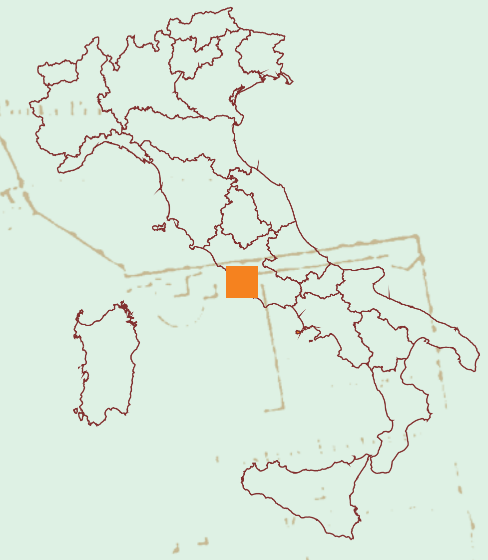

Geological surveying in a metropolitan area: The southern suburbs of Rome

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ABSTRACT

The southern suburbs of Roma were built up for the most part during the second half of the last century. This contribution illustrates the case study of the *Ostiense* area, located across the Tiber River valley, where the city's expansion has mostly not taken into account the geological and hydrogeological characteristics of the land. For this reason, many buildings and infrastructures of the area have been damaged by differential subsidence and flooding. This work proposes a hazard zonation based on the geotechnical, hydrogeological, hydraulic and seismic characteristics of the area, for the purposes of urban development planning and management.

AIMS

The main aim of the geological study of urban areas is to define the methodology through which geological information can be utilised in the urban planning process. The *Ostiense* area is a real case study where field geology, underground exploration, geotechnics, hydrogeology, hydrology and seismology have been integrated in order to model geological risks and define the hazard zonation of the area on the basis of its geological characteristics.
Data acquisition and processing were organised as follows:
a) definition of the geological framework (geological map);
b) analysis of urban development during the 20th century (comparison of topographic maps and aerial photos)
c) determination of the geometry of rock bodies and associated geotechnical properties (geological and geotechnical cross-sections, bore-holes, *in situ* measurements and correlations);
d) reconstruction of the ground water circulation (isophreatic levels of phreatic and confined, shallow, perched and deep aquifers);
e) reconstruction of the present and past hydrological regime (maximum expected rain and flood events);
f) reconstruction of fluvial dynamics (river channel evolution through time);
g) generation of synthetic ground shaking for seismic response analysis;
h) natural hazard zonation of the area.

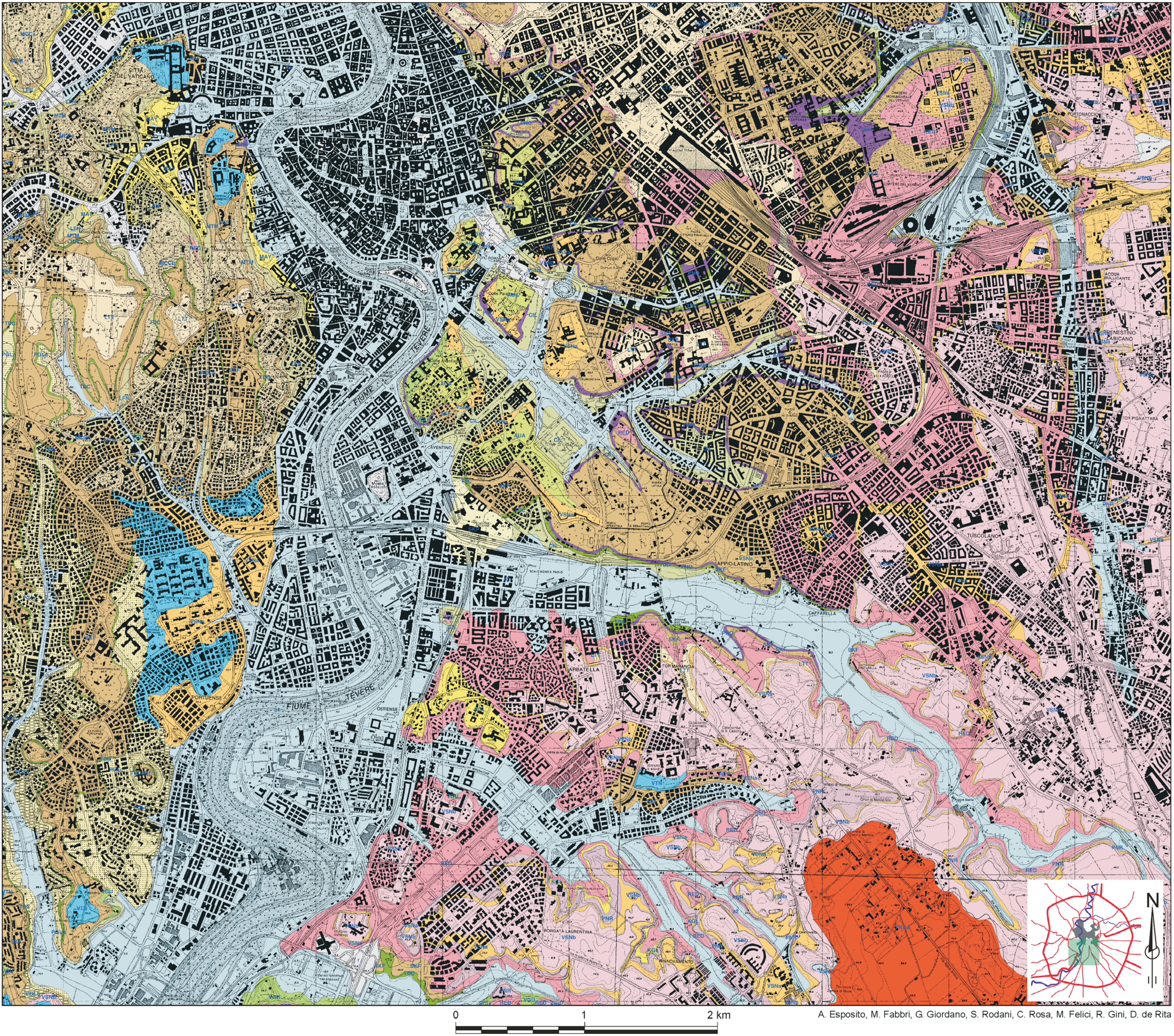
KEY WORDS

Urban geology, natural hazard, hydrogeology

RIASSUNTO

Il settore meridionale della città di Roma ha subito un'intensa urbanizzazione nel corso della seconda metà del secolo scorso. Il presente lavoro illustra il caso del quartiere Ostiense, a cavallo della valle del Tevere, dove l'espansione urbanistica non ha tenuto conto delle caratteristiche geologiche ed idrogeologiche dei terreni. Per tale ragione, edifici ed infrastrutture hanno subito nel tempo danneggiamenti legati a cedimenti differenziali ed episodi di allagamento. Viene proposta una zonazione sintetica di pericolosità basata Sullo studio delle caratteristiche geotecniche, idrogeologiche, idrauliche e di risposta sismica dell'area, per offrire un prodotto utile alla gestione e pianificazione del territorio.

GEOLOGICAL MAP OF THE SOUTHERN SUBURB OF ROMA



A. Esposito, M. Fabbri, G. Giordano, S. Rodani, C. Rosa, M. Felici, R. Gini, D. de Rita

Fig. 1 - *Geology of Roma has been mapped at the 1:10,000 scale for the realisation of the new 1:50,000 scale Geological Map of Italy (joint-venture Dipartimento di Scienze Geologiche Università Roma Tre-Servizio Geologico Nazionale). Densely urbanised areas have been surveyed integrating the classical geological field work with the collection and analysis of thousands of borehole stratigraphies, stored in a dedicated data-base. The map refers to the geology either outcropping or buried below the "anthropogenic fill cover", that is not represented. The uppermost stratigraphic unit, is constituted by the Tevere River Holocene alluvial deposits, which infill the valley eroded, during the Last Glacial Age low stand of the sea level, within the Middle-Upper Pleistocene volcanic succession and the underlying Pliocene-Lower Pleistocene sedimentary units.*

