. B) Affioramenti naturali del «tufo di Via Tiberina» giallo lungo la Via Tiberina, nella zona nord di Roma.

Cenci area has been excavated during every period since the roman epoch, it also provides historical documentation on the types of construction materials used and on the extraction techniques employed through time.

2.2. – The yellow "Via Tiberina tuff"

With increasing technological evolution and the expanding extent of controlled territory, small blocks of tuff originating from outside the city began to be used in buildings. One of the first lithotypes that was substituted for the "pisolithic tuff" was the yellow "Via Tiberina tuff", which was outcropping to the north of Roma at Grotta Oscura (the Grotta Oscura tuff; Coarelli, 1974 and bibliography therein) along Via Tiberina. The yellow "Via Tiberina tuff" is a pyroclastic flow deposit which originated from the Sacrofano volcano, located around 30 km to the north of Roma in the eastern sector of the Sabatini volcanic district (Fig. 1); (De Rita *et al.*, 1993). The related eruption, dated at around 500,000 years B.P., likely involved at least the partial interaction of water and rising magma. The eruption caused the deposition of more than one flow unit (Cioni, 1993 recognized at least 7 units) that covered a surface of more than 400 km^2 and attained a total volume equal to approximately 8 km^3 (De Rita, *et al.* 1993; Rosa, 1995). The considerable quantity of erupted material caused a significant impact on the surrounding environment, such as the obstruction of the Tevere River near Monte Soratte, and the movement of its valley towards the east, approximately in coincidence with its present course (Alvarez, 1972; 1973; Rosa, 1995).

Because the physical-mechanical characteristics of the "Via Tiberina tuff" are significantly better than those of the "pisolithic tuff" (see Tab. 1); (Nappi *et al.*, 1979) the "Via Tiberina tuff" was commonly used either as an ornamental stone or as a building stone for houses. It is important to note that the use of this tuff became common only after the roman conquest of Veio, the city which dominated the region rich in this natural resource (Coarelli, 1974 and bibliography therein). The use of this tuff in roman buildings is still well documented today. A large part of the Serviane Walls has been restored with this stone since 396 AD, following the damage caused to the original wall by the Gaelic invasion. Where presently visible (fig. 4A) the wall is constructed of rows of 59 cm-high blocks alternatively placed horizontally and vertically, thereby creating a structure that is up to 10 m high and sometimes greater than 4 m thick (Coarelli, 1974 and bibliography therein). The restoration took place in various locations simultaneously, as testified by the reconstructed rock junctions which do not always fit together perfectly. The total length of the wall has been calculated at around 11 km, encompassing a surface of 426 hectares and thus enclosing the largest city on the Italian peninsula. Even though the Grotta Oscura area quarries are now located within a military area and are thus not directly observable, the working faces of many old quarries are still visible along Via Tiberina.

These were operated up to modern times and were only recently abandoned. We believe that some of these should be protected as "Geotopo", twinned to the sites of the first documented restorations of the Serviane Wall and, more generally, used as references for construction or restoration of buildings by the Romans after the Gaelic Invasion (fig. 4B).

2.3. – THE "CAPO DI BOVE" LAVA FLOW (MELILITE LEUCITITE)

The roman ability to obtain building stones of optimal physical-mechanical characteristics was very high during the Republican Period (end of the IV - III centuries), as demonstrated by the extensive use of lava blocks for paving stone. Via Appia, the consular road between Roma and the Colli Albani area, was built during this period directly on the upper surface of the Capo di Bove lava flow (fig. 5). This unit erupted around 280,000 years B.P. (BERNARDI *et al.*, 1982) and forms one of the most impressive extrusions of the Faete edifice, located in the central area of the Colli Albani volcanic district (fig. 1); (DE RITA *et al.*, 1988). The lava was channeled in a valley that was almost radial about the central volcanic structure and extended 20 km to the area on which Roma was eventually built. The flow was named after the ox head perched on the Tomb of Cecilia Metella, which was built at the distal end of the flow. The highly under-saturated chemistry of the lava permitted it to flow great distances from its eruptive vent, and allowed it to form a very smooth and flat upper surface, a feature which was directly exploited by the Romans for the construction of the Appia. Via Appia Antica is without a doubt the most famous monument that can be considered as a human "Geotopo", and represents human use of lava blocks for road constructions. Many roman quarries were subsequently reused for similar purposes and then abandoned; some of these are still visible along Via Appia and we believe they should be preserved as testimony to their use in the past and for public education to observe lava flow characteristics in an environment of predominantly explosive volcanism (fig. 5).

Fig. 5. – Appia Antica road. Quarries of leucititic lava flow blocks.
– *Via Appia Antica. Cave di massi dal flusso di lava leucitica.*

2.4. – THE "PEPERINO", AND THE "LIONATO TUFF"

The most interesting period relative to the goals of this study is most certainly the Imperial Epoch, a time span which began a long period of prosperity for the roman civilization. During this time Roma greatly extended its dominion across the entire Mediterranean area and as a result the Romans introduced many "exotic" stones for ornamentation and construction of both their public and private buildings. However, many of these buildings still used local building stones for their foundations and internal structures. The higher technological ability allowed a more rigorous selection of the lithotypes. The monuments of this epoch used three principle types of volcanic building stone from the roman area: the "lionato" (or "litoide", or "Monteverde" tuff, or "Aniene" tuff), the "peperino" and the "sperone" tuffs.

The "lionato tuff" is a pyroclastic flow deposit that erupted from the central area of the Colli Albani volcanic district during the Tuscolano-Artemisio phase, around 400,000 years B.P. (DE RITA *et al.*, 1988). The eruption of the "lionato tuff", which was immediately followed by that of the "Villa Senni tuff" about 336,000 years B.P., caused the collapse of the central area of the volcano and marked the close of the Tuscolano-Artemisio eruptive phase. The lithological and depositional characteristics of the "lionato tuff" indicate that it sustained limited water/magma interaction during eruption, whereas its high degree of lithification is due to zeolitic alteration of the glassy matrix.

The name "peperino" actually refers to two different lithotypes: the "lapis Gabinus" and the "lapis Albanus". Both of these deposits are the result of violent hydromagmatic eruptions, the former related to the Gabii (or Castiglione) craters and the later related to the Albano crater. The eccentric Castiglione and Albano craters were formed as a result of the final

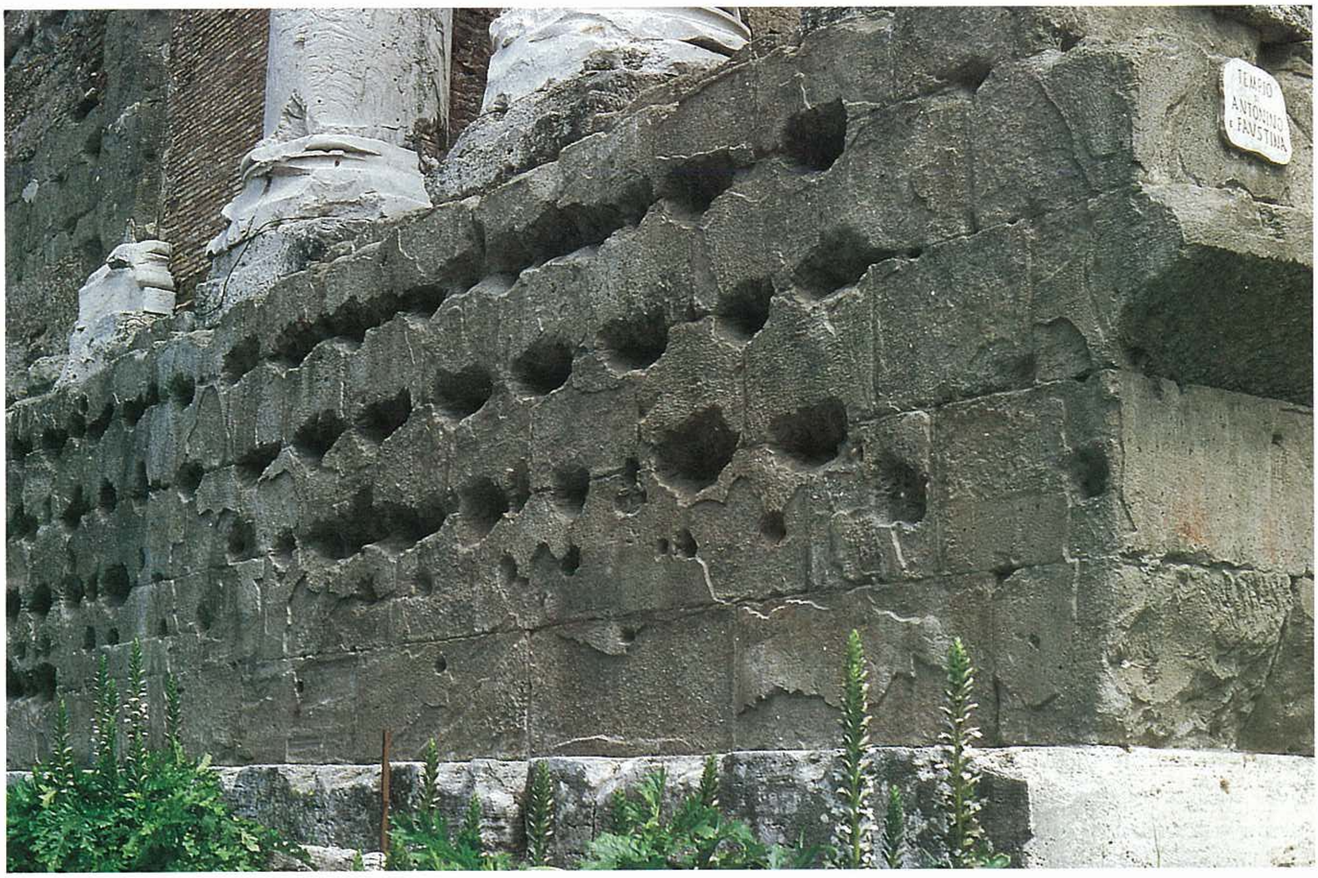

Fig. 6. – Foro di Cesare; the Antonino and Faustina temple whose basal structures are made with lapis Albanus.
– *Foro di Cesare; il tempio di Antonino e Faustina le cui fondamenta sono fatte con lapis Albanus.*

hydromagmatic activity of the Colli Albani volcanic district (DE RITA *et al.*, 1988; 1995). This region was active between approximately 200,000 years B.P. and also very recently: in particular "lapis Albanus" came from a detrital flow deposit erupted from the Albano crater during its final phase, at least 20,000 years ago (MERCIER, 1993). The two lithotypes have very similar lithologies and have, as their principle characteristic, a high level of lithification due to the presence of zeolites, in the rock matrix, that were derived from the alteration of volcanic glass. These rocks were used ubiquitously during the Imperial epoch. The most significant examples are visible in the Imperial Forums. In the most ancient of these forums the temple of Antonio and Faustina was constructed in part with "lapis Albanus" (fig. 6). In contrast the Forum of Augustus was largely created using "lapis Gabinus" and the "lionato tuff" (or "litoide"), with the latter unit also being used for the forum brick work and as a base for the temple of Marte Ultore (fig. 7). In addition, lapis Gabinus forms the foundation and walls of the Tabularium building at Campidoglio. The contemporaneous use of the "lapis Gabinus" and the "lionato tuff" suggests that the two lithotypes were quarried in closed areas of the volcanic district. In fact, the "lapis Gabinus" quarries occur along the border of the Castiglione crater (in the northern sector of the District near the Aniene River), not far from the "lionato tuff" quarries located along Via Tiburtina. It is highly probable that the Aniene River was the most direct route for transporting these two lithotypes from the countryside to the city. The "lapis Gabinus" quarries, abandoned during the roman Epoch, are still clearly visible at the edge of the crater. We believe these quarries would be excellent natural "Geotopo" to twin with the roman monuments (fig. 8); in this respect it is interesting to note that the Castiglione area is already being protected for the future creation of a scientific park. The quarries of the "lionato tuff" present a more complex situation, because these have been used since the roman Epoch, until quite recently. The "lionato" stone used during the roman Epoch was most likely excavated in the Monteverde area (Monteverde tuff) and in the Settecamini area (Aniene tuff) (fig. 9). Some of these last underground quarries have been subsequently enlarged and reused. Because they often occur on private land, their protection as cultural heritage "Geotopo" is highly improbable and problematic. Some quarry areas have been used to create artificial lakes for sport fishing, a solution which may represent a good compromise between maintaining a cultural heritage for direct use by the public and protecting it in some way as a monument itself. The roman quarries of the "lapis Albanus" were located along the northern borders of the Albano crater, near the city of the same name, or in the valley below the town of Marino . The "lapis Albanus" differs from the lapis Gabinus because it was excavated until the end of the most recent epoch and is still mined to a small extent today. Many of the roman quarries are now

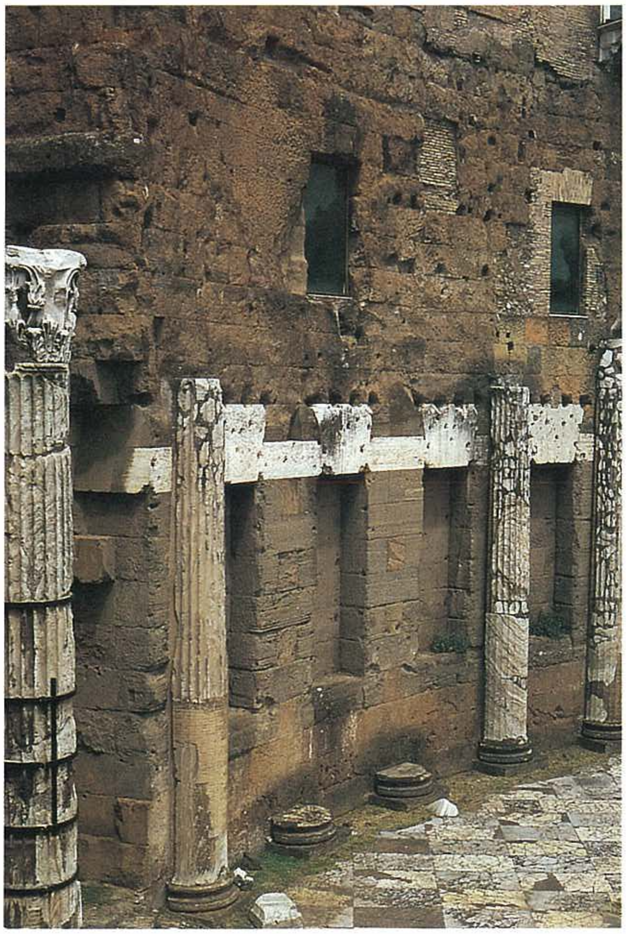

Fig. 7. – Foro di Augusto. This forum was largely created using "lapis Gabinus" and the "lionato tuff".

– *Foro di Augusto. Questo foro è stato realizzato per la maggior parte usando «lapis Gabinus» e «tufo lionato».*

Fig. 8. – Ancient quarry (arrow) of "lapis Gabinus" on the north-eastern rim of Gabii crater.

