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MAN-INDUCED CHANGES IN URBAN GEOMORPHOLOGY: THE HISTORIC CENTRE OF BOLOGNA (ITALY)

ABSTRACT: GIORGI G., *Man-induced changes in urban geomorphology: the historic centre of Bologna (Italy).* (IT ISSN 0391-9838, 2002).

The city of Bologna has been continuously inhabited for about three thousand years, though there have been phases of retreat and subsequent reoccupation. The urbanisation works over the years modified the territory on which the inhabited centre rose up. In particular, a continual accumulation of rubble determined the raising of the original level that Bologna was built on.

Reconstruction of the city's present day morphology was made possible through the gathering of spot elevations from large-scale maps and the subsequent creation of a digital elevation model. From this reconstruction, it was possible to obtain a first morphological representation which highlights the presence of an extensive alluvial fan and a raised area of chiefly artificial origin. Using *in situ* archaeological finds, dating from the Iron Age to the Roman period, it was possible to reconstruct the old ground level in a part of the present historic centre of the city. Comparison between the old and actual ground levels permitted identification of the areas in which anthropic intervention most significantly altered the morphology. In particular it seemed clear how in the parts where settlement was continuous for almost three thousand years, the surface was raised on average more than two and a half metres, with peaks reaching more than four metres. Where urbanisation works underwent prolonged interruptions, the ancient surface is usually at a depth of less than two metres and locally is very close to the actual ground level.

KEY WORDS: Geomorphology, Archaeology, Urban land, Holocene, Bologna (Italy).

RIASSUNTO: GIORGI G., *Mutamenti di origine antropica nella geomorfologia delle aree urbane: il centro storico di Bologna (Italia).* (IT ISSN 0391-9838, 2002).

La città di Bologna è stata abitata in modo continuo per circa tremila anni, sia pure con fasi di arretramento e successive rioccupazioni. Le opere di urbanizzazione succedutesi nel tempo hanno modificato il territorio su cui è sorto il centro abitato. In particolare il continuo accumularsi dei detriti ha determinato l'innalzamento dell'originale piano su cui Bologna è sorta.

La ricostruzione della morfologia della città è stata possibile grazie alla raccolta di punti quotati, desunti da carte a grande scala, che hanno consentito di realizzare il modello digitale altimetrico. Da questa base di partenza è stato possibile quindi ricavare una prima rappresentazione morfologica, che evidenzia la presenza di un esteso conoide e di altre sopraelevate di origine prevalentemente antropica. Utilizzando i reperti archeologici sicuramente in posto, cronologicamente compresi tra l'età del ferro e l'età romana, è stato possibile ricostruire l'antico piano di calpestio in una parte dell'attuale centro storico della città. Il confronto tra il piano attuale e quello antico ha permesso di individuare le aree nelle quali l'intervento antropico ha più fortemente modificato il territorio. In particolare è parso evidente che laddove l'insediamento si è protratto in modo continuo per quasi tremila anni, la superficie si è innalzata mediamente più di due metri e mezzo, con punte che superano i quattro metri, mentre laddove la continuità insediativa ha subito prolungate interruzioni, la superficie antica si rinviene mediamente a profondità inferiori a due metri, fino a lambire, in alcuni casi, l'attuale piano stradale.

TERMINI CHIAVE: Geomorfologia, Archeologia, Aree urbane, Olocene, Bologna.

INTRODUCTION

Geomorphologic study is very important to locate areas suitable for buildings (Coates, 1976; Cooke, 1976). Another important aspect of this discipline permits, through recognition of the morphological aspects of a territory, an understanding not only of the reasons that led populations to choose specific areas for their settlements but also of the modifications introduced artificially by man.

The choice of a suitable site for settlement does not only depend on the intrinsic features of the area but also on the position it will come to have in relation to the surrounding territory: preference goes to places near roads, near river outlets into the plains, in the vicinity of river mouths, or by a ford.

Abandonment of settlements or the movement of populations may be connected with changes in the site's geomorphologic conditions or those of the surrounding areas. In places where settlements have persisted for a long time it may happen that the original form of the territory is partly or wholly altered by human intervention. Recognition of the ancient buried surfaces also permits estimation of the

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quantity of material accumulated over the years as an effect of anthropogenic processes. The aim of this work is to identify the morphological changes induced by continuous inhabitation of the historic centre of Bologna (Italy).