AGE	LITHOSTRATIGRAPHIC UNITS
HOLOCENE	**r - Anthropic backfill.** Heterogeneous, unconsolidated deposits disposed to backfill dismissed quarries or to build road basements.
HOLOCENE	**a1 - Alluvial sediments.** Alluvial sediments of the Tevere river talweg and flood plain inside artificial embankments. Inter-stratified sand, silt, clay and layers rich in organic material. Thickness ranges from 0 to 10m.
HOLOCENE	**a2 - Fluvial deposits.** Silt-sand and silt-clay sediments of the Tevere river alluvial plain. Maximum thickness 50 m.
UPPER PLEISTOC.	**SKP - Saccopastore unit.** Conglomerate and sand rich of volcanic debris interbedded with silt and clay with brackish gastropod fossils. Fluvial to palustrine environment. Maximum thickness 20 m.
MIDDLE PLEISTOCENE	**VTN - Vitinia unit.** Conglomerate, sand and clayey-silt, rich in volcaniclastic debris, calcareous and siliceous pebbles with abundant remnants of vertebrates and travertine concretions. Fluvial environment. Maximum thickness 20 m.
MIDDLE PLEISTOCENE	**FKBa - Frascati-Capo di Bove succession.** Grey, fine-grained, K-foiditic lava with leucite and clinopyroxene phenochrists.
MIDDLE PLEISTOCENE	**AUA - Aurelia unit.** Silts, sand and conglomerate, with sea water gastropods and travertine concretions. Fluvial to lacustrine environment. Maximum thickness 20 m.
MIDDLE PLEISTOCENE	**VSNc, VSNb, VSNa - Villa Senni unit.** Compound ignimbrite unit, tephri-phonolitic in composition, constituted by:
MIDDLE PLEISTOCENE	**VSNc** massive to stratified, matrix rich, volcaniclastic sand and conglomerate, derived from reworking of VSNa and VSNb. Thinkness up to 8 m.
MIDDLE PLEISTOCENE	**VSNb** massive and chaotic, coarse grained and fines depleted, purple, lapilli and ash deposit, rich in bomb-sized black scorias, holocristalline and lava xenoliths and crystal fragments (leucite, biotite and clinopyroxene); the deposit is generally incoherent. Thickness up to 15 m. Villa Senni Auct.
MIDDLE PLEISTOCENE	**VSNa** massive and chaotic, yellow to red, ash and lapilli deposit rich in yellow pumices, grey scorias, holocrystalline and lava xenoliths; the unit is lithified by zeolitization; gas pipes and wood remnants are locally present. Thickness averages at 10 m. Tufo Lionato Auct.
MIDDLE PLEISTOCENE	**PNR - Pozzolane nere unit.** Ignimbrite unit, tephri-phonolitic in composition, made of a massive and chaotic, scoria and ash, with coarse tail grading of bomb- to lapilli size lava, holocristalline and sedimentary xenoliths, locally with gas-pipes. Crystals are leucite and clinopyroxene. Thickness ranges between 5 and 10 m.
MIDDLE PLEISTOCENE	**LTT - La Storta succession.** Stratified to massive pumice and scoria lapilli beds of fallout environment interbedded with cross-stratified volcaniclastic sand and conglomerate and paleosoils. Thickness up to 10 m.
MIDDLE PLEISTOCENE	**KGL - Conglomerato giallo unit.** Massive to poorly stratified, sandy-pebble lahar deposits, generally poorly sorted, made of mostly rounded, red to yellow scoria and lava clasts. Maximun thickness 30 m.
MIDDLE PLEISTOCENE	**RED - Pozzolane rosse unit.** Ignimbrite unit, tephritic in composition, made of a massive and chaotic, scoria and ash, with aboundant lava, thermometamorphosed sedimentary and olocrystalline xenoliths and leucite, clinopyroxene and biotite crystal fragments.Gas pipes are locally present. Maximum thickness 15 m.
MIDDLE PLEISTOCENE	**SKF - Sacrofano succession.** Inter-stratified, paleosoil bounded, reworked volcaniclastic and pumice and scoria lapilli deposits of fallout environment. Thinly bedded silt deposits of lacustrine are locally interbedded within the succession. Maximum thickness 10 m.
MIDDLE PLEISTOCENE	**PNO - Palatino unit.** Ignimbrite unit made of massive to stratified, dark grey ash and lapilli deposits, with lava and sedimentary xenoliths, and crystal fragments of altered leucite. Yellow, accretionary lapilli-rich ash layers are present at the top. The ignimbrite is underlined by a scoria lapilli fallout deposit. Maximum thickness of the unit 10-15 m. Tufi pisolitici Auct. p.p.
MIDDLE PLEISTOCENE	**VGU - Valle Giulia unit.** Stratified to concretional travertine containing lenses of calcareous and volcaniclastic sand and conglomerate of fluvial environment. Maximum thickness 12 m.
MIDDLE PLEISTOCENE	**TDC - Tor de Cenci unit.** Compound ignimbrite unit made of massive to stratified, grey-yellow ash and lapilli deposits, with abundant accretionary lapilli, lava and sedimentary xenoliths, and crystal fragments of altered leucite. The ignimbrite is underlined by a scoria fallout deposit. Maximum thickness of the unit 10-15 m. Tufi pisolitici Auct. p.p.
MIDDLE PLEISTOCENE	**CIL - Santa Cecilia unit.** Sand and conglomerate, massive to cross bedded, rich in volcaniclastic debris. Fluvial environment. Maximum thickness, 5 m.
MIDDLE PLEISTOCENE	**PGLa, PGLb, PGLc - Ponte Galeria unit.** Fluvial-deltaic succession, up to 40 m thick, constituted by different facies:
MIDDLE PLEISTOCENE	**PGLc** massive to faintly yellow to pinkish siliceous sand. Dune to fluvial environment.
MIDDLE PLEISTOCENE	**PGLb** interbedded grey clay, silty-clays and silt containing Helicella, Ostrea,and Venerupis in the lower horizon (Argille ad Helicella Auct.) and *Cerastoderma edule*, Ostrea, and *Venerupis senescens* in the upper horizons (Argille a Venerupis Auct.). Lagoonal to littoral enviroment.
MIDDLE PLEISTOCENE	**PGLa** low angle cross stratified calcareous and siliceous pebbles in sandy matrix. Fluvial to pro-deltaic environment.
LOWER PLEISTOCENE	**MCCb, MCCa Monte Ciocci unit.** Fining upward succession of transitional environment, up to 20 m thick, constituted by different facies:
LOWER PLEISTOCENE	**MCCb** grey clay and silt with *Venerupis senescens*. Lagoonal environment.
LOWER PLEISTOCENE	**MCCa** cross stratified calcareous and siliceous platy pebbles and cross stratified oxidised yellow to reddish sand. Beach to dune environment.
LOWER PLEISTOCENE	**MTM - Monte Mario unit.** Grey fossiliferous and micaceous sand with *Arctica islandica* ovarlain by yellow, low angle stratified siliceous sand interbedded with areanaceous anf fossiliferous beds with Ostrea and thin silt and clay layers. Infralittoral environment to transitional at the top. Maximum thickness 60 m.
LOWER PLEISTOCENE	**LFN - Farneto unit.** Grey clay and silt, interbedded with yellow to grey sand beds. Infralittoral environment. Maximum thickness 20 m.
PLIOCENE	**MAY - Monte Vaticano unit.** Grey consolidated clay and silt, interbedded with cross laminated grey micaceous sand. Circalittoral environment. Maximum thickness in outcrop 40 m.

INTRODUCTION

During the last century, the city of Roma has undergone a large expansion. Most of the peripheral areas, previously dedicated to farming and agriculture, have been densely urbanised. The Ostiense suburb, located just south of the historical city centre, is an excellent example of this territorial transformation. The area was planned as the Roman industrial site at the beginning of the 20th century, then dismissed and reconverted to residential. In the last ten years, the Ostiense suburb has become the site of the new Roma Tre University. The Department of Geological Sciences *(Dipartimento di Scienze Geologiche)*, has undertaken the task of characterising the geology and hydrogeology of the site, and the related hazards, as part of the planning and management of the urban development of the area (CAPELLI *et alii*, 2000: MERLONI *et alii*, 2002).

The residential districts built during the second half of the last century were developed disregarding the morphological, geological and hydrogeological characteristics of the area. The Tevere River tributary fluvial network has been forced into pipes and obliterated by backfill and buildings. In many cases, the poor geotechnical properties of the underlying alluvial terrains have caused differential subsidence and damages to buildings, such as in the cases of Via Giustiniano Imperatore, which runs along the old Grotta Perfetta gully, and of the Vasca Navale.

Damage to buildings has also been induced by amplification of seismic waves and even traffic vibrations due to the contrast of acoustic impedance between the Holocene fluvial deposits and the Pliocene-Pleistocene bedrock.

Furthermore, the continuity of the natural Tevere River alluvial plain has been dismembered by the construction of the artificial embankments and disposal of backfill. Some urbanised areas are built along this formerly active flood plain area, at the same elevation of the mean hydrometric level of the river, whereas nearby areas are superelevated. Properties are therefore exposed to main flooding events as well as to water retention during strong rain events.

The geological characterisation of development areas and the evaluation of the environmental impact of human activities are paramount in urban planning and management for the sustainable development of the city (GIORDANO *et alii*, 2000) and the prevention of geological hazards.