– *Antica cava (freccia) di «lapis Gabinus» sul bordo nord-orientale del cratere di Gabi.*

Fig. 9. – Settecamini locality. Abandoned quarries of lionato tuff (Aniene tuff).

– *Località di Settecamini. Cave abbandonate di tufo lionato (tufo dell'Aniene).*

destroyed or obliterated by urbanization in the Colli Albani area, although some very significant examples are still visible along Via dei Laghi between Via Appia and the city of Marino (fig. 10). We suggest that the ancient working faces of these abandoned quarries may be protected as "Geotopo", twinned to their corresponding monuments in Roma.

2.5. – The "sperone"

Finally, the monument which represents the most important symbol of Imperial Roma is the Colosseo. The structural base of the Colosseo was created, besides travertine, with "sperone" (fig. 11A), a rock type which was used to a relatively limited extent. This welded scoria deposit resulting from lava fountains, erupted from the fractures which controlled the collapse of the central part of the Colli Albani volcano, less than 336,000 years ago. These rocks compose the entire northern border of the Tuscolano-Artemisio belt and are located at an elevation of between 200 and 600 m. Although no definitive roman quarries have been found, it is highly probable that the original sources were located near Grottaferrata and Frascati, close to the principle transportation routes to Roma, but now obliterated due to the growth of these two cities. Due to the welding of the scoria upon contact with the ground the "sperone" has probably good physical and mechanical properties, and it is likely that its use was limited only because of the difficult access and transportation to and from the quarries. All the depositional and lithological characteristics of the "sperone" can be clearly observed in the "Tuscolo" area, one of more impressive localities related to the history of Roma in the Colli Albani volcanic region (fig. 11B). We believe this site must be considered as a cultural heritage "Geotopo" in order to protect all of its unique geological, biological naturalist and archaeological characteristics. The perfectly preserved remains of a roman village and a small theater built entirely with the "sperone" are still visible at this location. Furthermore the Tuscolo area is within the perimeter of the Castelli Romani Park and would be an ideal location for a public education exhibit outlining the processes of lava fountaning in an explosive volcanic environment.

After the Imperial Epoch the study of volcanic rocks used as building stones in Roma becomes almost impossible, as the Romans began to use manufactured bricks as their most important construction materials. Furthermore, they became commonly reused the stones of more ancient monuments that were in ruins, deteriorated with age or demolished by subsequent

Fig. 10. – Active quarry of the "lapis Albanus" in the Marino village area.

– *Cava attiva di «lapis Albanus» nella zona del paese di Marino.*

A

B

Fig. 11. – A) Colosseo. Blocks of "sperone" used together with travertine to build up the structure of the monument. B) Tuscolo locality. Natural outcrops of the "sperone" rocks.

– *A) Colosseo. Blocchi di «sperone» utilizzati insieme con il travertino per realizzare la struttura del monumento. B) Località Tuscolo. Affioramenti naturali delle rocce «sperone».*

emperors. The borders and power of the roman Empire were by this point so vast that the import and use of stone from around the world was very extensive. Beyond this point the link between man and his environment extended to the vast regions which reflected the power of Rome.

3. – CONCLUDING REMARKS

The use of volcanic stone as a construction material responded, through time, to the needs of the evolving civilization, representing further confirmation of the inseparable bond between man and nature. In this paper, we identify seven important volcanic building stones that were used in the constructions of many of the important monuments of ancient Roma. The types of stones used by the Romans to build, protect and beautify the city closely followed their societies, technological development. With time, rocks with increasingly better physical-mechanical characteristics were chosen and excavated at increasingly larger distances from their building sites in ancient Roma. For this reason it is important to protect both the ancient monuments, as well as the natural sites where the building stones were quarried. For each monument which contains the history of a period or of a fundamental phase of the evolution of the roman civilization it is possible to protect a quarry or an outcrop that remains as tangible evidence of the lithological and depositional characteristics of the stratigraphic unit from which the building stone was drawn. This twinning underlines the coupling of man and his habitat, and can represent a significant link between environment and cultural evolution. The protected natural sites could supply the original stone for restoration purposes. In addition, the human and natural twinned "Geotopo" provide a unique opportunity to develop public education about the different processes of explosive volcanic eruptions that formed the landscape of Roma, and how to read this information in the texture and composition of the rocks.

The lithotypes used for construction show comparable physical-mechanical characteristics (PENTA, 1956); all have an elevated level of lithification due to zeolites in the rock matrix, minerals which formed due to alteration of the glassy matrix. Furthermore, all units were produced by eruptions which involved, to different extents, the interaction of rising magma and ground water. In fact a direct connection appears to exist between the presence of zeolites and the level hydromagmatic activity. Based on this idea de Rita et al. (1986) hypothesized that the zeolites in this particular environment are syndepositional minerals whose development was strongly facilitated by favorable Eh and pH conditions. These observations become extremely interesting in the research and characterization of the building stones and clearly underline the necessity of mankind to clearly understand his environment in order to obtain the best benefits.

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Traces of historical landscapes preserved in the coastal area of Rome
Tracce di paesaggi storici conservati nell'area costiera di Roma

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ABSTRACT – Since Roman times, the coastline near Rome and the course of the Tiber river have been subject to variations. As a consequence of the seawards expansion of the coastline, many archaeological remains have beeen preserved under coastal and fluvial sediments. Also other natural changes, like the cutting off of a meander and the lateral displacement of river courses, have led to the preservation of parts of the former historical landscape. Some case studies are presented here, concerning the coastal zone and the lower Tiber valley between Rome and Ostia. Management problems of these archaeological areas, moreover solutions and suggestions, are considered. Given the view that the archaelogical heritage does not consist of isolated and fragmented sites, but of zones and landscapes of a certain extension, these areas merit fully to be considered as "geosites".

KEY WORDS – Alluvial sediments, Archaeology, Ostia, Rome.

RIASSUNTO – A partire dall'epoca romana, la linea di costa della Campagna romana e il corso del fiume Tevere, sono stati soggetti a cambiamenti. In concomitanza all'espansione della linea di costa, vari resti archeologici sono stati conservati al di sotto dei sedimenti costieri e fluviali. Anche altri eventi naturali, come il taglio di un meandro e lo spostamento dei corsi fluviali, hanno portato alla conservazione di tratti del paesaggio storico originario. Vengono presentati alcuni casi di studio che riguardano la zona costiera e il fondovalle tiberino tra Roma e Ostia. Vengono trattati i problemi di gestione di queste zone archeologiche, come anche soluzioni e suggerimenti. Considerato che il patrimonio archeologico non consiste in siti isolati frammentati, ma in zone e paesaggi di una certa estensione, tali aree possono essere proposte, a pieno titolo, come «geotopi».

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1. – INTRODUCTION

Since Roman times, both the coastline near Rome and the course of the Tiber river, have been subject to remarkable variations. The coastline near the mouth of the Tiber river has moved seawards for various km, with the consequential silting up of the harbours constructed by the Roman emperors Claudius and Trajan (fig. 1, letters C and T).

The phases of coastline advancement have been reconstructed through the position of the Roman buildings and the medieval coast towers (DRAGONE *et alii*, 1967; SEGRE, 1986). According to the geological map of Cerveteri (SERVIZIO GEOLOGICO, 1967), about half of the advancement has occurred between 100 and 1570 A.D., whereas the other half is from even later date. There are reasons to presume that the strong advancement phase started only after 500 A.D.

The reasons for this displacement must sought in a combination of factors. In the first place, in land use changes within the Tiber watershed, like deforestation and agricultural expansion. In the second place in climate change, and finally, in sea level variations. In fact, historical sea level changes are indeed known: in Roman times (between 600 and 100 b.C.), the sea level was about 1 m lower than today, whereas in the IV-V century A.D. it seems to have been about 1 m higher (LAMB, 1977).

The degradation, from the XVI century on, of the agricultural landscape in the hills and mountains

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behind Rome has been stressed by SERENI (1987): steeper slopes then formerly where brought into culture, thus provoking stronger erosion. A climate change, occurring from 1200 A.D. on, consisted in a lower average temperature, heavier winter rains and less summer rains (LAMB, 1977). Such a change leads to less favourable conditions for a protective vegetation cover, and thus potentially to stronger erosion.

Increment of sediment load in this period implied also more frequent and heavier floodings. In fact, the XVI century is characterized by the heaviest floodings known in historical times. Another contribution to these phenomena must have been the obstruction of the Tiber course in the city of Rome, in full urbanistical revival by this time, through buildings, bridges and floating water mills (DI MARTINO & BELATI, 1980).

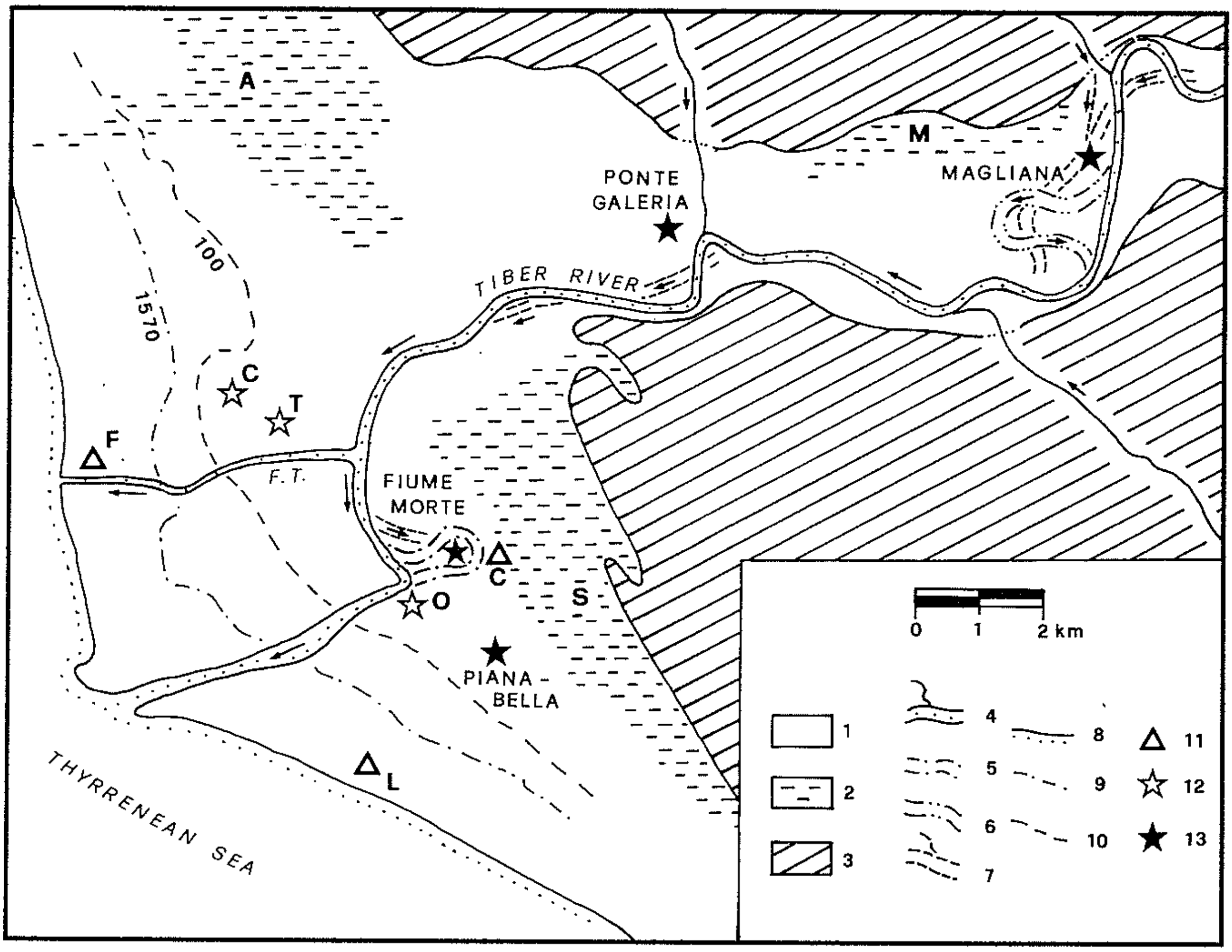

Fig. 1. – General map of the coastal area of Rome, with the case study sites: Ponte Galeria, Magliana, Fiume Morto and Pianabella; original scale 1:100.000.
Legend: 1) recent coastal plain; 2) former marshy areas (existing up to 1890) within the coastal plain: A: Stagno of Maccarese; M: Stagno of Campo Merlo; S: Stagno Ostiense; 3) areas beyond the recent coastal plain, situated at higher levels; 4) present river course, with flow directions; 5) variation existing up to 1557 (naturally cut); 6) variation existing up to ca. 1930 (artificially cut); 7) variation existing during Roman times, ca. 100 A.D.; 8) position of the present coastline; 9) coastline about 1570; 10) coastline in Roman times, ca. 100 A.D.; 11) present urban agglomerate: F: Fiumicino; C: Ostia Antica with Castle; L: Ostia Lido; 12) Roman structures: C: harbour of Claudius; T: harbour of Trajan; O: Roman Ostia; 13) case study sites. Tributaries of the Tiber River: Magliana river (right); Fontanile river (left); Galeria river (right). F.T: Canal of Trajan.

– Carta dell'area costiera di Roma, con l'ubicazione dei casi di studio: Ponte Galeria, Magliana, Fiume Morto e Pianabella; scala originaria 1:100.000. Legenda: 1) pianura costiera recente; 2) zone paludose all'interno della pianura costiera, bonificate dopo il 1890: A: Stagno di Maccarese; M: Stagno di Campo Merlo; S: Stagno Ostiense; 3) zone al di fuori della pianura costiera recente, ubicate a quote superiori; 4) attuali corsi d'acqua, con direzioni di flusso; 5) variazione esistente fino al 1557 (tagliata naturalmente); 6) variazione esistente fino a ca. il 1930 (tagliata artificialmente); 7) variazione esistente in epoca romana, ca. 100 A.D.; 8) posizione della linea di costa attuale; 9) posizione della linea di costa circa nel 1570; 10) linea di costa in epoca romana, ca. 100 A.D.; 11) agglomerati urbani: F: Fiumicino; C: Ostia Antica con Castello; L: Ostia Lido; 12) Strutture romane: C: porto di Claudo; T: porto di Traiano; O: Ostia romana; 13) localizzazione delle zone dei casi di studio; Affluenti del fiume Tevere: Fosso della Magliana (destra); Fosso del Fontanile (sinistra); Fosso Galeria (destra). F.T: Fosso di Traiano.

Thus, together with the advancement of the coastline, the level of the Tiber valley floor was raised and the equilibrium of its lenght profile restored. As a consequence, in some parts of the lower Tiber valley, tracts of the "Roman landscape" are preserved under fluvial deposits. Also other natural changes, like the cutting off of a meander and, more generally, the lateral displacement of river courses, has lead to the preservation of tracts of the former Roman landscape. Obviously, such remains are found mainly along the inner curves of meanders, where sediment deposition is the dominant process.

This was a short outline of the processes by which, along the Tiber valley and the Roman coast, antique structures were buried below natural sediments. An important aspect is that they were buried together with tracts of their original landscape. In land planning, considering archaeological sites within the context of their former landscape is in agreement with the modern vision that the archaeological heritage does not consist of dispersed monuments, but of archaeological sites within the context of their wider cultural or natural landscape (BARKER & LLOYD, 1991).