THE TERRITORY SURROUNDING THE CITY OF BOLOGNA

Bologna is an important centre of Northern Italy. It is the main town of the Emilia-Romagna Region and has a population of about 380,000 (fig. 1). The historic centre is the part of the city built within the mediaeval city walls, raised between the 13^{th} and 14^{th} centuries and largely lost today. The city stands near the Apennine foothills, on the southern boundary of the Po Valley, between the river Reno and the Savena torrent.

Immediately to the south of the historic centre there is raised ground with fairly steep slopes due to the activity of a tectonic structure which, in the course of the last few million years, has brought about a raising at a rate estimated at around 60-70 centimetres per thousand years (Bongiorni, 1962; Farabegoli & Onorevoli, 1996; Parea, 1989).

The terrain on which Bologna stands is of alluvial origin, deposited over the last 10,000 years (Giorgi, 1998). The rivers which contributed to the creation of this part of plain are the Reno and the Savena, whereas other shorter streams from the heights behind the city were responsible for the construction of the small alluvial fans on which Bologna was built. The plain north of Bologna looks monotonous and flat, but it if is observed by means of a contour map having an interval less than one metre, one realises that this is not so, and that there are elongated ridges and depressions. Ridges are morphological forms characterised by elongated raising of the terrain, whose height is generally not greater than five or six metres with regard to the surrounding plain. They are hard to distinguish with the naked eye because their sides slope at a gradient rarely greater than 0.3 %; these forms are linked to river deposits in alluvial environments. The beds of the rivers flowing through the Emilia plain are usually at a higher level than the flood plain itself. This phenomenon is due to a low gradient, a slow water velocity and subsequent bed load deposition. The consequence is a raising of the beds. When rivers overflow their banks, or flood, their course may alter, so there remains a relic elevation bearing witness to an early river course. From that moment the construction of a new ridge begins.

The ridges in the northern area of Bologna are attributed to the courses of the rivers Reno, Panaro, Samoggia, Savena and Idice.

Along the boundary separating the Apennine from the Emilia-Romagna plain, there is a series of small alluvial fans created by sediments deposited by minor rivers. An Holocene age is suggested for these alluvial fans, since their base is dated at little more than 10,000 years B.P. (Fontana, 1976; Cremaschi, 1979; Alessio & *alii*, 1980). Most of them have very slight slopes and are therefore classified as flat alluvial fans (Blissenbach, 1954). Their thickness generally does not exceed ten metres or so (Parea, 1989), and the particle size is generally fine and only rarely are there coarse intercalations.

The major Apennine rivers do not bring great quantities of gravel downstream as they did in earlier periods when the accumulation of great quantities of gravel in the subsoil, along the Apennine margin, was linked to an increase in the speed of the current, as a consequence of cold glacial phases and the consequent lowering of the base level (Parea, 1988).

The alluvial fan on which Bologna stands has been inactive at least since the Neolithic period: though it is difficult to carry out specific archaeological surveys in an urban environment, no objects or settlements prior to that date have ever been found on the surface.

Analysis of the contour levels permits understanding of the probable reasons why this site was chosen for a settlement (fig. 2). In fact it may be seen that in correspondence to the historic centre the contour levels appear closer together. This indicates that the slope of the terrain is greater than that in the surrounding areas, which obviously facilitates drainage. It is also in a higher position than the areas situated at the sides, thus offering greater safety in the case of flooding.