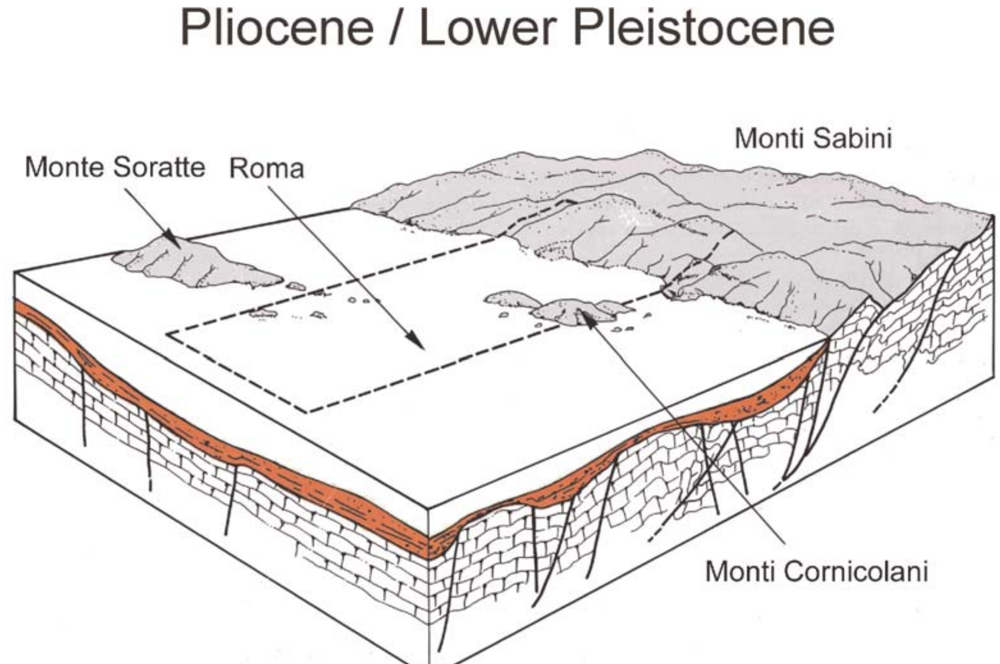
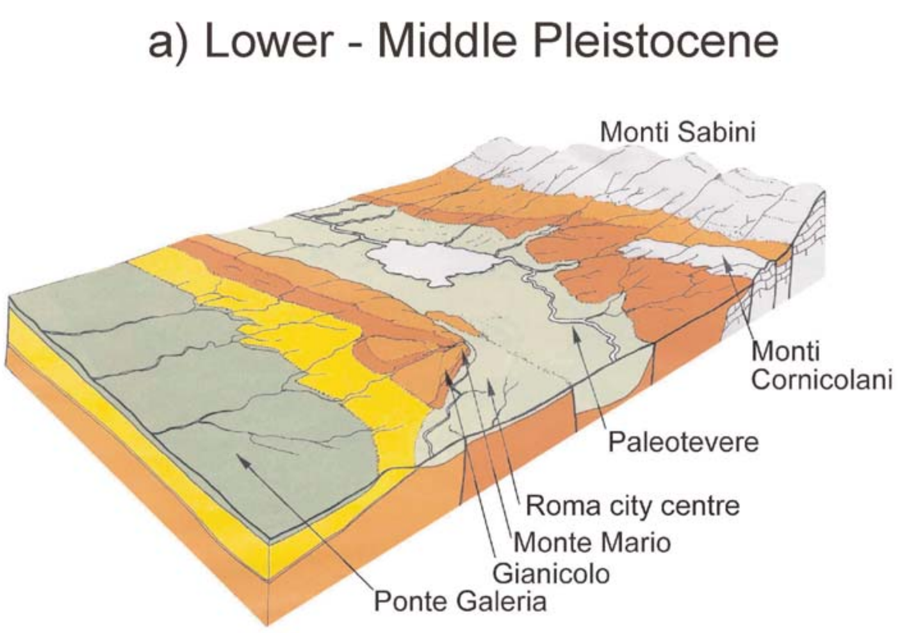


Fig. 2 - *The area corresponding with Roma (dashed line) was submerged by the Tyrrhenian sea from which isolated blocks emerged to form islands (FUNICIELLO, 1995).*

GEOLOGICAL SETTING

The Ostiense area extends across the Tevere River Valley (Fig. 1), which was cut during the Last Glacial Age and presently filled in by up to 60 m of Holocene alluvial deposits mainly consisting of unconsolidated and water-saturated clay and sand (FUNICIELLO *et alii*, 1995). The bedrock consists of a marine to continental Pliocene-Pleistocene succession, characterised at the base by Pliocene circalittoral clay, unconformably overlain by Lower Pleistocene infralittoral marine clay and sand. The area emerged during Lower-Middle Pleistocene and was the site of the palaeo-Tevere River delta. During Middle-Upper Pleistocene, the volcanic activity of the Colli Albani to the south and of the Sabatini volcanoes to the north, emplaced large volumes of volcanic rocks which shifted the course of the Tevere to its present position and created the vast ignimbrite plateau that forms most of the outcropping rocks in the area. The most recent activity of the Colli Albani volcanoes is interfingered with the alluvial fill of the Tevere Valley and its left tributaries.

Three main aquifers are located within the Holocene alluvial units on the Pliocene-Lower Pleistocene clay aquiclude. The base of Holocene alluvial sediments consists of a gravel bed that hosts a pressurized and highly productive aquifer. More superficially, multiple aquifers are present within the permeable sediments. These shallow aquifers may be in hydraulic continuitywith the River Tevere.



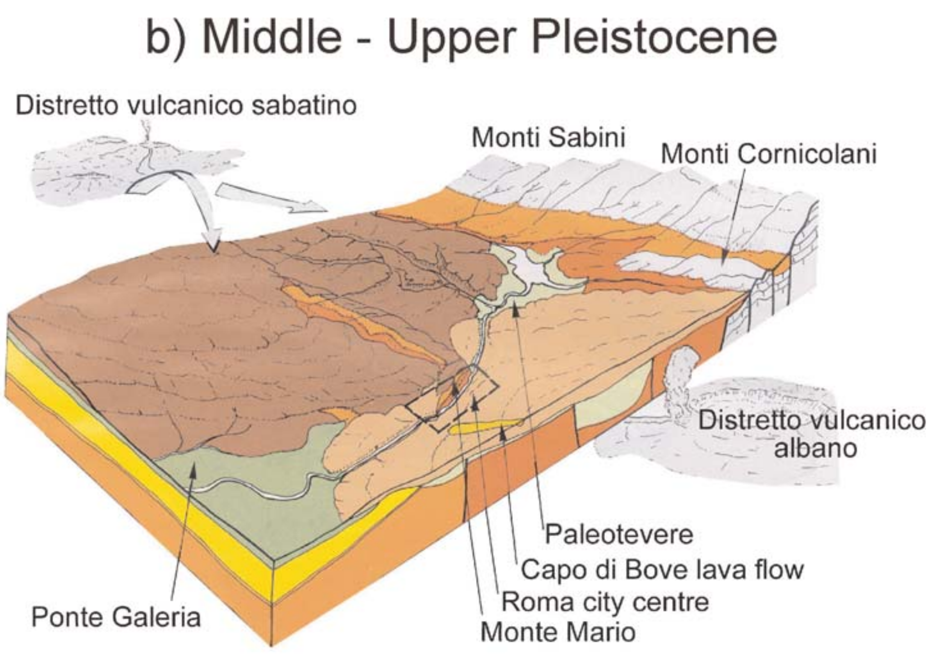
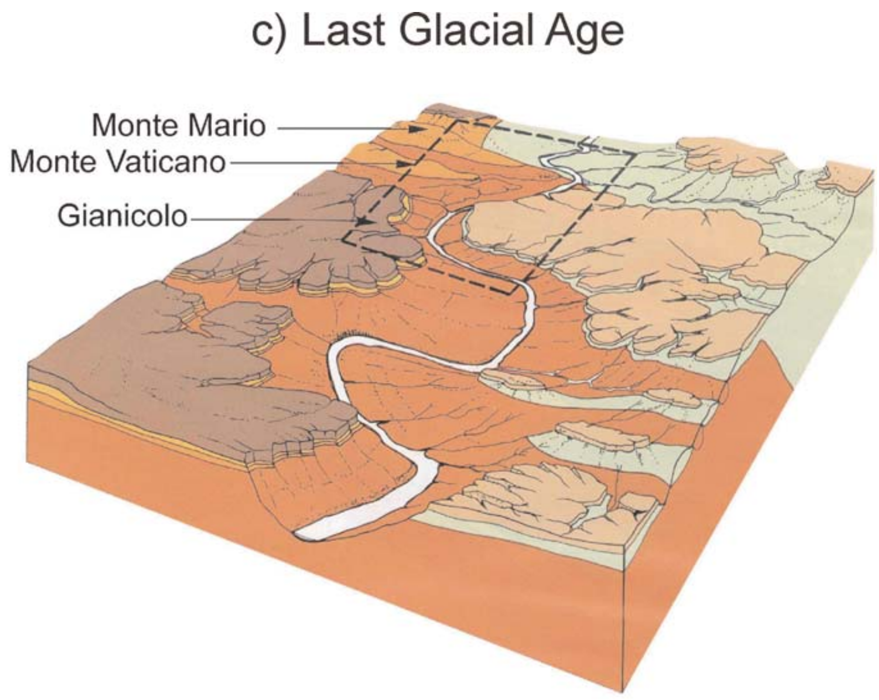


Fig. 3 - *(a) The marine domains extinguished and the delta of the palaeo-Tevere River shifted south-westward. The uplift of the Monte Mario-Gianicolo rise shifted the course of the Tevere southward. (b) The edification of the Colli Albani and Sabatini volcanoes forced the course of the Tevere back northward to its present position (FUNICIELLO, 1995).*

The anthropogenic cover, which locally can be up to 10 m thick, may contain a noticeable aquifer alimented by rainfall and seepage from drain and sewage network losses. The complex 3D geometry of the rock units, as well as of the hydrogeological system, determine a strong lateral and vertical variability of the geotechnical characteristics of the foundational ground. However the urban expansion immediately after the second World War interested indifferently the competent bedrock formations as well as the unconsolidated Holocene alluvial deposits.