2. – CASE STUDIES

Various case studies of the area between Rome and the coast will be treated shortly hereafter. Their position is indicated in fig. 1: Magliana, Fiumicino-Ponte Galeria, Trastevere Ostiense-Fiume Morto and Pianabella. The first belongs to the territory of the Soprintendenza Archeologica di Roma, whereas the latter three reside under that of Ostia. Altogether, these areas occupy only a small portion of the total surface of the coastal plain, but it is extremely probable that the observed phenomena may be extrapolated to larger areas. And moreover, though the denoted landscape changes may be insignificant when seen from the geological viewpoint, they are not at all so when seen from the archaeological viewpoint, since they have been essential in the preservation of important parts of our cultural heritage.

2.1. – MAGLIANA AREA

Near the Magliana area, the relicts of a Roman bridge and dam were found close to each other, buried below various meters of fluvial sediments of the Tiber valley. Presently, both dam and bridge are quite distant from any river course. The bridge, with a lenght of ca. 40 meters, was anyway too small to have crossed the Tiber river (CATALLI *et alii*, 1995). The dam was constructed about halfway the I century A.D.

During the archaeological excavation by the Soprintendenza Archeologica di Roma (1993), special attention was paid to the natural layers exposed below and above the dam, which allowed the reconstruction of the natural historical events for this area, and which lead moreover to the formulation of an hypothesis on the original function of both the bridge and the dam.

Near the dam and the bridge, a long and narrow depression was encountered, filled in with grey loam. The line of this depression was visible on the aerial photographs for over 700 meters, and turned out to cross the bridge at a right angle. This depression was interpreted as the old course of the Magliana tributary, crossed by the bridge. Aerial photographs showed traces also of the displacement of the Tiber river in historical times.

The dam, with a lenght of ca. 20 m, was oriented parallel to the former course of the "Magliana" tributary. Moreover, at a close distance behind the dam, a marshy area (FRUTAZ, 1972) was known from medieval times on ("Campo Merlo"), that could well have existed already in Roman times. The hypothesis was forwarded that the dam was constructed to protect the marshy area from the increasing floods in the I century (cfr. the "Fiume Morto" area). In CATALLI *et alii* (1995), detailed maps show both the present river courses as well as their reconstruction for Roman times. A less detailed reconstruction is given here in fig. 1.

The natural layers exposed near the dam showed below the structure the traces of at least two strong floods, that could be dated (considering the age of the dam) as probably having occurred in the years 15 and 36 A.D. (cfr. LE GALL, 1953). The layers deposited after the construction of the dam showed, through a clear differentation in characteristics before and behind the structure, it's effective functioning, maybe until the IV century A.D., but finally it's total overriding by the later and higher floods.

2.2. – FIUMICINO-PONTE GALERIA AREA

The area of "Fiumicino-Ponte Galeria" (PETRIAGGI *et alii*, 1995), with an extension about 100 ha., is situated on the right hand side of the Tiber river, close to the "Fosso Galeria" tributary, and at an elevation between 2 and 5 m a.s.l.

During the archaeological survey by the "Soprintendenza Archeologica di Ostia" (1992), in many trenches the valley floor of Roman times could be detected below more than 1 meter of fluvial sediments and modern infill. The buried surface was marked not only by the relicts of Roman structures (including an aqueduct) but also by a distinct buried soil marker.

Soil type distribution in this area, ranging from sandy to clayey soils, with a dominance of loamy soils, turned out different for Roman times with respect to the present surface. This original distribution explained better the position of the aqueduct: at the boundary of well drained soils with Roman building relicts (to the north), and less drained soils, probably less accessible, and where cultural remains were indeed lacking. There are indications that during Roman times the Tiber river had, in this area, a slightly straighter course. Fig. 2a shows the soil map of the present surface, whereas fig 2b shows the soil map as reconstructed for Roman times (buried surface). On both maps the position of the acquaduct is indicated. Confronting the soil maps, one notes the general coarsening of the Tiber sediments in time. Roman structures were often found covered by a clayey layer, testifying an initially slow increment of the valley level, datable probably to the first centuries A.D.. The overlying layers were coarser (mainly loamy), thus confirming the intense flooding peaks known for the later periods.

Near the "Fosso Galeria" tributary outlet, an alluvial fan with sandy sediments could be distinguished from the typical loamy Tiber sediments. The distal (lower) part of the alluvial fan turned out to be buried below recent Tiber sediments. This alluvial fan, and it's partial burial below later Tiber sediments, are also visibile on the soil maps of fig. 2a and 2b. Antique water distribution structures (canalizations) were excavated in the alluvial fan area. The latter was apparently the preferential zone for settlement, both for water avaliability (and quality) as well for the slightly higher elevation with respect to the main valley.

2.3. – Trastevere ostiense-Fiume Morto (Roman Ostia)

Near Ostia, until the year 1557, the Tiber river followed a narrow meander. The area enclosed by the meander belonged in Roman times structurally to the city of Ostia; it is known as "Trastevere ostiense" ("Ostia on the other side of the river"; Arnoldus-Huyzendveld & Paroli, 1995). During the huge flood of 1557, the meander was naturally cut off, leaving behind a characteristic oxbow lake, still existing a hundred years ago (Amenduni, 1880), and moreover an isolated area, known, from the disastrous flood on, as the "Fiume Morto" (Dead River). The event competely isolated the Castle of Ostia, constructed less than a century before, from it's strategical position along the river. This can be seen in fig. 3, were the meadow in the foreground marks the area of the former river course. Modern city streets of Ostia Antica still slope slightly down were crossing the former Tiber bed.

During the excavation by the "Soprintendenza Archeologica di Ostia" (1992) of part of the inner bank of the abandoned river course, three phases of meander shift could be distinguished: one of Roman times (I century A.D., probably towards the end of the century) and two much later ones (1530 and 1557). Each time a cycle of events could clearly be deduced from the layer structure: first erosion, than sand deposition, followed by a horizontal fine layering. The flooding events were dated by combining the archaeological data with the list of known historical floods (Di Martino & Belati, 1980). Lateral river bed displacement was, in this tract of the river, for each event about 4 meters. Fig. 4 is a schematic W-E section through the easternmost part of the meander.

The infill of the former meander bed, after it's isolation from the main river course, is at the base composed of a sandy layer and upwards by horizontal clayey and peaty layers, with traces of marshy vegetation, indicating a low energy environment. Several times this regular sequence is interrupted by thin sandy layers, apparently due to later floodings.

Fig. 2. – Fiumicino-Ponte Galeria area: soil map of the present surface (2a) and of the buried surface of Roman age (2b).
Legend, with soil names indicated according to FAO/UNESCO (1988): 1) S: coarse loamy calcareous soils in Tiber sediments (Calcaric Cambisols); F: coarse loamy over sandy soils in the Galeria fan (Eutric Cambisols); 2) LS: fine loamy and coarse loamy calcareous soils in Tiber sediments (Calcaric Cambisols); FL: fine loamy over sandy soils in the transition area (Eutric Cambisols); 3) L: fine silty calcareous soils in Tiber sediments (Calcaric Cambisols); 4) C: clayey calcareous soils in Tiber sediments (Calcaric Cambisols & Gleyic Cambisols); 5) limit of mapped area; 6) present road Via Portuense; 7) Roman Acquaduct; 8) directions of Galeria fan sediments.

– Zona di Fiumicino-Ponte Galeria area: carta dei suoli della superficie attuale (2a) e della superficie romana sepolta (2b).
Legenda, con i nomi dei suoli secondo FAO/UNESCO (1988): 1) S: suoli calcarei franco-grossolani in sedimenti del Tevere (Calcaric Cambisols); F: suoli franco-grossolani su sabbia nel conoide alluvionale del Galeria (Eutric Cambisols); 2) LS: suoli calcarei franco-fini e grossolani in sedimenti del Tevere (Calcaric Cambisols); FL: suoli franco-fini su sabbia nella zona di transizione (Eutric Cambisols); 3) L: suoli calcarei limoso-fini in sedimenti del Tevere (Calcaric Cambisols); 4) C: suoli calcarei argillosi in sedimenti del Tevere (Calcaric Cambisols & Gleyic Cambisols); 5) limite dell'area cartografata; 6) Via Portuense moderna ; 7) Acquedotto romano; 8) direzioni dei sedimenti del conoide del Galeria.

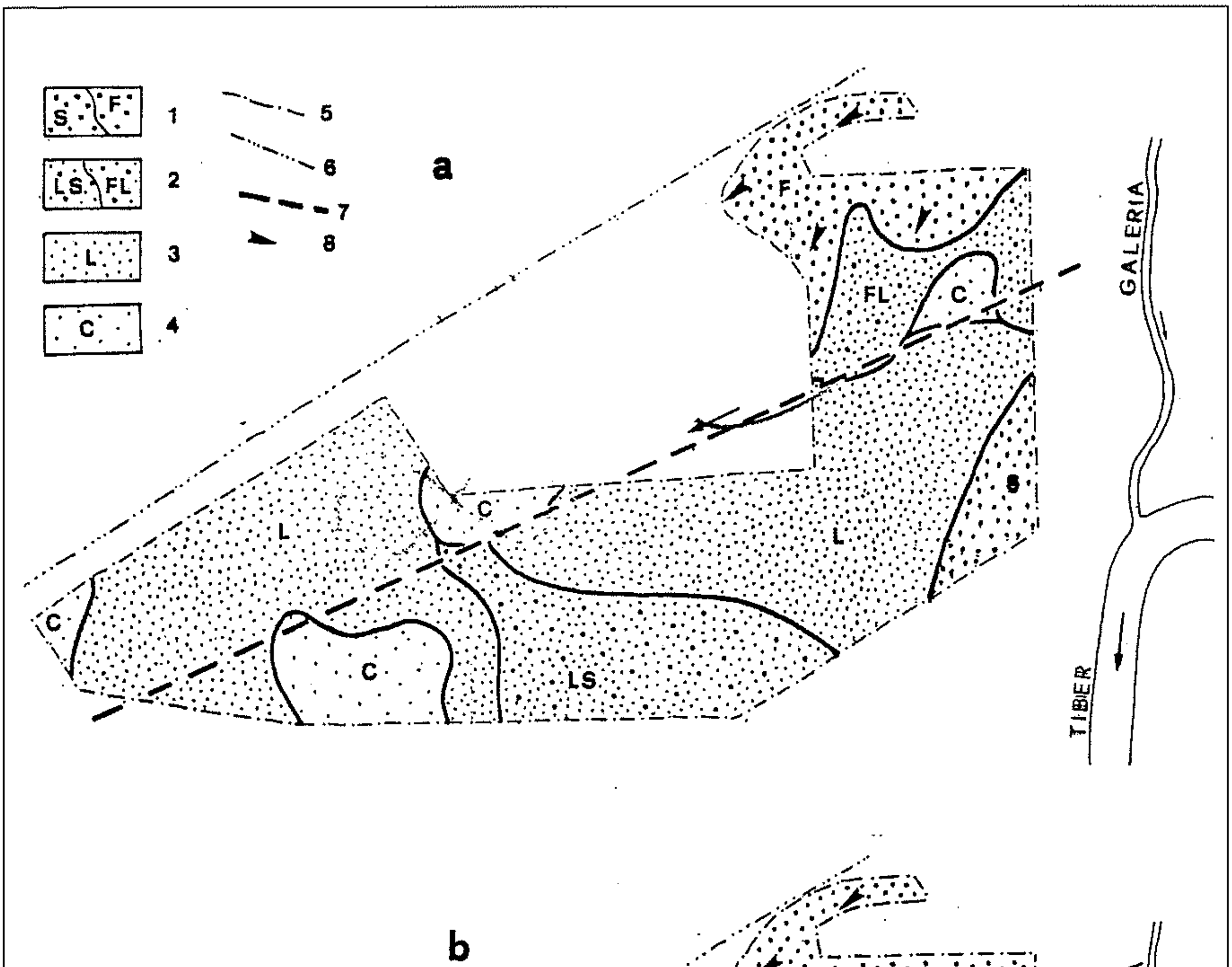

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Fig. 3. – The Castle of Ostia-town, constructed towards the end of the XV century, which strategical position along the Tiber was completely annulled during the flood of 1557, through the formation of the dead meander. The meadow on the foreground marks the former river bed (photo Arnoldus).

– Il Castello di Ostia-città, costruito verso la fine del secolo XV, la cui posizione strategica è stata completamente annullata in occasione dell'alluvione del 1557, quando si formo' il «Fiume Morto». Il prato in primo piano corrisponde al precedente letto del fiume (foto Arnoldus).

The evident stability, in this tract, of the river course between the I and XVI centuries coincides with the functioning of an artificial river outlet near Fiumicino, the "Fossa Traiana" (fig. 1), which was constructed near the end of the I century A.D. This rather precise time overlap could, to our opinion, indicate the effective functioning of this channel, not only as a water way (as such it was originally dug), but also as a buffer against the energy surplus of the river during high water stands.

2.4. – Pianabella (Roman Ostia)

To the south of the the Roman city of Ostia, along the coast, a part of the dune landscape of Roman epoch ("Pianabella"), with an extension of about 50 ha., is preserved, The landscape is slightly undulating, and has an elevation of about 2 m a.s.l. In this case, the post-roman dune deposits have overlapped the original coastline, but not the Roman landscape, which is still exposed at the surface. Here, the present coastline is shifted seawards for almost 2 km with respect to the historical one (fig. 1).

The most external dune ridge of the Roman "Pianabella" area is covered with the ruins of villa's. The position of this ridge close to the sea is known through the description, by a classical writer, of the seaview from one of the villa's. Moreover, there are in this area relicts of rows of tombs, alined along small streets linked with the Roman city of Ostia, and now marked in the field as "ridges". According to a survey executed in 1996 for the Soprintendenza Archeologica di Ostia, these streets do not follow the direction of the dune ridges; therefore, their orientation seems mainly motivated by the already existing urban layout of Ostia.

The surface deposits of the "Pianabella" zone are sandy. Landinwards, the area is bordered by the clayey-peaty infill of a former lagoon (the "Stagno Ostiense"). This confinement of the area between recent sand dunes and clays, and moreover its evident isolation from the Tiber groundwaters, has given rise to a small, shallow but still clean groundwater reservoir, until recently used as drinking water, and presently for irrigation purposes.

The Roman city of Ostia is situated on the prolungation of this narrow land stretch to the north. So, to the positional advantages in Roman times of this dune belt (near the lagoon, the river and the sea; several meters above sea level) may be added now the availability of good water at a shallow depth.

3. – MANAGEMENT OF ARCHAEOLOGICAL SITES AND LANDSCAPES

In Italy, the safeguarding of the antique monuments is ruled by the application of the law 1089/39, concerning the "protection of the goods of artistical and historical interest". However, this law allows essentially only the protection of the monument itself, on the basis of article 1, foreseeing the institution of an archaeological restraint. However it is possible to apply, by means of article 2, the restraint also to part of the surrounding land, in order to prevent damage to the light and perspective of the monument, thus guaranteeing the necessary conditions of decorum and dignity reserved for the historical-archaeological heritage.