Observing the terrain morphology in the immediate foothill area, starting from the west, one notes a small allu-

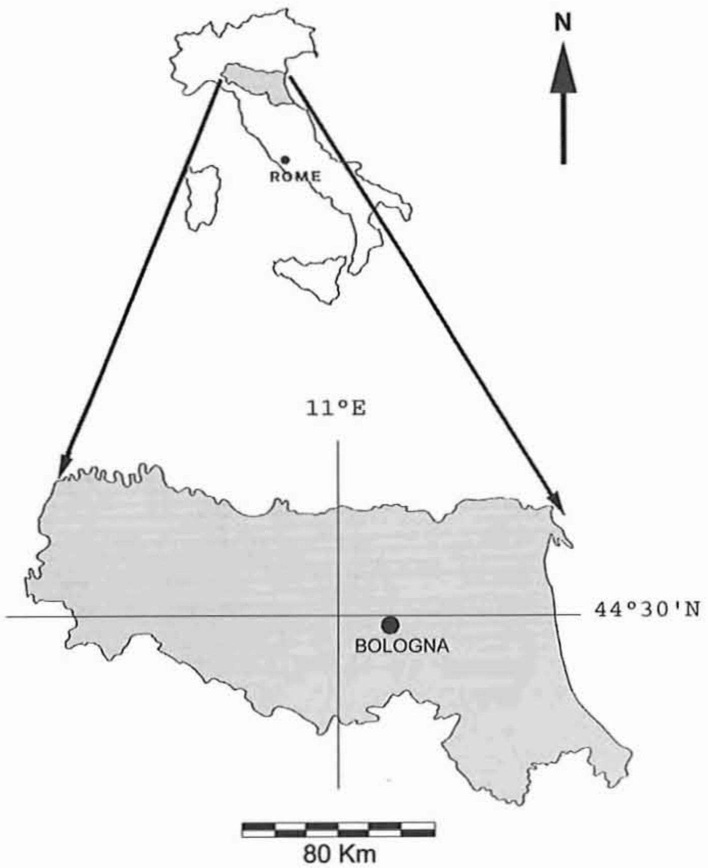

FIG. 1 - Location of Bologna.