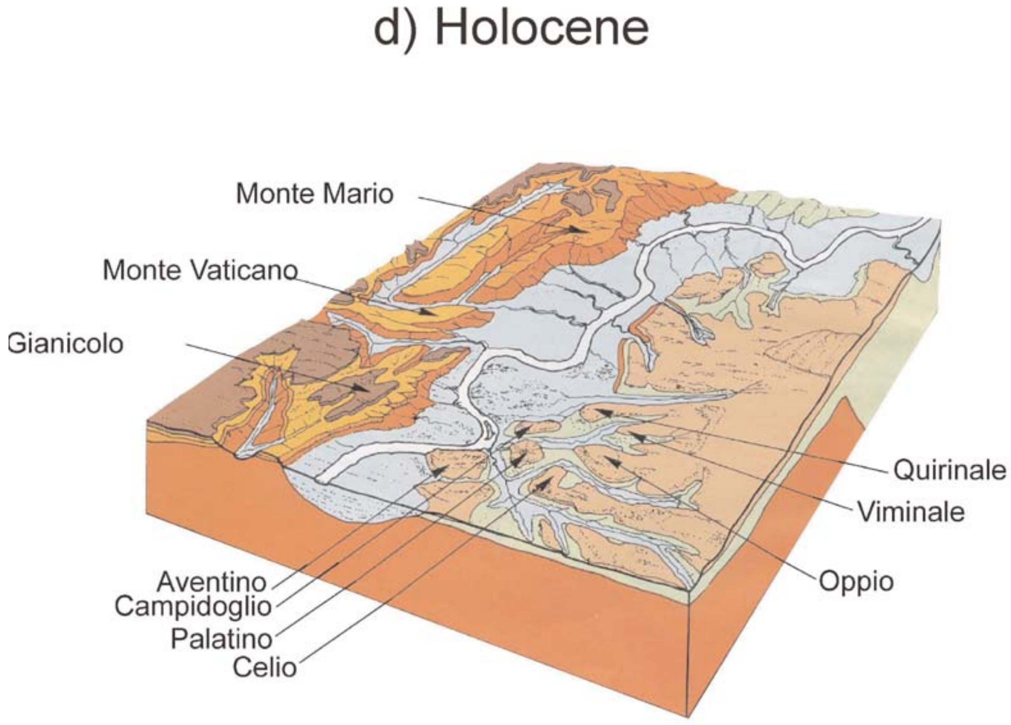
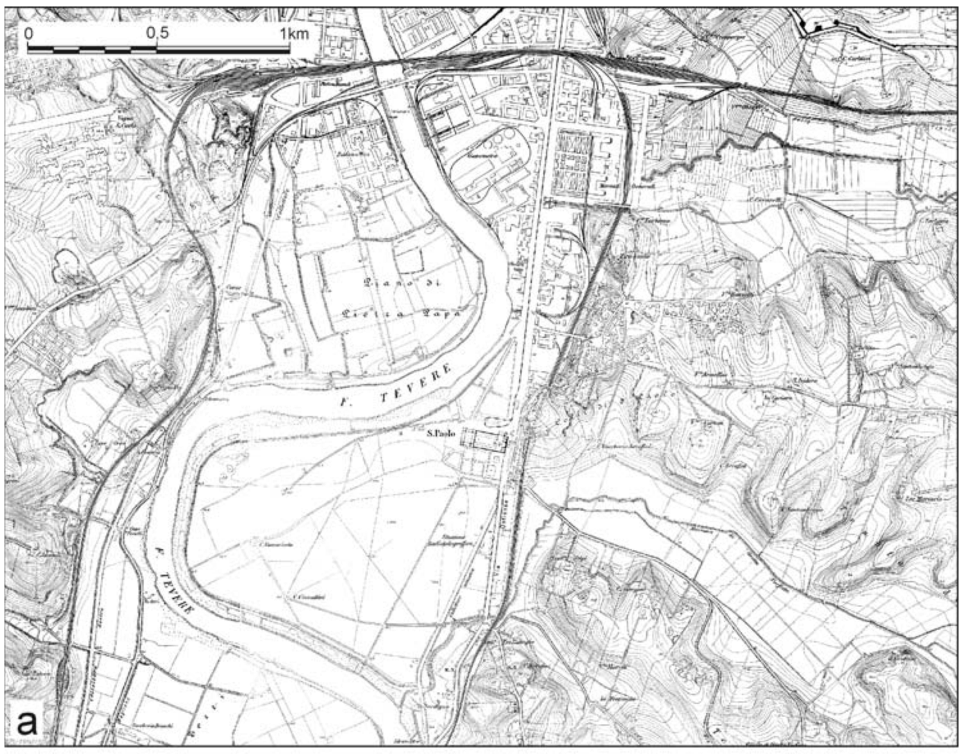
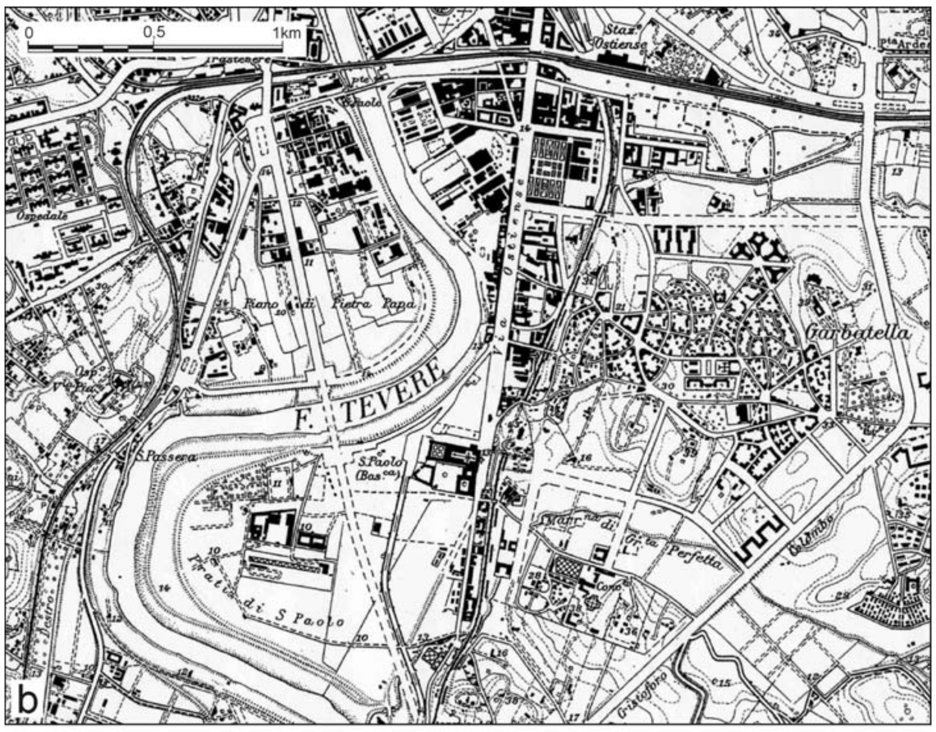


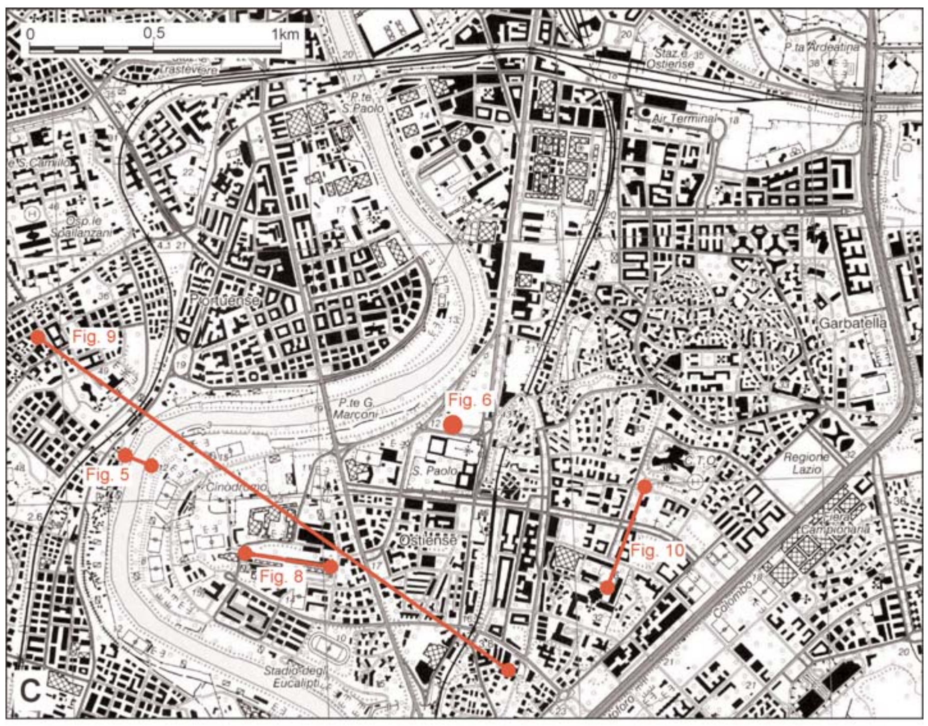
Fig. 3 - *(c) During the last glacial age, the Tevere River valley deeply eroded the volcanic and pre-volcanic rock succession; (d) The rise of the sea has induced the filling of the Tevere River valley with its alluvial deposits. The block-diagram magnifies the dashed square of Fig. 3c (*FUNICIELLO*, 1995).*



The early years of last century (1907 upgraded in 1924).