So, in the juridical context, the conservation of the environment has always been considered as subordinate to the importance of the antique construction, for which it had to serve mainly to increment the value. One understands therefore, how this normative does not foresee the protection of the territory intended in its historical values, i.e. as physical testimony of the historical geographical situations that have allowed the development of human activity through the centuries.

Another law, the 1497/39, refers essentially to "the protection of the natural and panoramical beauties", with a vision still based on the traditional esthetical values of landscape, without regarding substantially the history of the territory. In the last decennia, fortunately, the sensibility of the lawgivers seems to have grown more attentive to the topic of the Environmental and Landscape Heritage, which is finally considered in strict and inseparable connection with the archaeological presences. This is demonstrated by the issuance of the so-called law "Galasso", n. 431/1985: in this law, in article 1, letter m) - in the context of particular territorial circumstances - is contem-

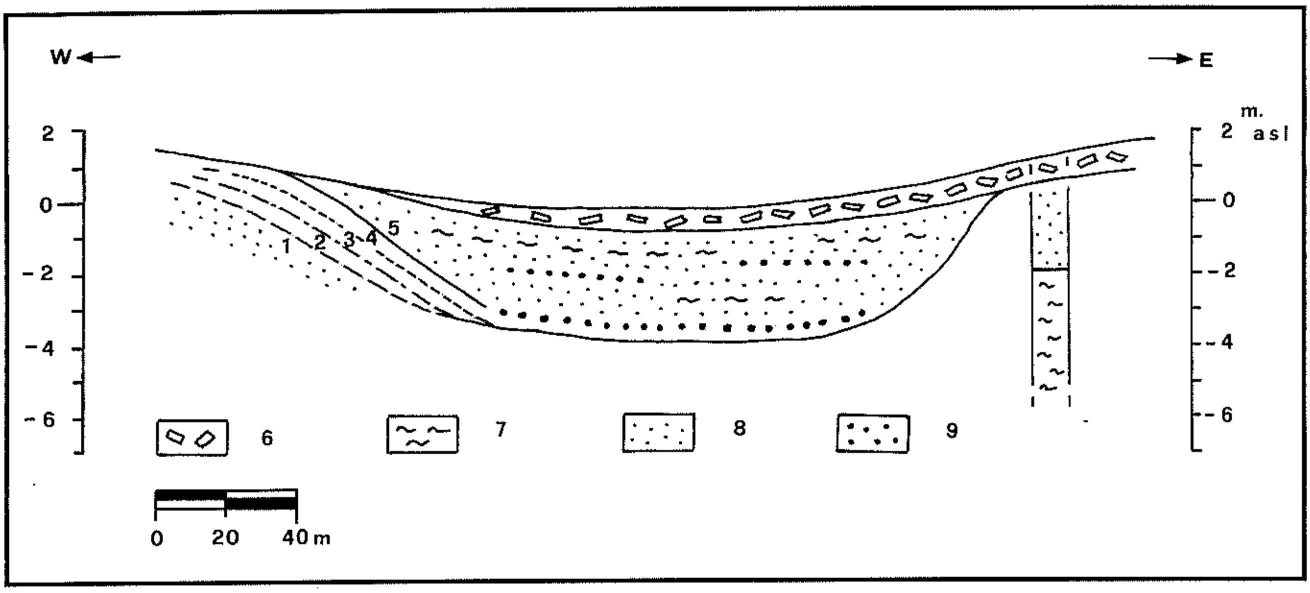

Fig. 4. – Schematic W-E section through the easternmost tract of the dead meander near Ostia ("Fiume Morto").
Legend: 1) river bank before I century A.D.; 2) displacement of the river bank during a flood of the I century A.D.; 3) displacement of river bank during the flood of 1530; 4) displacement of the river bank during the flood of 1557, before the meander cut; 5) surface and infill of the dead meander, formed after the year 1557; the sandy inclusions mark later floods; 6) artificial infill; 7) clay and peat layers; 8) loamy layers; 9) sandy layers. The stratigraphy of the surroundings is given by a boring executed to the east of the dead meander. Note that the present surface is still slightly concave, thus marking the position of the former river course, in the field and in the streets of modern Ostia Antica.

– Sezione schematica W-E attraverso il tratto piu' orientale del meandro abbondonato di Ostia («Fiume Morto»).
Legenda: 1) riva del fiume prima del I secolo A.D.; 2) spostamento della riva durante un'alluvione del I secolo A.D.; 3) spostamento della riva durante l'alluvione del 1530; 4) spostamento della riva durante l'alluvione del 1557, prima del taglio del'ansa; 5) superficie e riempimento del meandro abbandonato, formatisi dopo l'anno 1557; gli straterelli sabbiosi registrano alluvioni successivi; 6) riempimento artificiale; 7) strati argillosi e torbosi; 8) strati limosi; 9) strati sabbiosi. La stratigrafia degli strati circostanti e' registrata da un carotaggio effettuato ad est del meandro. Si noti che la superficie attuale è ancora leggermente concava, ad indicare cosi' il tracciato del fiume preesistente, sia in campagna che nella sagoma delle strade di Ostia Antica moderna.

plated the joined protection of the antique remains and the entire tract of land forming their context, both under the geographical and the historical profile.

In the first years, unfortunately, the practical application of this law has met, for various reasons, with remarkable difficulties, but now the Latium Regional Board has issued a "Normative Outline of the Territorial Landscape Plans" that, though not yet completely satisfactory in it's contents, seems to respect already essentially the basic requirements of the law "Galasso", and which has already allowed to indentify, on a large scale, vast tracts of land of archaeological-environmental interest to be safeguarded.

Undoubtedly, also the Central Office for the Environmental and Landscape Goods of the Italian Ministry for the Cultural and Environmental Heritage, of recent institution, operates in the same spirit, when qualifying, in a circular of 1995, as areas of archaeological interest also those territories not necessarily characterized by visible antique remains.

With reference to the case studies that belong to the Ostiense territory, it can be remarked that the Soprintendenza Archeologica, circumstances and legal limitations permitting, has often tried to propose wide-ranging archaeological restraints, certainly not limited to the safeguarding of the sole archaeological testimony.

As for the **"Fiumicino-Ponte Galeria"**, it has been possible to issue restraints of the "traditional" type, limited to the single antique remains brought to light in the last years, since to the site, formerly completely unknown under the archaeological profile, had already been assigned, on the basis of the Urban Development Plan, an urban destination. In such circumstances one could only restraint the single archaeological areas, although quite close together, with so many single and separate measures of protection: a cistern with the D.M. of 22.4.1995, and successively a rural republican complex, the late-republican canalizations and a street with the DD.MM. of 21.1.1996, of 10.2.1996 and of 12.2.1996.

Different instead is the case of the so-called **"Trastevere Ostiense"** or **"Fiume Morto"** area, i.e. the zone to the north of the district of the Scavi of Ostia, in Roman times occupied by a dense town quarter with houses and commercial buildings. With the D.M. of 20.4.1994, issued on proposal of the Soprintendenza di Ostia, a wide-ranging restraint was imposed here, that, in union with former smaller and more restricted restraints, has finally allowed the overall protection of the entire tract of land delimited by the old river meander, thus also safeguarding an important testimony of the antique geography of the Roman and medieval city of Ostia, preserved up to our days. The measure foresees the absolute non-edificability, with the exception of the reconstruction of the present rural houses. The immediate programs of the Soprintendenza include the project to enlarge such restraints to those areas within the modern town of Ostia that are not yet occupied by constructions; unfortunately, there has been in the last years a strong urban expansion, illegal and legal.

It is a duty to mention how a large part of the old river course, bordering originally the northern edge of Ostia, was earlier protected by an archaeological restraint, with the D.M. of 5.2.1959 issued on proposal of the former Soprintendente Doct. Pietrogrande, who, particularly diligent to the problems of territory protection, and by mentality and sensibility clearly ahead of his times, had the intention to create a large belt of respect around the entire antique city of Ostia.

Remains to be treated the zone of **"Pianabella"**. Fortunately, here also at the time Doct. Pietrogrande intervened, who, in spite of the strong opposition by some sectors of the academical world (raised to the level of juridical contention by the proprietors of the land), succeeded, quite remarkable for that period, in imposing a wide-ranging restraint (D.M. of 14.9.1963) that included a whole tract of land along the railroad and the so-called "ridges", although only partially. Towards the end of 1996 the Soprintendenza of Ostia, also guided by recent archaeological and soil investigations, presented to it's Ministry a new restraint proposal that substantially completes that of Pietrogrande: in the hope that this will be accepted, the entire large district of Pianabello, between the Via di Castel Fusano, the antique emissary of the Stagno Ostiense and the former coastline, will be submitted to global restraint, thus preserving intact for the future generations another piece of the history of Ostia.

4. – CONCLUSIONS

Until recently, little attention has been given in archaelogical management policy to such a fundamental concept as landscape. Traditionally, there is an implicit agreement that the archaeological heritage consists of isolated, clearly visible and recognizable objects or monuments such as prehistoric dolmen, Roman buildings and medieval structures.

It is of course true that this "standing part" of the heritage accords a special visual quality to the landscape, but perhaps it is insufficiently recognized that these elements cannot be fully understood when they are isolated from their original surroundings. A policy that supports a selective management will ultimately lead to a fragmentation of our knowledge of the past. Therefore, an alternative approach to the archaeological heritage in landscape terms is required.

Especially the areas where archaeosites are strongly intertwined with their original landscapes, merit fully to be proposed as geosites as well, thus stressing the vision that, on the one hand, the archaeological heritage should not be isolated from the remains of its original landscape and, on the other hand, the archaeological content can be considered as one of the values of an geological situation or landscape.

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Le sorgenti di Roma antica: un geotopo di grande valore
Old Rome springs: a very important geotope

CORAZZA A. (*)

RIASSUNTO – Nell'antica città di Roma esistevano numerose sorgenti che, insieme ai pozzi ed al Tevere, costituirono per molti secoli le uniche fonti d'acqua della città e influenzarono sicuramente, con la loro presenza, la localizzazione dei primi insediamenti abitativi.
Alcune delle sorgenti usate in epoca romana ancora permangono e rappresentano un notevole patrimonio geologico e archeologico.

PAROLE CHIAVE: Roma, antiche sorgenti, geotopi.

ABSTRACT – In ancient times, Rome was watered by springs, a number of wells and by River Tiber. For many centuries, no other source of water was available to the inhabitants and their location proved certainly determinant to first human settlers.
Some of the springs used in Roman times are still active, representing a significative geological and archaeological heritage.

KEY WORDS: Rome, ancients springs, geotopes.

1. – INTRODUZIONE

In epoca romana nella città di Roma esistevano numerose sorgenti alcune delle quali sono giunte fino ai giorni nostri e costituiscono, per il loro valore idrogeologico ma anche archeologico e monumentale, un geotopo di grande importanza scientifica.

Si pensi a questo proposito, vista la loro collocazione in una metropoli la cui storia è di oltre 2700 anni:

- alla loro rarità e diversità rispetto a qualsiasi altro tipo di sorgente;
- alla loro rappresentatività: si tratta di emergenze, peraltro concentrate in un territorio di ridotte dimensioni, connesse con diversi tipi di circolazioni idriche (libere ed in pressione) e con diversi complessi idrogeologici;
- al loro valore storico (per alcune attestato fin dall'epoca antica) e alla loro «posizione chiave»;
- alla loro agevole accessibilità (alcune di esse rientrano negli itinerari turistici canonici nella città di Roma), che ne facilita enormemente la fruibilità culturale;
- alla loro estrema vulnerabilità sia ai fenomeni di inquinamento ma anche, specialmente per quelle non situate in aree archeologiche, agli interventi antropici, anche modesti, che, se non studiati nei minimi dettagli, potrebbero determinarne la scomparsa;

(*) IRSA - CNR - Via Reno, 1 - Roma.

- al loro valore scenico, visto che sono state, fin dall'epoca romana, monumentalizzate con la realizzazione di vasche e ninfei, e ricadono in zone archeologiche famose in tutto il mondo, come il Foro Romano o le Terme di Caracalla, oppure rientrano in zone estremamente suggestive dal punto di vista naturalistico, come l'Orto Botanico o il Parco della Caffarella.

2. – LA STORIA DELLE SORGENTI

Le sorgenti, insieme ai pozzi e al Tevere, costituirono per molti secoli le uniche fonti di approvvigionamento idrico della città e il rinvenimento e la diffusione di cunicoli di presa e di pozzi su tutti i colli romani conferma la ricchezza d'acqua del territorio nell'antichità.

Le sorgenti e i pozzi vennero in gran parte abbandonati con la costruzione degli acquedotti che dotarono la città di grandi quantità d'acqua (oltre 13,5 m^3/s nel 226 d.C., data della costruzione dell'ultimo degli undici acquedotti romani). Alcune sorgenti vennero invece sacralizzate e venerate e si conservarono ancora per molti altri secoli.

Dopo il taglio degli acquedotti ad opera dei barbari (537 d.C.) si ritornò all'uso delle sorgenti delle quali tuttavia, in epoche successive, eccettuati alcuni interventi operati dai Papi tra il XVI e XVIII secolo, si persero completamente le tracce a causa del loro abbandono e del progressivo interramento della città. Nel corso dell'ottocento e nei primi del novecento alcune delle antiche fonti furono ricercate e, a volte, anche ritrovate.

3. – INQUADRAMENTO IDROGEOLOGICO DELLA CITTÀ

L'assetto idrogeologico dell'area romana è molto complesso (figg. 1 e 2) ed è stata oggetto di numerosi studi (ALBANI *et alii*, 1972; CARBONI *et alii*, 1990; CORAZZA *et alii*, 1989; CORAZZA & GIULIANO, 1994; CORAZZA & LOMBARDI, 1995 a, 1995 b; VENTRIGLIA 1971, 1990) che ne hanno chiarito gli aspetti generali e, in alcune zone, anche gli aspetti di dettaglio. Esso è caratterizzato dalla presenza, generalmente in profondità e solo in alcune zone in affioramento, di un substrato impermeabile, costituito da argille marine plio-pleistoceniche (*complesso delle argille marine*), al di sotto del quale nessuna circolazione idrica è possibile.

Su questo substrato poggia una successione di terreni di età quaternaria, di origine vulcanica (*complesso idrogeologico delle vulcaniti*) e sedimentaria (*complessi idrogeologici dei depositi alluvionali e dei depositi pleistocenici*) che sono sede, in ragione della permeabilità relativa dei terreni e delle loro giaciture, di circolazioni idriche sotterranee poste a varie profondità.