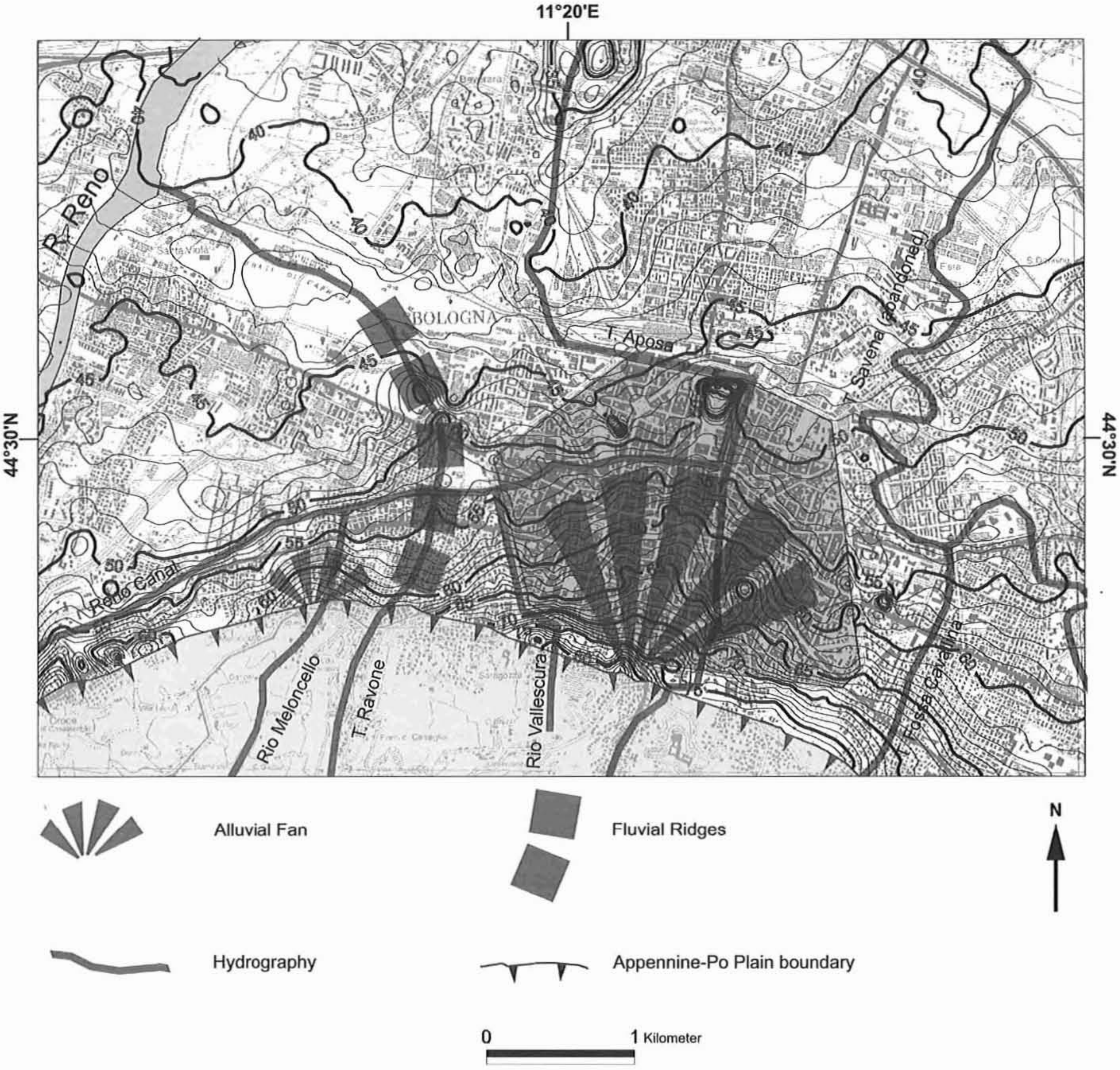

FIG. 2 - Geographical and geomorphological settings of the Bologna surrounding area.

vial fan located at the point where the Meloncello stream enters the plain. Slightly eastwards is the torrent Ravone, a tributary of the Reno, which shows no evidence of the presence of an alluvial fan. It appears instead a small, slightly arched ridge, created by the continuous and progressive raising of the course above its own alluvial sediments. In this way, the Ravone created a suspended bed, typical of alluvial areas with very slight slopes. Bearing witness to how dangerous it could be on occasions of heavy rainfall. On the basis of the morphology of the territory, the hypothesis put forward by many researchers that the torrent reached the historic centre of Bologna is to be excluded. Still farther east is the Vallescura stream, which has not determined any evident morphological structures. In all probability it flowed through the westernmost part of the historic centre, but due to its small drainage basin it certainly presented no danger to the populations who had settled nearby. Proceeding eastwards, there is the Aposa torrent. Unlike the Ravone, this river shows a very pronounced alluvial fan. The northernmost part follows an artificial course whereas in ancient times it perhaps flowed into the Savena. The Fossa Cavallina stream, which flows in the eastern edge of Bologna, is a small-size watercourse which until the 18th century ran into the Savena. The last mentioned river ran through the city until 1776, the year in which it was diverted into the Idice. Another important element of local hydrography is the Reno Canal. It was built prior to 1185, bringing the water of the river Reno into the city where it was divided into numerous branches.

The hydrographical evolution of the area around Bologna during the Holocene has been deduced from the interpretation of the sedimentary bodies found in the first 20 metres of depth (Artioli & *alii*, 1999). The Savena ran in the vicinity of the eastern boundary of the present historic centre and flowed into the Reno, which was farther east than it is today, north of the northern boundary of the present city walls. The Aposa, whose position was farther west than today, ran into the Savena with some difficulties that led to the creation of marshlands. The Ravone does not appear clearly in this period: it is probably confused with the sediments of the Reno into which it flowed shortly after entering the plain. With the passage of time, the Reno began to move increasingly towards the west and the confluence with the Savena migrated farther north. In this way the Ravone and the Aposa, no longer restrained within a confined space, extended their length. In a later period, probably on the beginning of the first human settlements in the area, there was a progressive separation of the Reno and the Savena, with the abandoning of the easternmost bed of the Reno and the creation of the course still existing today. In this phase the Aposa took up its present position, though there were still traces of activity in the old riverbed. The Ravone took a more developed course in comparison with its earlier one, both spreading into the depressions between the Reno and the Savena and flowing directly into the Reno.

HISTORICAL NOTES ON HUMAN SETTLEMENT IN THE BOLOGNA AREA

It has been ascertained that the first sporadic settlements date to the Neolithic period, around 4000 BC, but the first population concentrations date to the late Bronze Age, between the 13th and 12th centuries BC (Mansuelli, 1958). Some were in the foothills, especially in the vicinity of the rivers, with a prevalent distribution within the altimetric belt between 70 and 120 metres above sea level. This led to thinking of the existence of an ancient foothill route in an east-west direction, following the Apennine margin, where the terrain was more stable, the marshlands more distant and the crossing of the watercourse easier. In particular, it seems that there were three main settlements.