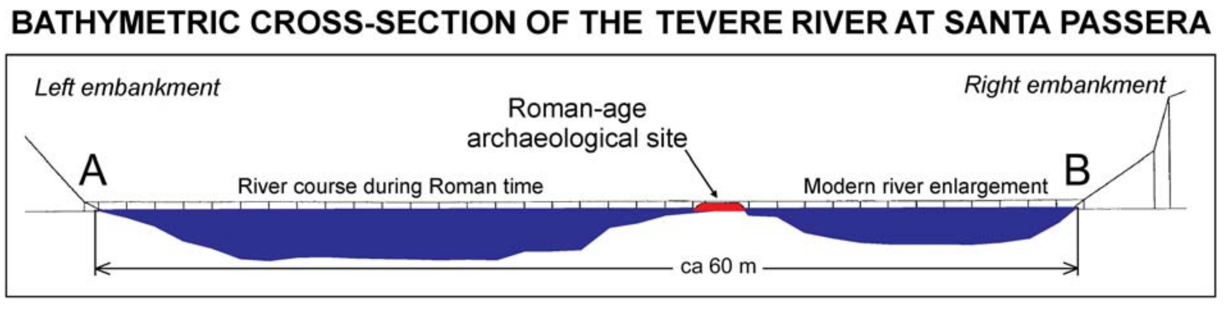


Mid-century (1949).



Present situation (2000) showing the intense urbanisation of the Ostiense area. Locations of next figures are shown in red.

Fig. 4a, b, c - *Comparison of IGM (Military Geographic Institute) topographic maps referred to the Ostiense area. Note that the physiographic features of the topography appear today almost completely buried. The drainage network has been diverted or covered, and backfill has smoothed the differences in elevations. The alluvial plain of the Tevere River has been completely constructed.*



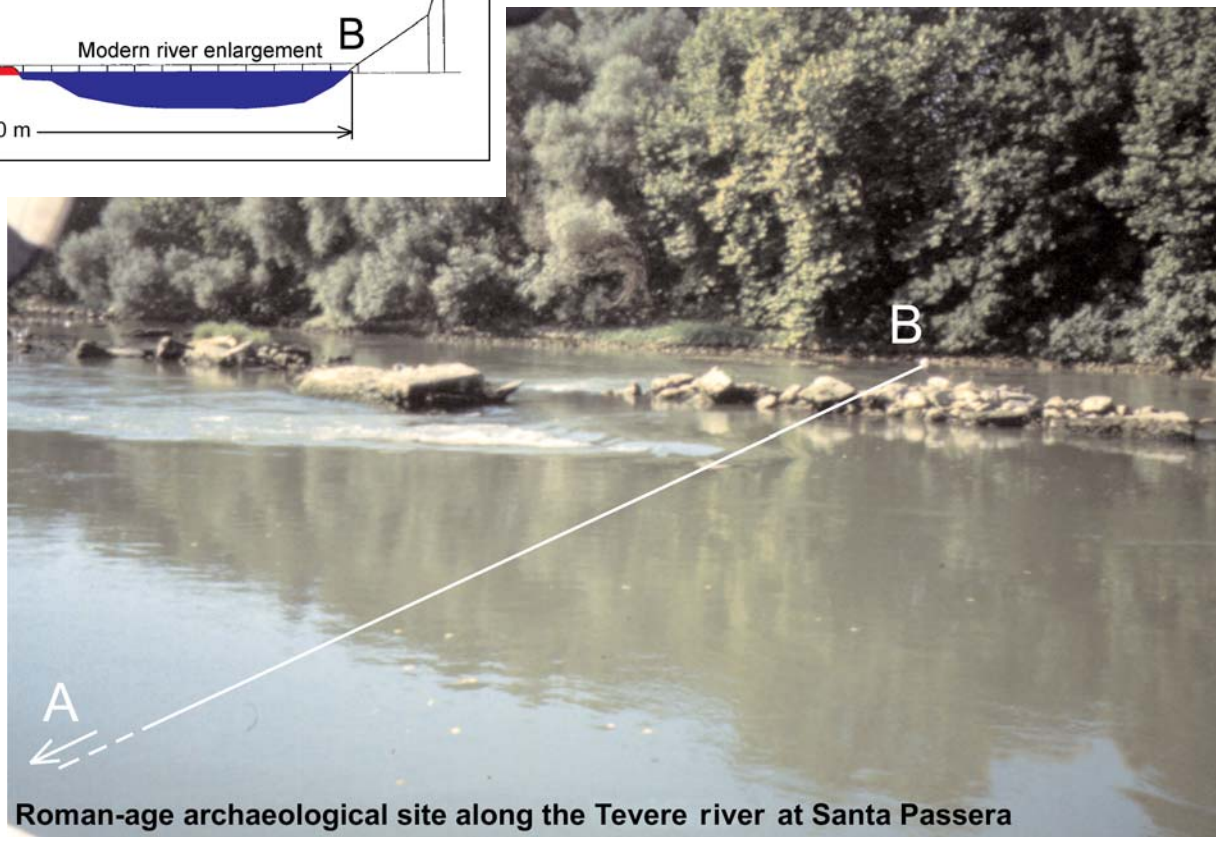


Fig. 5 - *The rapid evolution of the Tevere fluvial dynamics is testified by the position of the archaeological sites of a Sanctuary of Imperial Roman Age at Santa Passera, presently at the centre of the river thalweg, which indicates that the river course has shifted in time.*

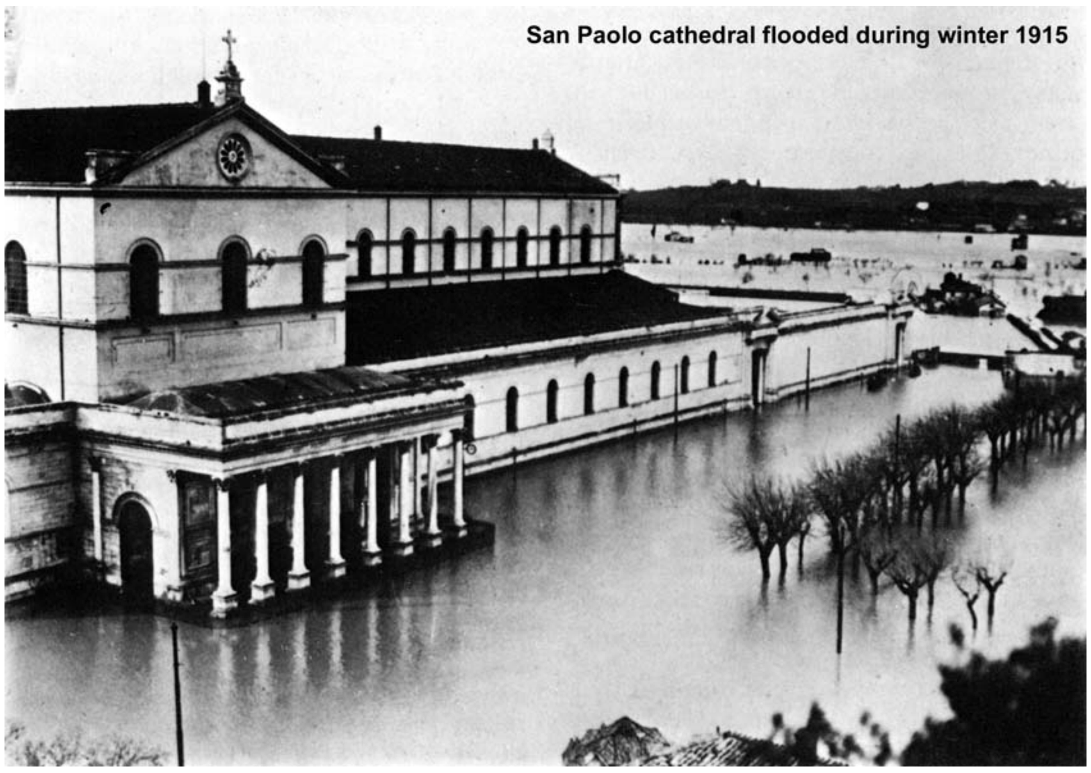


Fig. 6 - *The Tevere hydrological regime is characterised by the recurrence of severe floods, at a rate of two per century, capable of invading several parts of the city. The photo shows the effects of the 1915 flood in the S. Paolo Fuori le Mura Cathedral.*