Il *complesso dei depositi pleistocenici* è formato da terreni eterogenei, quali argille, limi, sabbie, ghiaie, diatomiti, travertini. In questo complesso, nella zona centrale dell'urbe e in riva destra del Tevere, è presente una modesta circolazione idrica superficiale, contenuta entro terreni sabbioso-ghiaiosi e sostenuta da terreni limo-argillosi. La circolazione dava luogo sui colli Vaticano e Gianicolo a piccole sorgenti, molto note fin dall'antichità: Acqua Damasiana, A. di S. Maria delle Grazie o A. della Fontana delle Api, A. Pia, A. Lancisiana, A. Innocenziana o A. del fontanile delle mole gianicolensi, A. del Tempio Siriaco, Sorgenti Corsiniane (solo queste ultime permangono ancora oggi). Nello stesso complesso, in tutta la riva sinistra della città, è presente invece una importante circolazione idrica in pressione contenuta in un orizzonte ghiaioso poggiato direttamente sulle argille plioceniche. Tale circolazione dava luogo in epoca romana ad importanti sorgenti situate laddove le incisioni dei paleoaffluenti del Tevere erano giunte a tagliare l'orizzonte ghiaioso. Le sorgenti di cui si hanno notizie storiche sono: Acque Lautole, Acqua di Mercurio, Fonte di Apolline, Fonte delle Camene, Acqua Tulliana, Fonte di Giuturna, Piscina Pubblica, Acqua di S. Clemente (le ultime quattro tuttora visibili).

Il *complesso delle vulcaniti* comprende i prodotti piroclastici del Distretto vulcanico dei Colli Albani e di quello dei Sabatini e anche, vista la loro limitata estensione e il modesto spessore, i depositi sedimentari sin e post vulcanici qualora questi siano direttamente sovrapposte alle vulcaniti. In questo complesso, in riva sinistra del Tevere, dove sono presenti prevalentemente i depositi vulcanici attribuibili all'attività del Distretto dei Colli Albani, la circolazione principale é quella situata alla base della serie vulcanica che scende in maniera radiale dai Colli Albani e che interessa le zone orientali e meridionali della città. Tale falda alimenta gran parte dei corsi d'acqua presenti nell'area romana e ad essa si ricollegano alcune antiche emergenze poste entro la città, come la Fonte Egeria, tuttora esistente, e le maggiori sorgenti d'acqua potabile poste ai margini della stessa: tra queste quelle dell'Acqua Vergine e dell'Acqua Appia che ali-

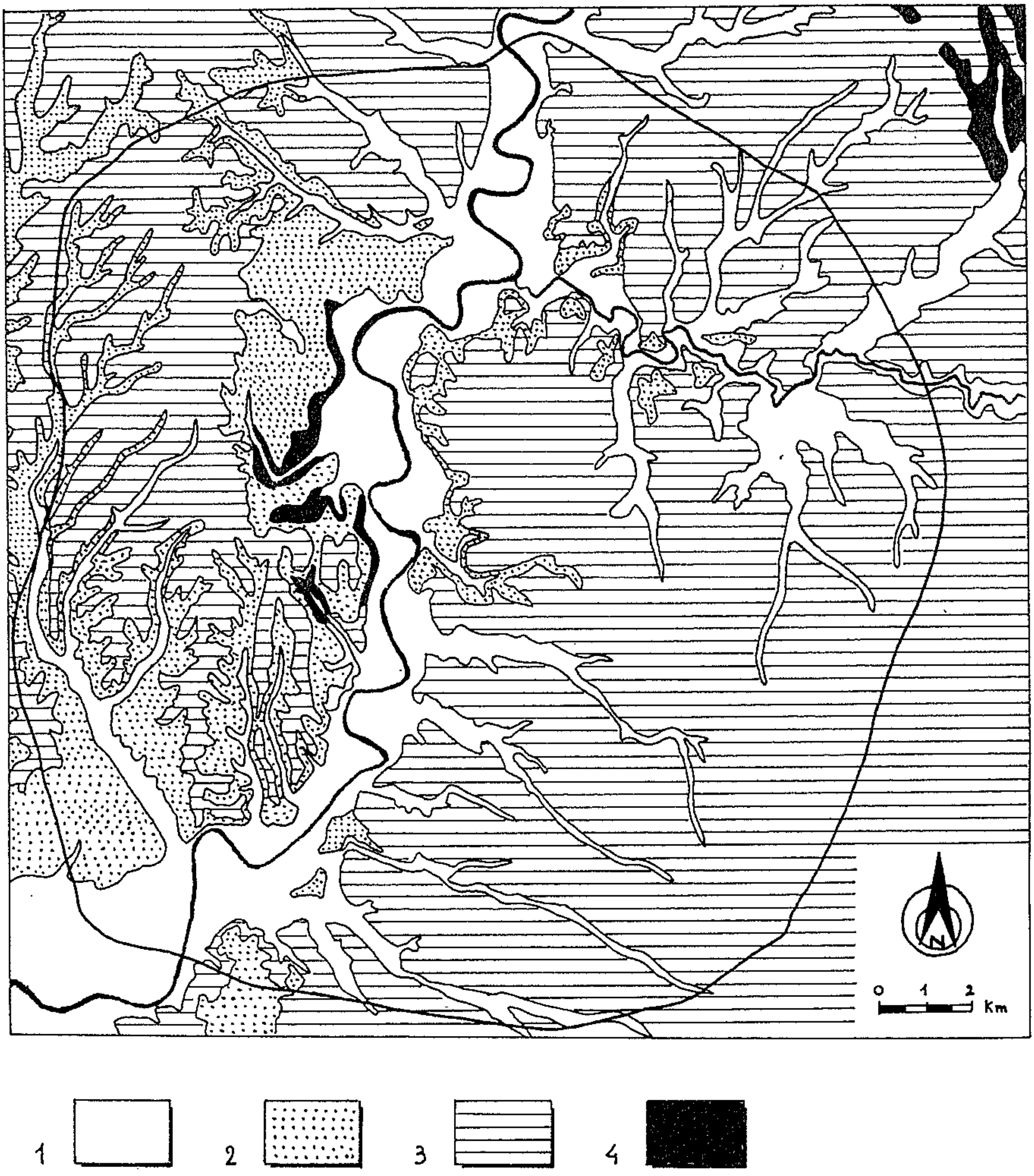

Fig. 1. – Complessi idrogeologici dell'area romana.: 1) Complesso dei depositi alluvionali; 2) Complesso delle vulcaniti; 3) Complesso dei depositi pleistocenici; 4) Complesso delle argille marine.

– *Hydrogeological complexes of roman area: 1) Complex of alluvial deposits; 2) Volcanic complexes; 3) Complex of pleistocene sediments; 4) Complex of marine clays.*

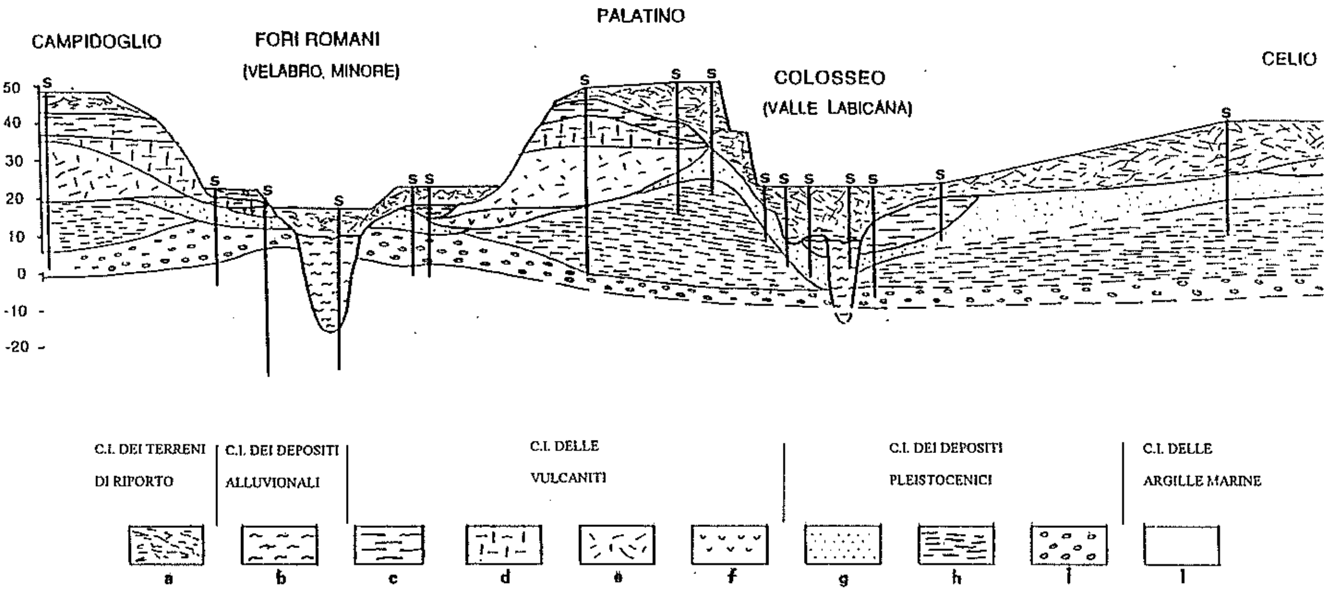

Fig. 2. – Sezione idrogeologica tipo dell'area romana centrale: a) terreni di riporto; b) alluvioni recenti; c) argille post-vulcaniche; d) tufo litoide lionato; e) piroclastiti rimaneggiate *acquifere*; f) tufi granulari; g) sabbie; h) argille; i) ghiaie *acquifere*; l) argille plioceniche; s sondaggi

– Typical hydrogeological section of the central roman area.: a) carried soils; b) recent alluvial soils; c) post-volcanic clays; d) lithoid lionato tuff; e) rearranged porous pyroclastites; f) granular tuff; g) sands; h) clays; i) porous pebbles; l) pliocenic clays; s drilling

mentavano gli omonimi antichi acquedotti romani e che oggi alimentano quelli moderni del Vergine Nuovo e dell'Appio-Alessandrino (AA.VV., 1986; COPPA *et alii,* 1984).

Sulla stessa riva, nella zona centrale della città è presente un'altra circolazione idrica, molto più modesta di quella proveniente dai Colli Albani e non collegata con essa, la cui alimentazione avviene in loco. Tale circolazione emergeva lungo le valli degli antichi corsi d'acqua affluenti del Tevere dando luogo a numerose sorgenti generalmente di modesta portata. Tra queste, una certa importanza avevano le Sallustiane, che rappresentavano in epoca romana una fonte di approvvigionamento non indifferente per la città e, di minore importanza, le fonti del Lupercale, di S. Felice (*Fons Cati*), di Pico e le Acque *Fontinalis* (nessuna di esse è oggi osservabile).

Al di sopra dei terreni di origine naturale poggia, sulla quasi totalità del territorio cittadino, un manto di terreni di riporto dovuti all'attività umana (*complesso dei terreni di riporto).* Questo manto, nelle porzioni più permeabili, è sede anch'esso di varie circolazioni idriche, sia pure molto limitate arealmente. Le circolazioni mostrano a volte potenzialità elevate per cui è ipotizzabile, oltre al contributo dell'infiltrazione diretta delle precipitazioni (minimo vista l'urbanizzazione), un'alimentazione da parte di antiche emergenze, oggi interrate e poste ad alcuni metri di profondità, e di perdite dei sistemi acquedottistici e fognari moderni che diffondono le loro acque all'interno dei terreni antropici.

Le sorgenti, esistenti e scomparse, ubicate nella antica città di Roma sono riportate nella fig. 3.

4. – LE SORGENTI ANCORA ESISTENTI

Le sorgenti dell'antica città di Roma tuttora esistenti, facendo riferimento alla numerazione della fig. 3, sono:

- Sorgenti Corsiniane (n. 5);
- Acqua Tulliana (n. 14);
- Fonte di Giuturna (n. 16);
- Acqua di S. Clemente (n. 18);
- Piscina Pubblica (n. 22);
- la Fonte Egeria (n. 24).

Sorgenti Corsiniane

Alle pendici del colle Gianicolo, nel giardino di Palazzo Corsini (ora Orto Botanico), scaturivano due emergenze che venivano utilizzate per l'approvvigio-

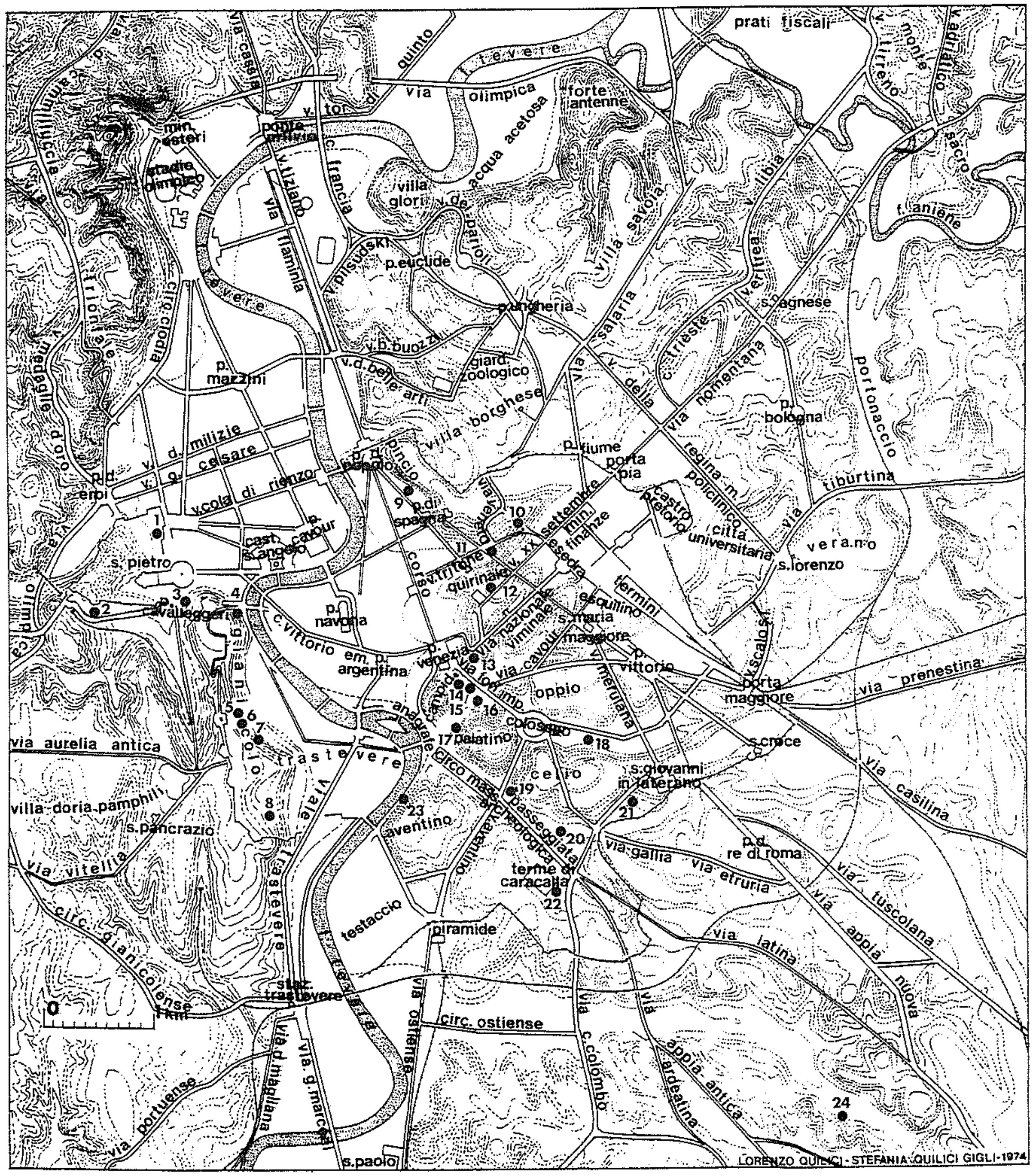

Fig. 3. – Pianta di Roma con la morfologia originaria (in tratteggio) e con l'ubicazione delle sorgenti (da QUILICI, 1990; modificato): 1) Acqua di S. Maria delle Grazie; 2) Acqua Damasiana; 3) Acqua Pia; 4) Acqua Lancisiana; 5 - 6) Acque Corsiniane; 7) Acqua Innocenziana; 8) Acqua del Tempio Siriaco; 9) Acqua di via Margutta; 10 - 11) Acque Sallustiane; 12) Acqua di S. Felice; 13) Acque *Fontinalis*, Acqua Tulliana; 15) Acque Lautole; 16) Fonte di Giuturna; 18) Acqua di S. Clemente; 19) Acqua di Mercurio; 20) *Fons Apollinis*, 22) Piscina Pubblica; 23) Fonte di Pico; 24) Fonte Egeria.