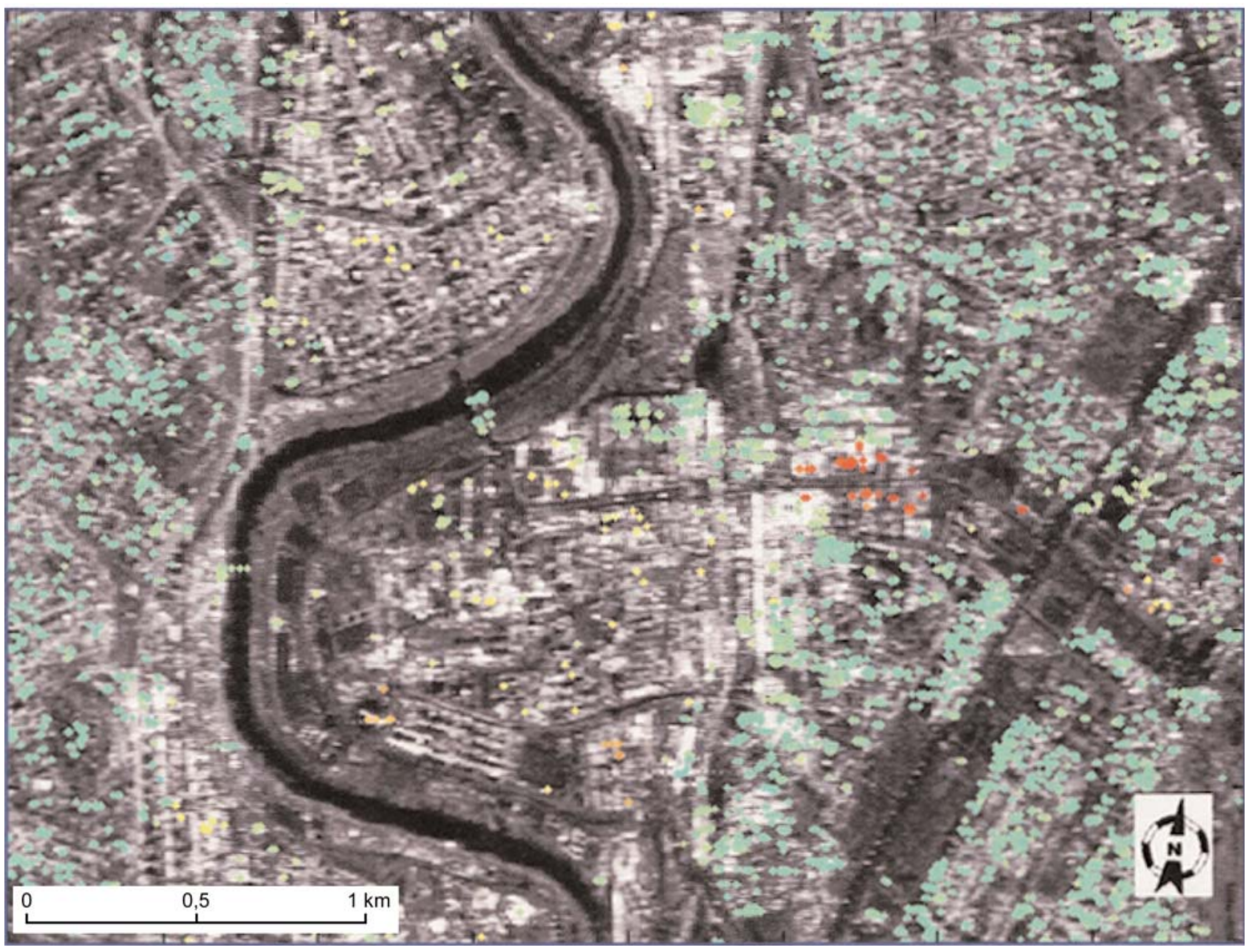


Fig. 7 - *At present, several edifices built over unconsolidated clays are monitored for selective subsidence. This image is a courtesy of F. Ferrucci and has been obtained by comparing 10 years of satellite images.*

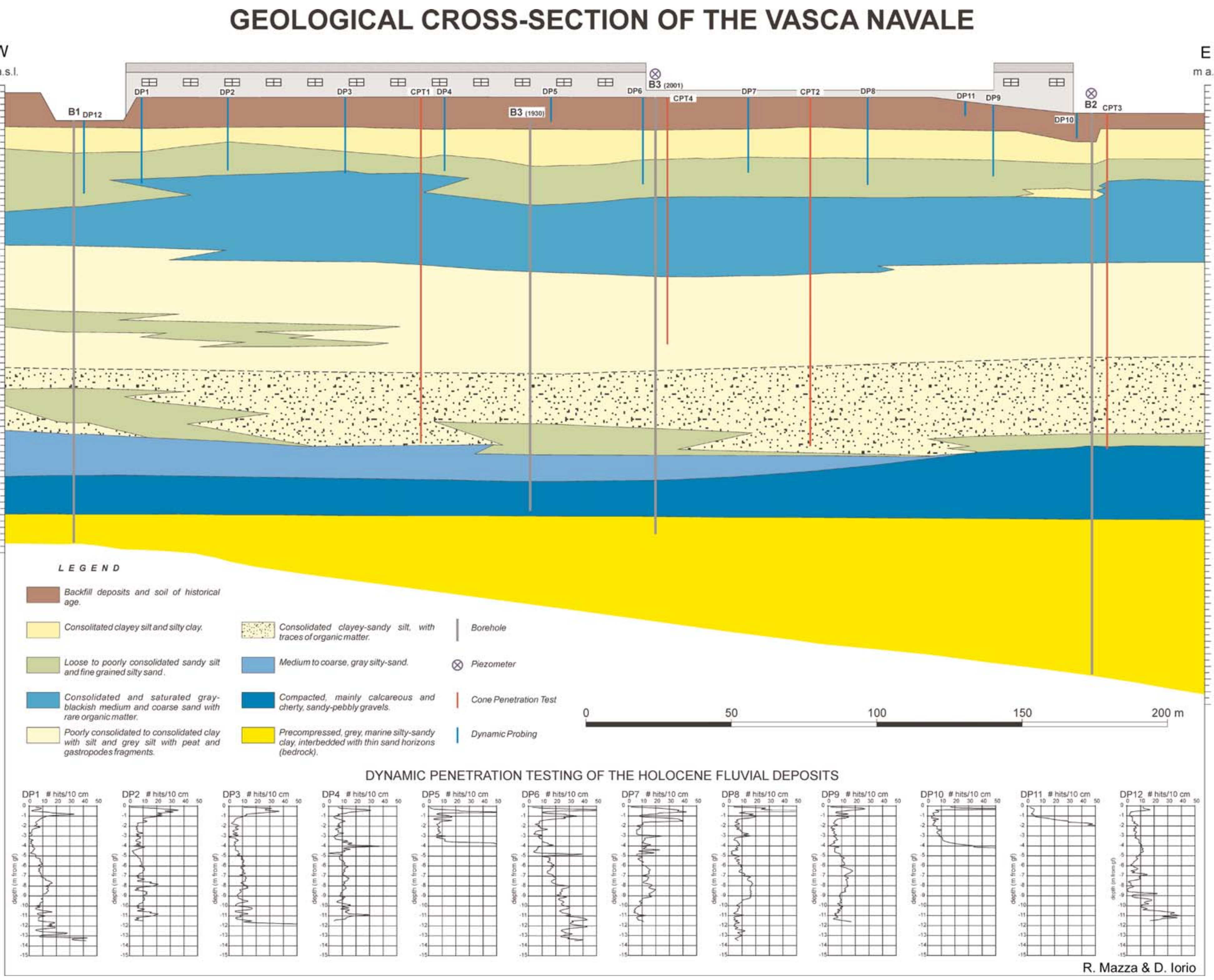
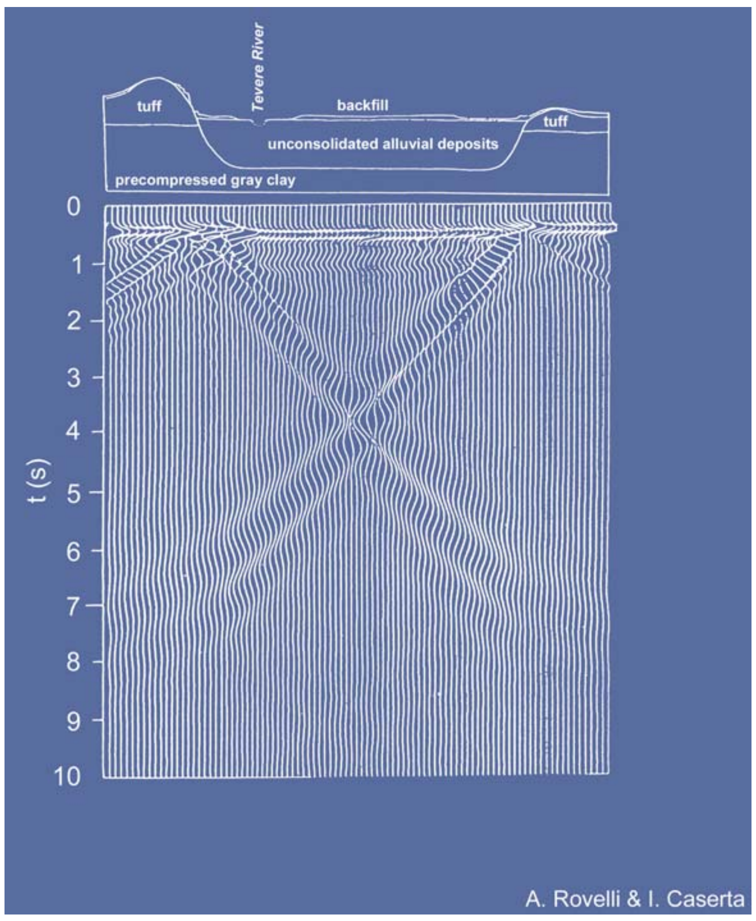
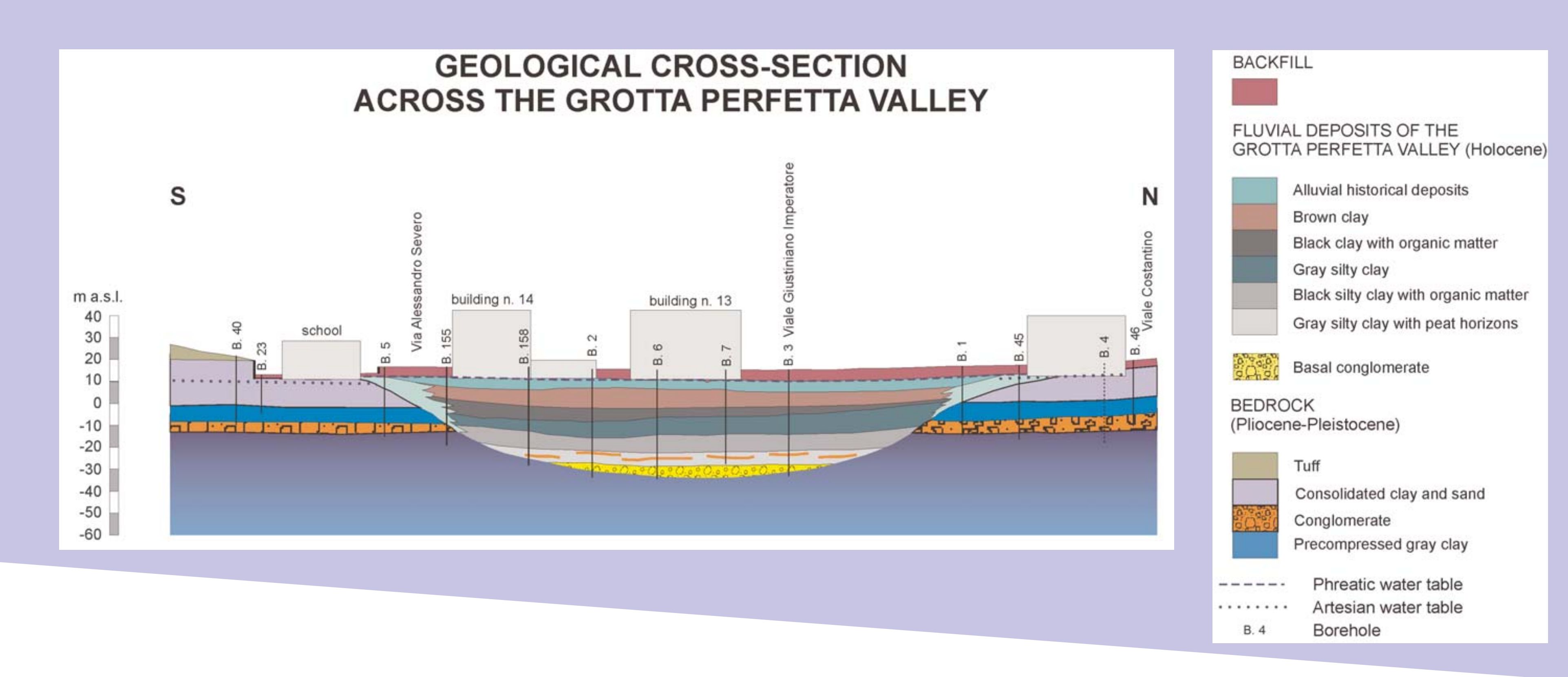


Fig. 8 - *The figure shows the stratigraphic cross-section across the meander of Valco San Paolo-Vasca Navale where the edifices of the Dipartimento di Scienze Geologiche are located. The Holocene alluvial cover is composed by several different lithological, geotechnical and hydrogeological units. Below the superficial layer of the historical alluvial deposits, there are black clays with organic matter interlayered with incoherent sand, at least 20 m thick. The basal part of the Holocene alluvial succession is composed by sands and gravels, which overlie the pre-compressed and impervious grey clays of Pliocene age.*



SYNTETIC ACCELEROGRAMS CALCULATED ACROSS THE TEVERE RIVER VALLEY

Fig. 9 - *A synthetic accelerogram set across the Tevere River valley in the Magliana-Ostiense sector was calculated taking in account the thickness of the main geological units, the geotechnical behaviour of the alluvial cover and simulating a vertical seismic pulse to the base of the alluvial blanket. This methodology shows the theoretical dynamic behaviour of the valley during a seismic shock coming from seismogenetic provinces surrounding Roma (Central Apennines and Colli Albani). The seismic shaking is clearly more intense and last longer within the Holocene alluvial valley (*CAPELLI* et alii, *2000).*



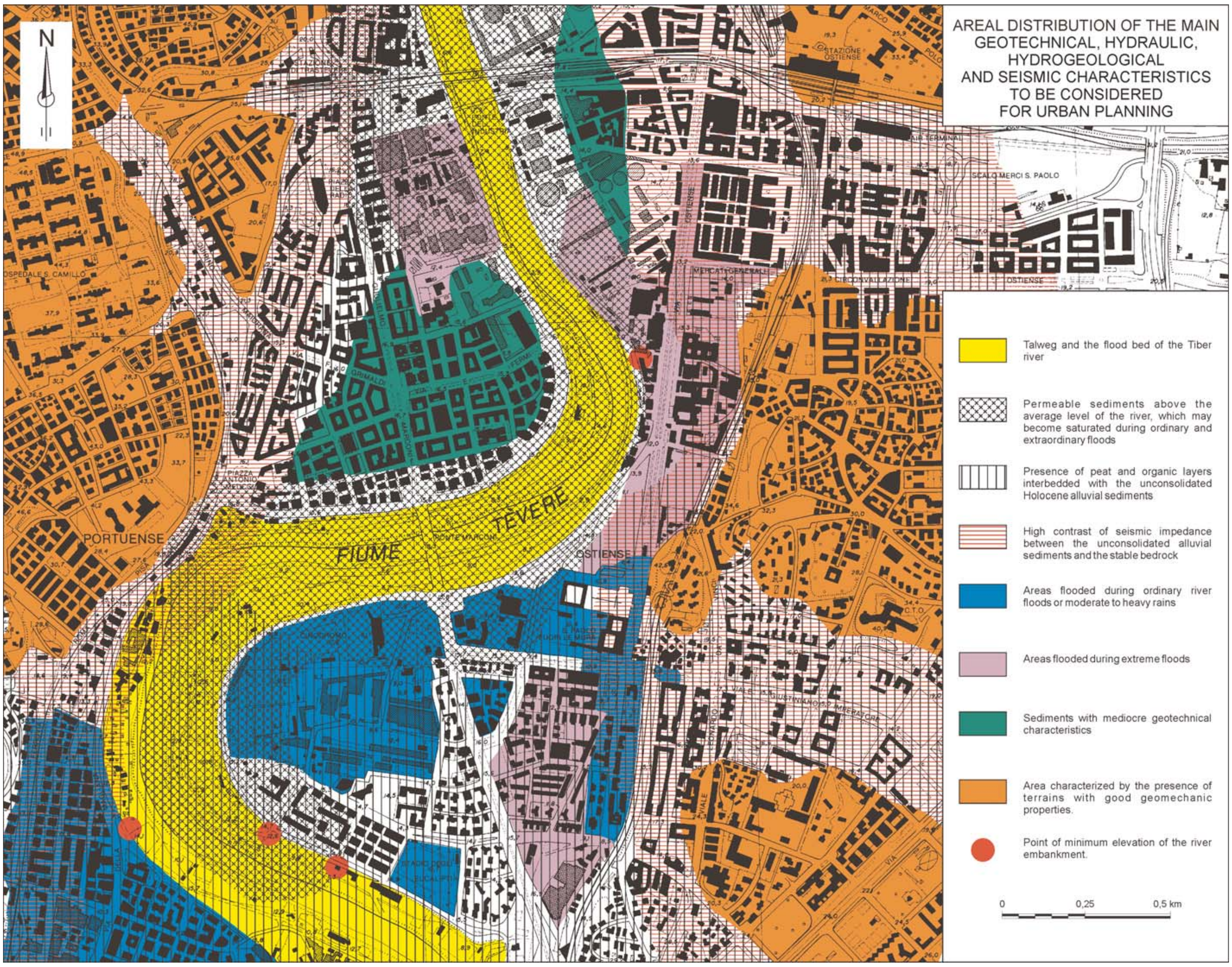


Fig. 11 - *Zonation of the Ostiense suburb in order to rationalise the urban planning and mitigate the impact of geological hazards. Different colours and patterns indicate different characteristics which may overlap, increasing the exposure of an area to geological hazards.*
The yellow area corresponds to the talweg and the flood bed of the Tevere River confined by the embankments.
The dramatic reduction of solid transport caused by the construction upstream of several dams since 1970, is causing a severe erosion of the fluvial channel which at places is 4 m below sea level. As the process of vertical excavation of the talweg is limited by hydraulic constrains, the present condition will change to lateral erosion of the embankments.
Black crosses indicate the presence of permeable sediments (sand) above the average level of the river, which may become saturated during ordinary and extraordinary floods. The variation of interstitial fluid pressure may worsen the geotechnical properties of these sediments and in worst cases lead to liquefaction.
The vertical black lines indicate the presence of peat and organic layers interbedded with the unconsolidated Holocene alluvial sediments which increase the hazard related to differential subsidence.
Red horizontal lines indicate areas where the high contrast of seismic impedance between the unconsolidated alluvial sediments and the stable bedrock may induce an amplification of seismic waves.
The pale blue colour indicates areas that may be flooded during ordinary river floods or moderate to heavy rains. Flooding may be just related to upwelling of water from the sewer and drain systems, which are at lower elevation respect to the level of the river during ordinary floods which are contained by the embankments.
The purple indicates areas flooded during extreme floods. The red dots indicate the lowest elevation of the embankments, where the river can break out. Note that the purple areas joins with the pale-blue areas.
The green indicates the presence of sediments with mediocre geotechnical characteristics and shallow aquifers.