– Rome map with original morphology (out-lined) and with location of springs (from QUILICI, *1990; modified): 1) S. Maria delle Grazie Water; 2) Damasiana Water, 3) Pia Water, 4) Lancisiana Water, 5) - 6) Corsiniane Waters, 7) Innocenziana Water, 8) SyriacTemple Water, 9) Margutta Way Water, 10) - 11) Sallust Waters, 12) S. Felice Water, 13) Fontinalis Water,Tully Water 15) Lautole Water, 16) Giuturna Source, 18) S. Clemente Water, 19) Mercury Water, 20) Apollinis Fons, 22) Public Swimming-pool, 23) Pico Source, 24) Egeria Source.*

namento d'acqua del palazzo e di altre utenze. La quota delle sorgenti era tale da consentire nell'800 l'adduzione dell'acqua con tubazioni fino all'ultimo piano del palazzo nobiliare.

Una di queste sorgenti ancora esiste ed in epoca romana veniva captata con drenaggi e con una galleria di circa 100 m (fig. 4). L'opera di presa doveva, presumibilmente, alimentare la *Domus Clodiae* di cui vasti resti furono rinvenuti e reinterrati nel 1880 sulla piana del Tevere durante la costruzione dei muraglioni del fiume (STACCIOLI, 1986).

Fig. 4. – Sorgenti Corsiniane: cunicolo romano di captazione.

– *Corsiniane Sources: roman cuniculus of getting.*

Fig. 5. – Acqua Tulliana: cella inferiore del Carcere Mamertino con il pozzo dal quale fuoriesce l'acqua.

– *Tully Water: inferior cell of Mamertino Prison with the well from which the water comes out.*

Acqua Tulliana

La sorgente si trova nei sotterrannei della Chiesa di S. Pietro in Carcere posta ai piedi del colle Campidoglio. Il nome di questa piccola fonte deriva da quello della cella inferiore del Carcere Mamertino, dal cui pavimento ancora oggi sgorga (fig. 5), che veniva chiamata *Tullianum*, da *Tullus* (polla d'acqua).

L'Acqua Tulliana è spesso citata dalle fonti essendo collegata alla storia del carcere, il più antico e famoso di Roma essendovi stato rinchiuso anche l'apostolo Pietro. La leggenda vuole che il santo abbia fatto scaturire miracolosamente l'acqua durante la sua prigionia per poi utilizzarla per battezzare tutti coloro che si convertivano al cristianesimo.

L'acqua di questa fonte viene fatta defluire da una rete di cunicoli sotterranei, anche di epoca romana, che sicuramente afferiscono all'asse fognario principale della zona costituito dalla Cloaca massima.

Fonte di Giuturna

La *Fons Juturnae* è situata nel Foro Romano ai piedi del Palatino.L'acqua sorgiva emerge tuttora dal pavimento di una vasca di marmo quadrata collocata in epoca antica a testimonianza dell'originaria sorgente (fig. 6). La fonte, che fu oggetto di culto nell'antichità, viene citata numerose volte nei testi antichi (da Dionisio, Frontino, Livio, Ovidio, Svetonio) in relazione soprattutto al suo carattere sacro ma anche perché

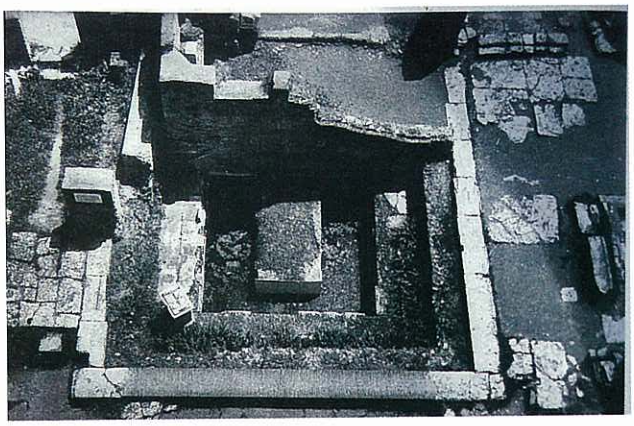

Fig. 6. – Fonte di Giuturna: vasca sul fondo della quale è visibile l'acqua sorgiva (archivio della Soprintendenza Archeologica di Roma).

– *Giuturna Source: basin where spring water appears from the bottom (archives of Archaeological Superintendence of Rome).*

sembra che le sue acque andassero a formare una zona paludosa tra Palatino e Celio, il *Lacus Curtius*, che fu probabilmente prosciugato con la costruzione della Cloaca massima.

Il battente d'acqua all'interno della vasca è minimo e varia stagionalmente. La modesta portata così come la saltuarietà di questa fonte, le cui acque secondo le testimonianze di vari autori sono scomparse e ricomparse più volte nel corso dei secoli, possono essere messe in relazione con la forte azione drenante esercitata sulle acque sotterranee dal collettore della Cloaca massima.

Acqua di S. Clemente

L'acqua attualmente esce da un condotto romano posto al livello della casa di età repubblicana che costituisce la struttura più antica presente nel sottosuolo della Chiesa di S. Clemente, situata non distante dal Colosseo (fig. 7). Il cunicolo, che proviene con ogni probabilità dall'opera di presa della sorgente, porta un discreto quantitativo d'acqua (oltre 1 l/s).

Piscina Pubblica

Lanciani (1881) ubica questa sorgente ai piedi del colle Piccolo Aventino tra l'entrata delle Terme di Caracalla, le mura Serviane e la Via di Santa Balbina. La fonte, così come le altre della Valle Camena, doveva essere di notevole importanza, tanto da dare, in epoca romana, il nome a tutta la zona.

L'edificio centrale delle Terme di Caracalla è percorso nel sottosuolo da una grande fogna nella quale scorre tuttora acqua sorgiva captata dalle pendici dell'Aventino. È molto probabile che le sorgenti della «Piscina Pubblica» al momento della costruzione delle Terme, siano state incondottate e fatte defluire nella fogna profonda per garantirne la costante pulizia. L'acqua venne utilizzata anche in epoche successive tramite l'apposizione di una vera di pozzo su uno dei pozzetti di accesso alla fogna profonda (fig. 8).

Fonte Egeria

L'area della Valle della Caffarella, posta poco fuori delle Mure Aureliane tra la via Latina e la via Appia Antica, è ricca di emergenze di acque mineralizzate, molto note nell'antichità per le loro virtù terapeutiche.

Fig. 7. – Acqua di S. Clemente: condotto romano dal quale fuoriesce l'acqua della sorgente.

– *S. Clemente Water: roman pipe from which the spring water comes out.*

La mineralizzazione delle acque è da mettersi in relazione alla attività vulcanica dei vicini Colli Albani e in particolare alla venuta a contatto della circolazione idrica sotterranea presente alla base del complesso dei prodotti vulcanici con i convogli fluido-gassosi di origine magmatica che risalgono lungo le fratture di origine vulcano-tettonica nei pressi delle quali, nell'intera area romana, sono ubicate le sorgenti minerali (CAMPONESCHI & NOLASCO, 1982).

La *Fons Egeria*, citata da Tito Livio, Vitruvio, Plutarco e Giovenale è posta in sinistra orografica della Marrana della Caffarella. Era utilizzata fin dall'anti-

Fig. 8. – Piscina Pubblica: pozzo per il prelievo dell'acqua sorgiva che scorreva (e scorre tuttora) nella fogna delle Terme di Caracalla.

– *Public Swimming-pool: well for drawing of spring water that has ran (and is running) in the drain of Caracalla Thermae.*

chità, quando venne fatta captare da Erode Attico per alimentare un ninfeo della sua grande villa (fig. 9). Benchè il condotto principale che portava l'acqua al ninfeo sia crollato alla fine del '500, dal monumento romano, completamente abbandonato ed in rovina, fuoriesce ancora un discreto quantitativo d'acqua, acidula e mineralizzata.

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Fig. 9. – Fonte Egeria: Ninfeo di Erode Attico.

– *Egeria Source: Nynpheo of Attico Erode.*

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Seismic response of the historical centre of Rome
Risposta sismica del centro storico di Roma

DONATI S. (*), FUNICIELLO R. (*) & ROVELLI A. (**)

ABSTRACT – In this work, the results of a comprehensive analysis of seismic damage to 149 monuments in the historical centre of Rome are shown. Thanks to the study of geological and seismotectonic features of the area and the reconstruction of the geometry of the old hydrographic network of the Tiber River, the analysis of seismic effects enhances a significant correlation between damage distribution and variations of local geology. Confirming previous studies (AMBROSINI *et alii,* 1986; MOLIN & GUIDOBONI, 1989), the largest part of the serious damage occurs in the holocenic alluvial area, tending to concentrate along the edges of the Tiber valley as well as near the major slope changes of topographic relieves. These results are interpreted in terms of source and site effects through seismological models which take into account the main physical characters of both source and nearsurface geology (ROVELLI *et alii*, 1994; 1995 b): the synthetic accelerograms show the largest ground motion in those geological situations where observations show the maximum concentration of heavy effects.

In conclusion, the correlation between the damage distribution and the numerical modelling stresses the role played by the heterogeneities of nearsurface geology on the level of seismic excitation. These site effects may represent a serious threat for the archaeological and architectural heritage of our historical cities, even in areas far away from seismogenic districts.

KEY WORDS: Seismic risk.

RIASSUNTO – In questo lavoro, vengono illustrati i risultati di una analisi comprensiva del danno sismico per 149 monumenti del centro storico di Roma. Grazie allo studio delle caratteristiche geologiche e sismotettoniche dell'area e la ricostruzione della geometria della vecchia rete idrografica del fiume Tevere, l'analisi degli effetti sismici evidenzia una significativa correlazione tra la distribuzione del danno e la variazione della geologia locale. A conferma dei precedenti studi (AMBROSINI *et alii*, 1986; MOLIN & GUIDOBONI, 1989) la maggior parte dei danni importanti si verifica nell'area alluvionale olocenica, tendendo a concentrarsi lungo i margini della valle del Tevere così come vicino ai principali cambi di pendenza dei rilievi topografici. Questi risultati sono interpretati in termini di origine e luogo degli effetti attraverso modelli sismologici che tengono conto dei principali caratteri fisici sia dell'origine che della geologia di superficie (ROVELLI *et alii*, 1994; 1995 b): l'accelerogramma sintetico mostra il maggior movimento del suolo in quelle situazioni geologiche in cui le osservazioni mostrano la massima concentrazione degli effetti evidenti.

In conclusione, la correlazione fra la distribuzione del danno e la modellazione numerica accentua il ruolo giocato fra l'eterogeneità della geologia di superficie e il livello di eccitazione sismica. Questi effetti locali possono rappresentare una minaccia per il patrimonio archeologico e architettonico delle nostre città storiche, anche in aree lontane da siti sismogenetici.

PAROLE CHIAVE: Rischio sismico.

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1. – INTRODUCTION

During more than 2.500 years of history, Rome has been interested by a considerable number of events, causing severe damage to the artistic patrimony of the city. Since 441 B.C., historical sources and macroseismic surveys report about ten events with intensity up to VII-VIII degree MCS, and more than 60 earthquakes felt by the population (POSTPISCHL, 1985; BOSCHI *et alii*, 1995 a). Because of these strongest earthquakes, many important monuments were affected by significant damage (see MOLIN & GUIDOBONI, 1989; MOLIN & ROSSI, 1993; GUIDOBONI & MOLIN, 1995; CASTENETTO *et alii*, 1995; ROSSI, 1995; DONATI, 1996; FUNICIELLO *et alii*, 1996). In a few specific cases, a detailed study of the local geology allowed seismologists to estimate ground motion produced by earthquakes. For the sake of example, the paper by BOSCHI *et alii* (1995 b) infers a large difference of the shaking level between the Column of Marcus Aurelius and the Column of Trajan in case of strong Apennine earthquake. This difference is as large as a factor of 7 in the frequency band around 1 Hz, and is caused by the different geological conditions of the sites of the two columns. Their different level of damage resulted to be consistent with the inferred variation of ground motion. Moreover, the study by FUNICIELLO *et alii* (1995) investigated the geological numerical modelling (see MOCZO *et alii*, 1995) inferring large differential motions at the basement of Colosseum: shaking was found to be largest at the transition from Pleistocene units and Holocene sediments, in agreement with the highest damage zone (southern external ring). The present work investigates the relationship between distribution of the historical earthquake effects and nearsurface geology.

2. – GEOLOGICAL SETTING

The geology of the area of Rome presents complex features (MARRA & ROSA, 1995), characterized by the emergence of marine Plio-Pleistocene units, continental Upper Pleistocene sediments and Sabatini and Albani volcanic products. The sedimentary sequence, from the bottom to the top, is composed by the Monte Vaticano Pliocenic clays and the Pleistocene marine deposits (the Monte Mario, the Monte Ciocci and Monte delle Piche Units). Some regional structural features regulate the different outcropping of these sediments. In Upper Pleistocene, the intense tectonic activity and the climatic and paleogeographic changes related to the glacial and interglacial periods generate a complex transgressive cycle characterized by the alternation of depositional and erosive phases. The sedimentation of PaleoTevere units 1 and 2 (see AMBROSETTI & BONADONNA, 1967, and MARRA *et alii*, 1995 b) is related to these phases. Starting from 0.6 Ma, Sabatini (NW from Rome) and Albani (SE) volcanic district began to spread around their products (LOCARDI *et alii*, 1977; BARBERI *et alii*, 1994). The tectonics, coupled to the widespread of a great deal of volcanic products, changed completely the geomorphology and hydrology of the Roman area, confining the Tiber to the present riverbed. In the last phase of the Würmian glacial period, the relevant eustatic regression of the sea level accelerated the Tiber's erosive process, escavating the Pliocenic bedrock down to -50 metres under the sea level. During the subsequent rise of the sea level, the articulated network escavated by the Tiber River and its tributaries was backfilled with alluvial Holocene deposits, consisting of unconsolidated clayey-sandy sediments. The contact between the Plio-Pleistocene bedrock and Holocene alluvium is characterized by a high seismic impedance contrast (by a factor of 3 to 4, on the average).

3. – SEISMOTECTONIC FEATURES

According to the Italian seismotectonic context, the seismicity of Rome is quite moderate. Nevertheless, considering the existence in the urban area of both a priceless historical and monumental patrimony and of old buildings extremely vulnerable, seismic risk can not be neglected; the historical centre of the city could be damaged even in the occurrence of low levels of ground motion. The city of Rome is mainly affected by the earthquakes associated to three different seismogenic districts: the Central Apennines area ("regional seismicity"), the Colli Albani area ("local seismicity") and the Rome area ("urban seismicity"). The Apennine seismogenic sources, located between 60 and 130 Km from Rome, produced the strongest intensity felt in the city (VII-VIII MCS). The Aquilano and Fucino districts, in particular, can generate events of high magnitude (nearly 7) with hypocentral depth between 10 and 15 km. The Colli Albani area is characterized by very frequent earthquakes with a maximum magnitude around 5 (AMATO *et alii*, 1994), hypocentral depth between 5 and 10 Km and felt intensity V-VI MCS. The urban seismogenic area, within a radious of 20 km, is characterized by a low frequency of occurrence, maximum intensity around VI-VII

MCS (see TERTULLIANI & RIGUZZI, 1993), magnitude values probably less than 4 and maximum hypocentral depth around 12 km (BASILI *et alii*, 1996).

4. – METHODOLOGY

The present work has selected a sample of 149 monumental buildings in Rome, resulted to have been damaged by historical earthquakes in the most recent historical seismology studies (MOLIN & GUIDOBONI, 1989; BUDRIESI, 1989; GUIDOBONI *et alii*, 1994; BOSCHI *et alii*, 1995 a; ROSSI, 1995; LEGA, 1995; DONATI, 1996). The file consists of 78 ecclesiastic, 46 public and 13 roman period buildings, 5 monumental doors of the Aurelian Walls, 3 Middle Age towers and 1 monumental fountain. A record including date of the event and seismogenic area (*Central Apennines, Colli Albani and Rome Area*), damage description and intensity evaluation (*weak, intermediate* and *serious,* according to the methodology proposed by AMBROSINI *et alii*, 1986), has been compiled for each building. No seismogenic area was associated to the ancient earthquakes (events until 1091 A.D.). To analyse the connection between the spatial distribution of the sample and the nearsurface geology, the Geological Map of Rome (MARRA & ROSA, 1995) has been reduced to a simplified map, considering exclusively the geotechnical heterogeneities of the outcropping units. According to this, marine and continental Plio-Pleistocenic sedimentary units and Sabatini and Albani volcanic products have been unified in an undifferentiated unit (conventionally called *bedrock*).

5. – DAMAGE ANALYSIS

Previous studies (AMBROSINI *et alii*, 1986; MOLIN & GUIDOBONI, 1989; SALVI *et alii*, 1991; BOSCHI *et alii*, 1993; MOLIN & ROSSI, 1993; BOSCHI *et alii*, 1995 a) had stressed the particular role of unconsolidated Holocene alluvial deposits in the areal distribution of seismic damage. In this work, the correlation between the damage distribution to the artistic and monumental patrimony and the geolithology has been largely confirmed, showing some significant systematic variations even considering single seismogenic areas (fig. 1). Almost 80% of the serious damage occurs in the Holocenic alluvial area, tending to concentrate along the narrow bands close to the edges of the Tiber valley (*edge effect*, see TERTULLIANI & RIGUZZI, 1995). This percentage decreases to 60% for the weak damage, particularly influenced by the structural framework of the buildings. It is note worthy to observe that the spatial distribution of the monuments sample strictly reflects the percentage of weak damage (60% of monuments on the alluvial deposits, 40% on the bedrock outcrops). This suggests that the distribution of weak damage is probably random (fig. 2 and 3).

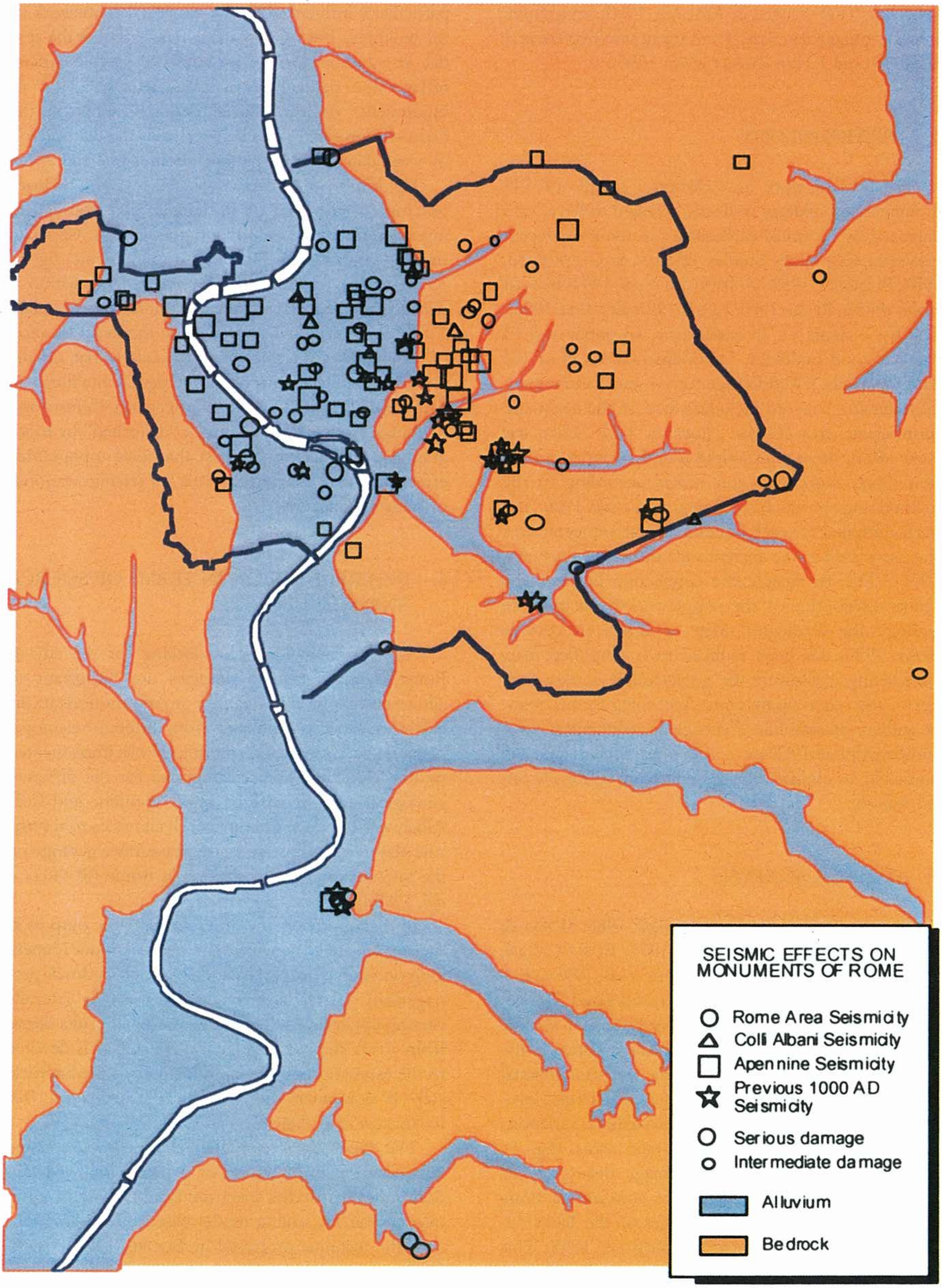
The sample of buildings located over the bedrock outcrops of the Hills of Rome has been analyzed to investigate the role of topographic effects. Considering the ubication of 24 damaged monuments (fig. 4), 13 of them resulted to be concentrated within a distance of 20 metres from the border of the relief. This is a significant result, because the usual location of monuments on the Hills, particularly flat on the top, tends to concentrate monumental buildings in their central part. The seismic effects on 13 historical buildings located over a bedrock "disturbed" by topographical irregularities suggest that local topographic effects can play a significant role on seismic response of bedrock outcrops.

6. – INTERPRETATION IN TERMS OF SOURCE AND SITE EFFECTS

As instrumental data are lacking for the city of Rome, numerical methodologies are important to allow seismologists to quantify ground motions in the city as caused by earthquakes from different seismogenic areas. A numerical methodology was implemented by to yield synthetic accelerograms for the different geological units, in case of both Apennine and Colli Albani earthquakes. This approach allows us to test the role played by both source and nearsurface geology on the intensity of ground shaking in Rome (ROVELLI *et alii*, 1995 b).

In that approach, the different synthetic outputs at the surface are obtained from a bedrock input (depending on source properties and source-to-bedrock propagation) which is propagated through laterally varying upper-layers. Therefore, the final results derive from a two-step process (A and B): step A is devoted to the estimation of the input incident at the bedrock; step B computes the very local propagation (see ROVELLI *et alii*, 1994).

The "bedrock accelerograms" are computed (step A) through the generation of a time-windowed random series whose flat spectrum is modulated by a frequency-domain scaling model based on observations (it is the tecnique proposed by BOORE, 1983, basically). In our approach, the source contribution is given


SEISMIC EFFECTS ON MONUMENTS OF ROME
Rome Area Seismicity
Colli Albani Seismicity
Apennine Seismicity
Previous 1000 AD Seismicity
Serious damage
Intermediate damage
Alluvium
Bedrock

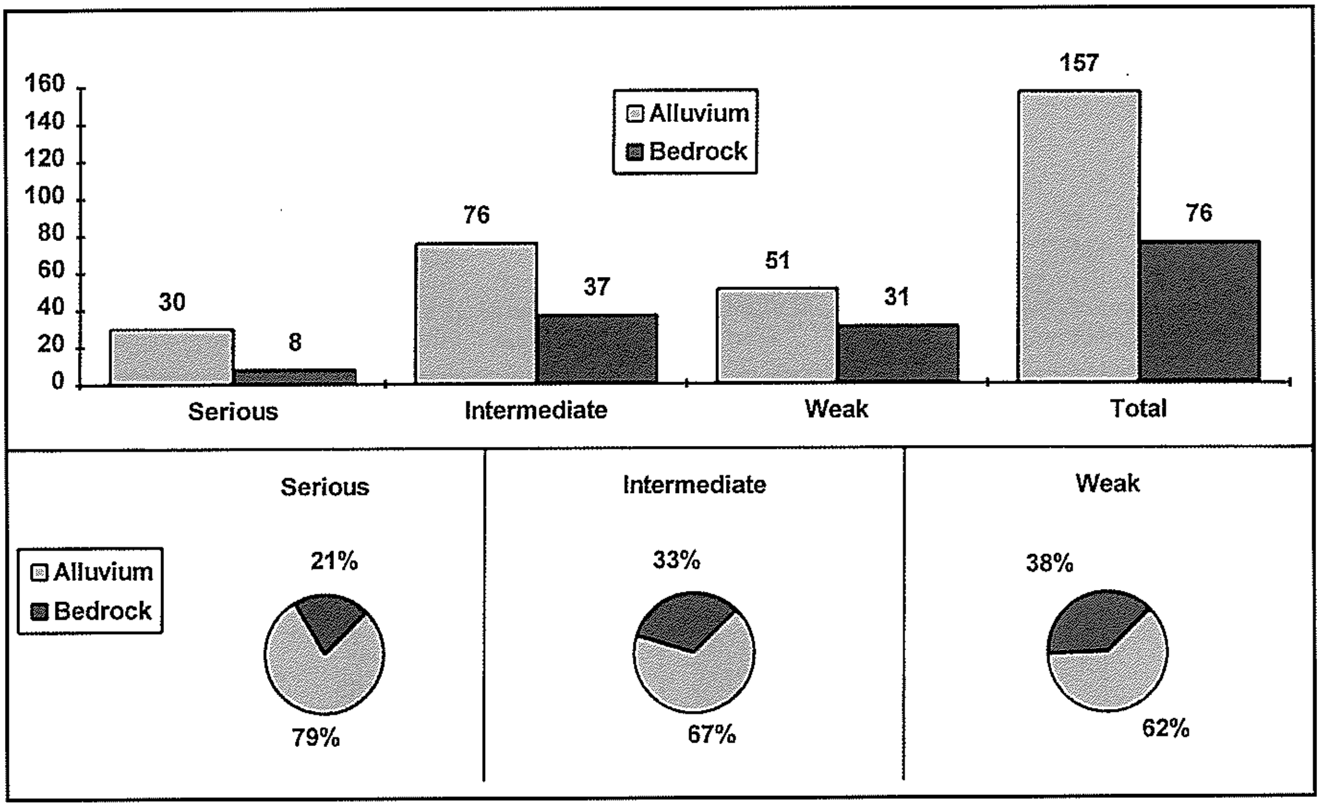


Figure 2. – Statistical distribution of seismic damage on monuments of Rome as a function of nearsurface geology (events from 441 BC to 1995).

– *Distribuzione statistica dei danni sismici ai monumenti di Roma in funzione della geologia delle zone superficiali (eventi dal 441 AC al 1995).*

by the omega-square spectral model of shear-waves, and the whole-path propagation is modelled in the frequency-domain by the combination of a low-pass filter (the effect of anelastic dissipation, see ANDERSON & HOUGH, 1984) and a high-pass filter (the effect of decreasing seismic impedance in the upper crust, see JOYNER & FUMAL, 1984). The procedure details are presented in ROVELLI *et alii* (1994; 1995 a); in those papers, the advantages of using a stochastic approach compared to deterministic ones are also discussed. In the sketch of figure 5, the local upper-layer propagation (step B) is simulated with a 2-D finite-difference technique (ROVELLI *et alii*, 1994). The outputs at the surface, obtained from a delta-like input obliquely incident as a plane SH wave, are used as site transfer functions. Therefore, the convolution of the bedrock accelerograms of step A by these site transfer functions yields the transverse component expected at the surface for the horizontal ground motion in a 2-D approximation.

The spatial variation of time histories is consequently estimated as a function of the local geology; engineering interest parameters such as peak ground velocity and acceleration, Arias intensity, duration, flux of seismic energy, response spectra can be simply computed for different types of earthquakes and incidence angles (e. g., see fig. 8 and 10 in ROVELLI *et alii*, 1994).

Figure 1. – Geological scheme of the Historical Centre of Rome and distribution of serious and intermediate seismic damage on the monumental patrimony of the city for different seismogenic areas (events from 441 BC to 1995).