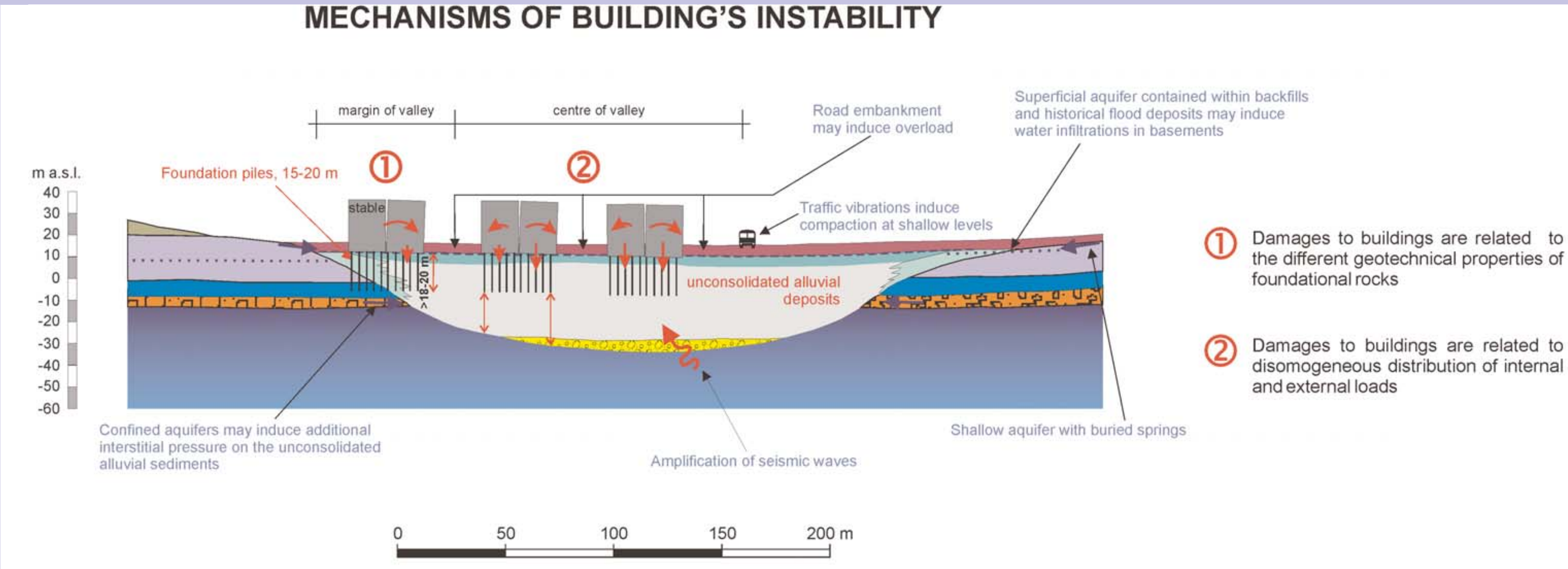


Fig. 10 - *Differential subsidence provoked severe damages and collapses to edifices with structure partially founded on bedrock and partially on alluvial deposits. Damages were also caused by differential loading due to the surrounding buildings.*

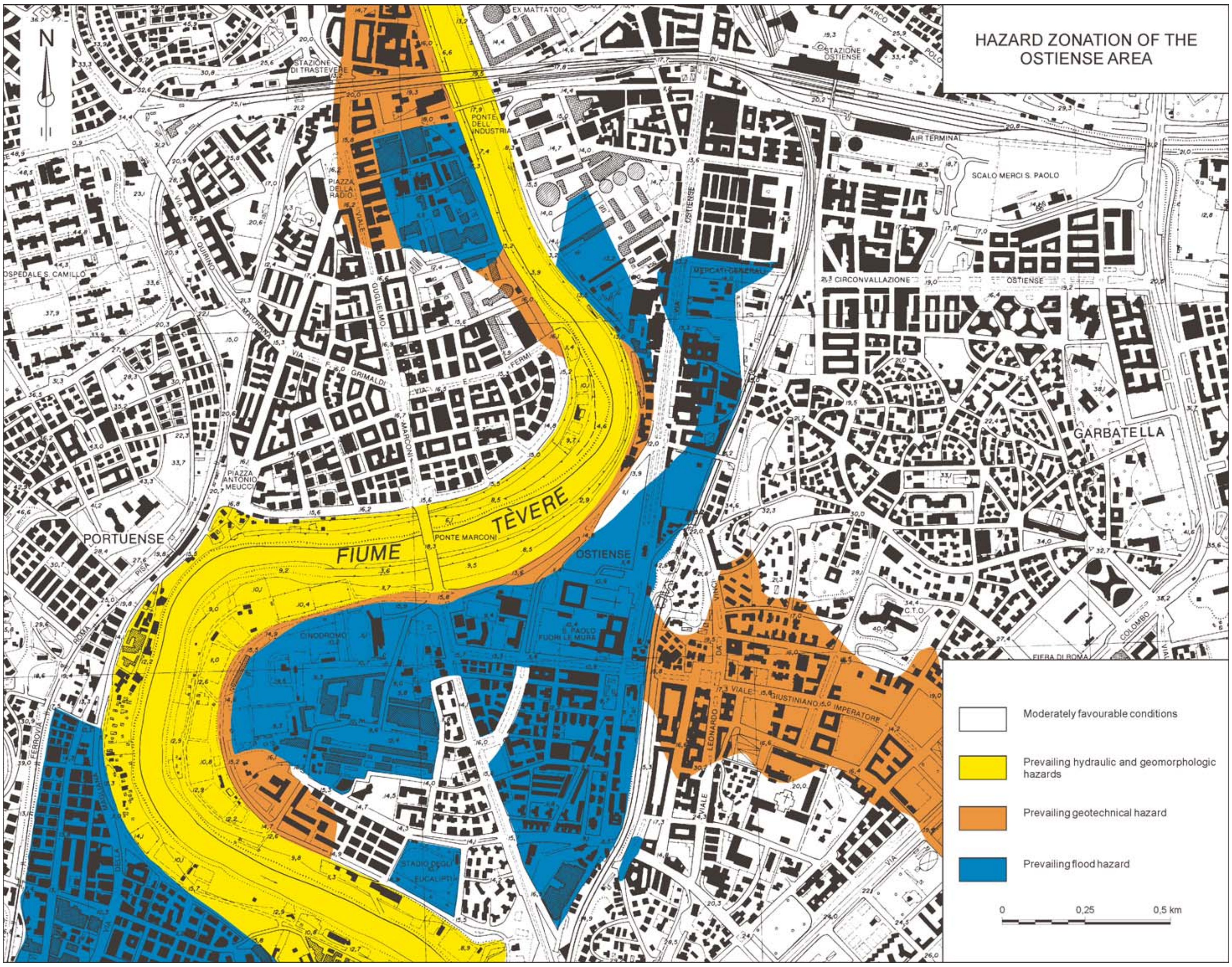


Fig. 12 - *The map has been realised in order to simplify the information contained in Fig. 11 for the legislator, emphasising the main hazard for each area.*
The white colour indicate moderately favourable conditions like the bedrock relieves, or areas with limited problems like areas of the alluvial plain not subject to flooding and with acceptable geotechnical properties.
The yellow indicates the river talweg and the flood bed within the embankments where the hydraulic and geomorphologic hazards are prevailing and no anthropic structures should be planned.
The orange indicates areas where the geotechnical hazard is prevailing, because the characteristics of the sediments are poor and may further decay in case of floods, earthquakes and overload.
The pale-blue indicates areas where the flood hazard is prevailing.

CONCLUSIONS

In summary, the main geological and hydrological problems to be taken into account for the urban planning of the Ostiense area are the poor geotechnical characteristics of the alluvial sediments, exposure to floods, overexcavation of the river thalweg and contrast of seismic impedance between different rock bodies.
As mentioned, the urban development of the Ostiense area has mostly disregarded the geological constraints related to the distribution of the geotechnical, hydraulic, hydrogeological and seismic characteristics.

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