– *Schema geologico del Centro Storico di Roma e distribuzione di danni sismici seri ed intermedi al patrimonio monumentale della città per differenti aree sismogeniche (eventi dal 441 AC al 1995).*

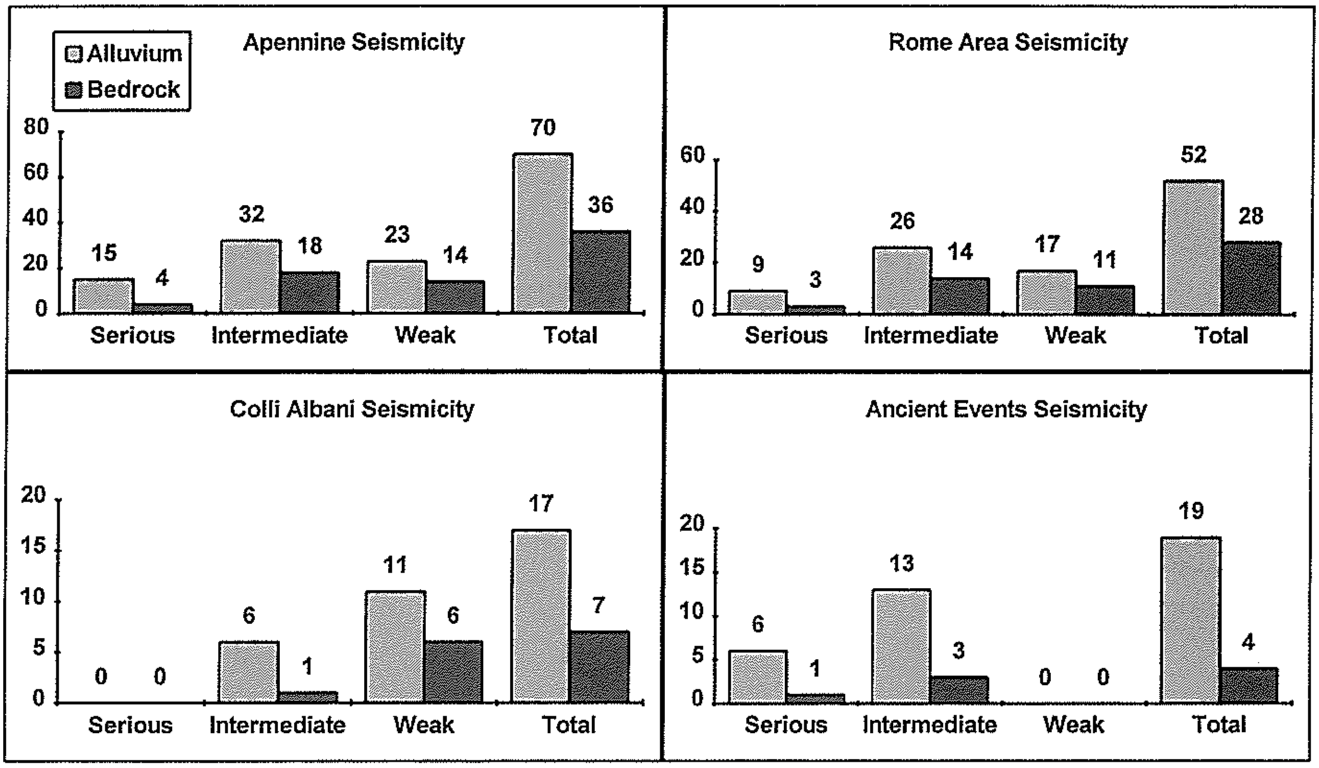


Figure 3. – Statistical distribution of seismic damage on monuments of Rome as a function of nearsurface geology, for different seismogenic areas.

– Distribuzione statistica del danno sismico ai monumenti di Roma in funzione della geologia delle zone superficiali, per differenti aree sismogeniche.

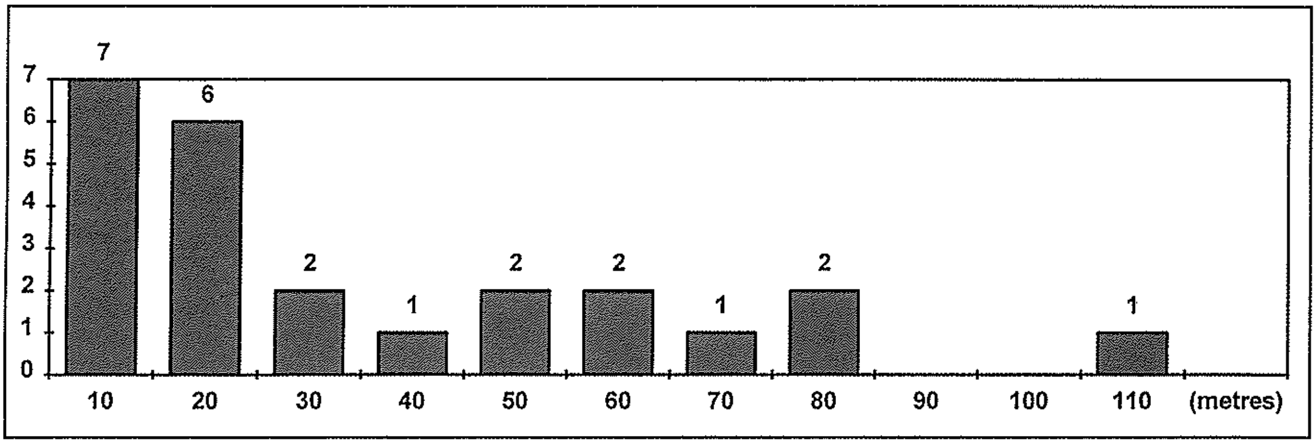


Figure 4. – Distribution of monuments damaged by historical earthquakes on the Hills of Rome as a function of the distance from the border of the relief.

– Distribuzione dei monumenti danneggiati da terremoti storici sui Colli di Roma in funzione della distanza dal confine del rilievo.

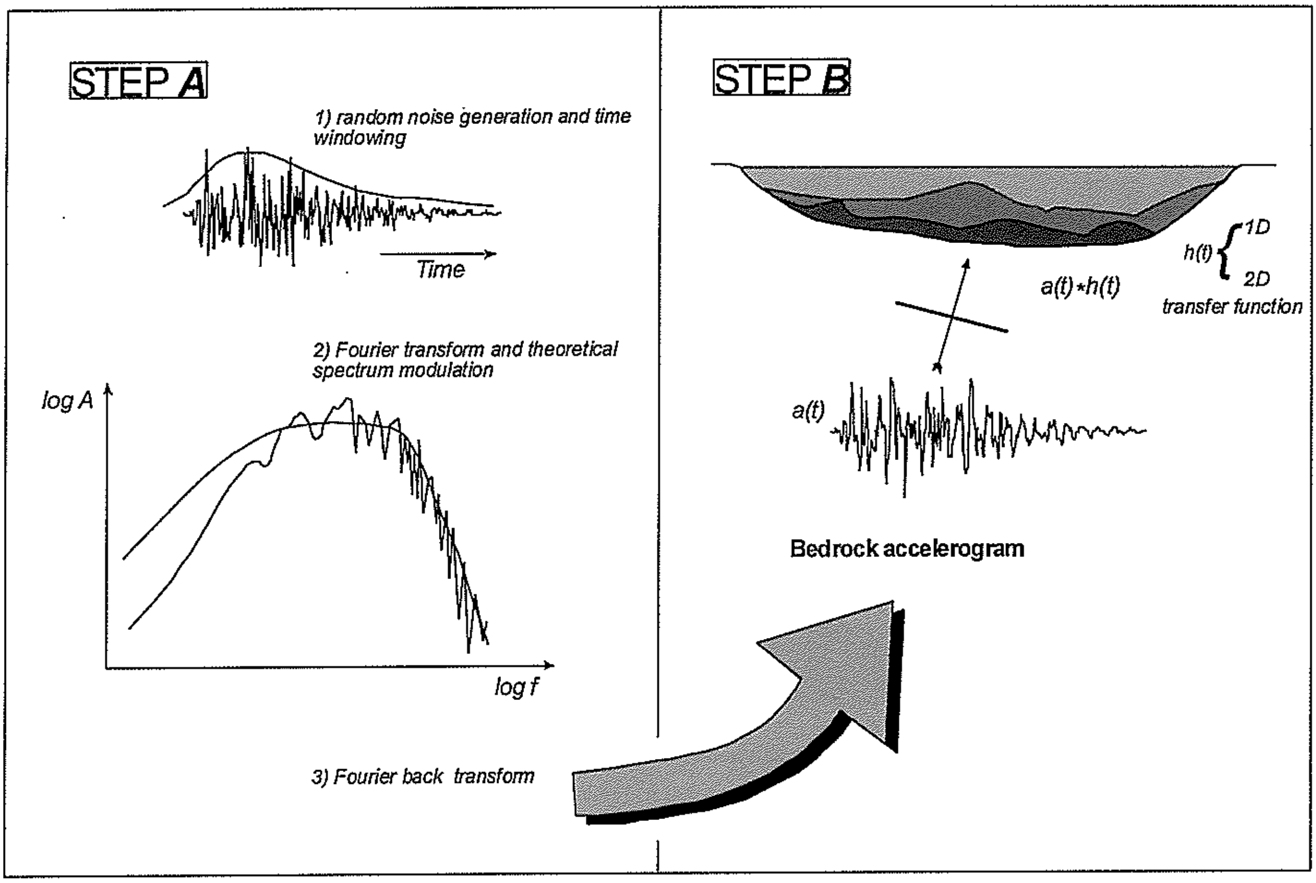


Figure 5. – Main features of the method used to compute synthetic time histories of ground motion at the surface as a function of the nearsurface structure (from ROVELLI *et alii*, 1995 a).

– Caratteristiche principali del metodo utilizzato per calcolare le storie temporali sintetiche del movimento del suolo alla superficie in funzione della struttura delle zone superficiali (da Rovelli et alii, 1995 a).

For sake of example, peak ground acceleration (*PGA*) and peak ground velocity (*PGV*) estimated for the maximum expected Apennine and Colli Albani earthquakes are shown in figure 6. The geological cross-section is relative to the Tiber river valley, which is the main geological element of the city: a large, quite regular NS structure incised down to the Pliocene bedrock and filled up by a 60 m thick layer of unconsolidated, water saturated sandy clays.

These Holocene sediments form a wide, flat alluvial plain including the most part of the historical centre. In the 2-D profile of figure 6, two hills border the edge of the Tiber river valley (namely Gianicolo and Quirinale, on the left- and right-hand side, respectively). Elastic and anelastic parameters used for the different geological units are listed in Table 1.

The most evident feature emerging from figure 6 is that, in the numerical simulations, ground accelerations are similar for earthquakes belonging to the two different seismogenic areas, while ground velocities modelled for Apennine earthquakes are significantly larger than those resulting for Colli Albani earthquakes. This can justify one degree difference in terms of MCS intensity which has been observed in Rome for the strongest past earthquakes occurring in the two areas.

Moreover, figure 6 shows that, in terms of ground acceleration, the largest values are found at the edges of the Tiber river valley. Also topographic irregularities (see Gianicolo Hill) are characterized by large amplifications of ground motion, probably enhanced by the presence of a soft-sediment shallow layer covering the top of the hill.

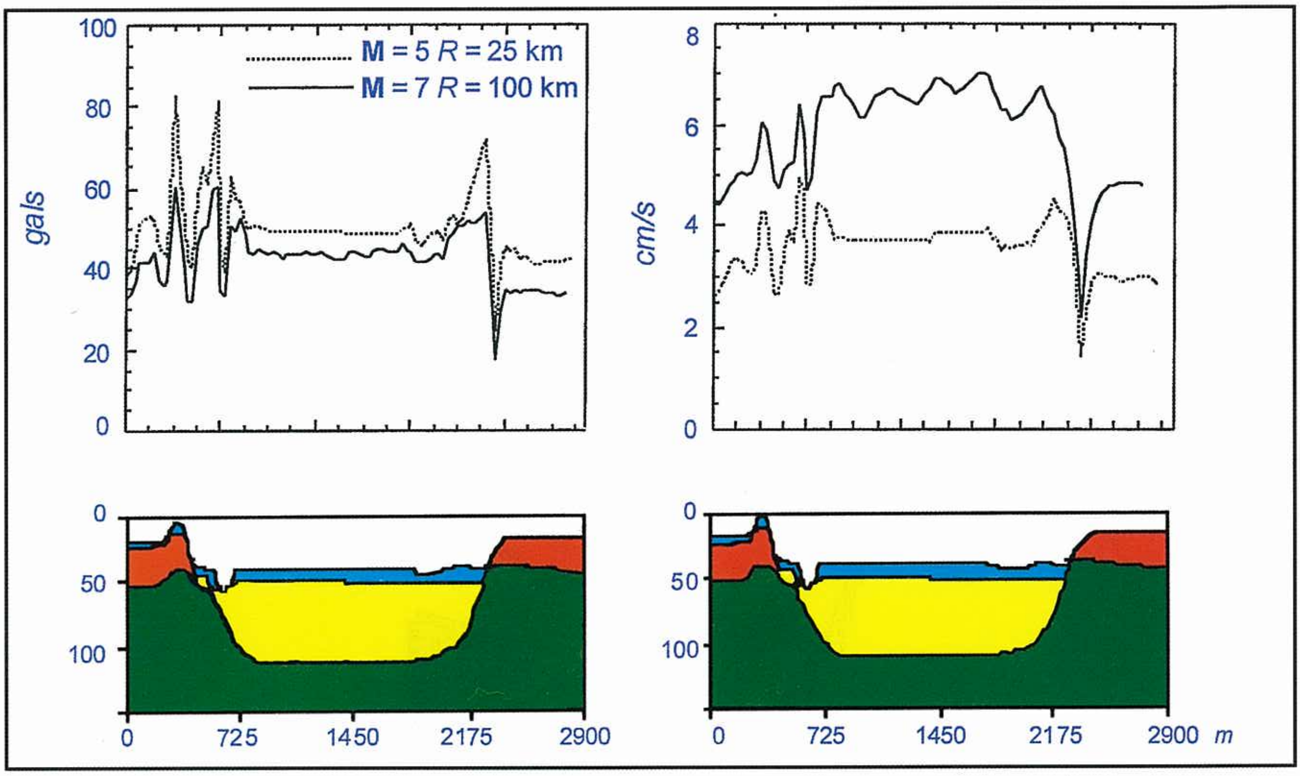


Figure 6. – Behaviour of (a) *PGA* and (b) *PGV* computed as a function of topography and nearsurface geology along the Tiber Valley.
– *Comportamento di (a) PGA e (b) PGV calcolati in funzione della topografia e della geologia delle zone superficiali lungo la Valle del Tevere.*

In conclusion, the results derived from numerical modelling stress the role played by the heterogeneities of nearsurface geology on the seismic excitation level. In our numerical simulations, the largest amplifications of ground motion are found for those geological situations where in reality the damage distribution shows the maximum concentration of heavy effects.

The knowledge of the urban areas geology jointly with the numerical modelling of ground motion appears a very powerful tool to mitigate seismic risk and define priorities in the safeguard of cultural heritage in earthquake prone areas.

TAB. 1 – Elastic and anelastic parameters used for the near-surface propagation modelling.
– *Parametri elastici ed anelastici utilizzati per il modello di propagazione nelle zone superficiali.*

Geological unit	Density (g/cm^3)	Shear-velocity (m/s)	Quality factor
Fill deposits	1.95	150	5
Holocenic Alluvium	1.95	300	10
Volcanic deposits and Pleistocene sediments	2.0	400	20
Pleistocene clays	2.1	600	50

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