In the Iron Age, from the 9th century BC, two important settlements were established, situated east and north-east of the present historic centre. They grew up along the ancient course of the Savena torrent (Pincelli & Morigi Govi, 1975; Morigi Govi & *alii*, 1980). Another settlement, belonging to the same period, was found near Villa Cassarini (Kruta Poppi, 1976) in the first raised areas south of Bologna. These inhabited zones show that they were already in a phase of abandonment in the 8th century BC. From this moment on there began a new phase of population concentration in the area between the Aposa and Ravone torrents. The peoples that lived in these places in the Iron Age are still called Villanovan, after the place they first founded, Villanova di Castenaso near Bologna. So when reference is made in the text to Villanovan populations or settlements, we are dealing with the Iron Age. This new inhabited centre probably stood on an area of about 200 hectares and was characterised by a type of settlement that was not yet concentrated as in the subsequent Etruscan phase and, to a greater extent, in the Roman. Henceforth the development of the city, though there were phases of expansion and contraction, was always to have this area as a reference basis.

The reasons leading to the population concentration on this site, to the detriment of the former sites, are still not clear. Certain hypotheses cite the hydraulic instability of the Savena (Giorgi, 2000), or the approach to the traffic ways that favoured the Reno valley (Tovoli, 1972). In this phase, and especially between the 6th and 4th centuries BC, there was a continual development in which a village transformed itself into a town, taking the name of Felsina, due to the increasingly frequent cultural and trade exchanges with Etruria (Pallottino, 1984).

Towards the 4th century BC Celtic tribes invaded much of the Po Valley. The Boii Gauls settled in Felsina. As they were mainly dedicated to agriculture and livestock breeding, there was a recession and progressive abandonment of Etruscan urbanisation.

We thus arrive at the moment when the Romans, having defeated the Boii Gauls, founded a new colony, Bononia, in 189 BC on the remains of Felsina. The city was to develop particularly in the imperial age, probably reaching a population of 10,000 on an area of about 46 hectares (Mansuelli, 1958).

Between the 4th and 5th centuries AD, following the decline of the Roman empire and the continual barbarian invasions, the built-up area was once more reduced in size, only the easternmost part by the Aposa torrent remaining. This small nucleus was to be surrounded by a wall in chalky rock from which it took the name of «selenite circle». The inhabited area was thus reduced to only 19 hectares.

In 728 the Longobards arrived at the settlement, creating an area of about 3.5 hectares, probably fortified, in the shelter of the selenite walls.

From then on, right up to the present days, the city was to expand progressively. Particularly in the 12th century Bologna was to become one of the main cities in Europe, thanks to development of its famous university, and in a short period two subsequent walls were built around it. The first one, dating to the 12th century, is called the Torresotti city wall. It enclosed an area of 112 hectares. The second, which currently encloses the historic centre, was completed in 1374 and circumscribes an area of about 410 hectares.

The area within the old selenite walls has been continuously inhabited for almost three thousand years, perhaps interrupted only during the period of Celtic domination. This makes Bologna one of the oldest cities in the Western World (fig. 3).

GEOMORPHOLOGIC PROCESSES ACTIVE IN THE HISTORIC CENTRE OF BOLOGNA

The construction of the territory on which the historic centre of Bologna directly stands took form over the last 2000-3000 years due to various geomorphologic processes. Some of these are peculiar only to urban areas, and the intensity with which they manifested themselves varies in time (fig. 4).

Rivers, and especially the Aposa torrent, were the main morphogenetic agents. The intensity of fluvial processes gradually diminished with the development of settlements. The works carried out to safeguard the inhabitants from the dangers of the water gradually reduced the risk of flooding, except for a return of the risk after the fall of the Roman empire, due to failure to keep the territory under control. Around the year 1000 work was resumed to avoid flooding from the Aposa, and this was drastically reduced and later eliminated when the river was completely covered.

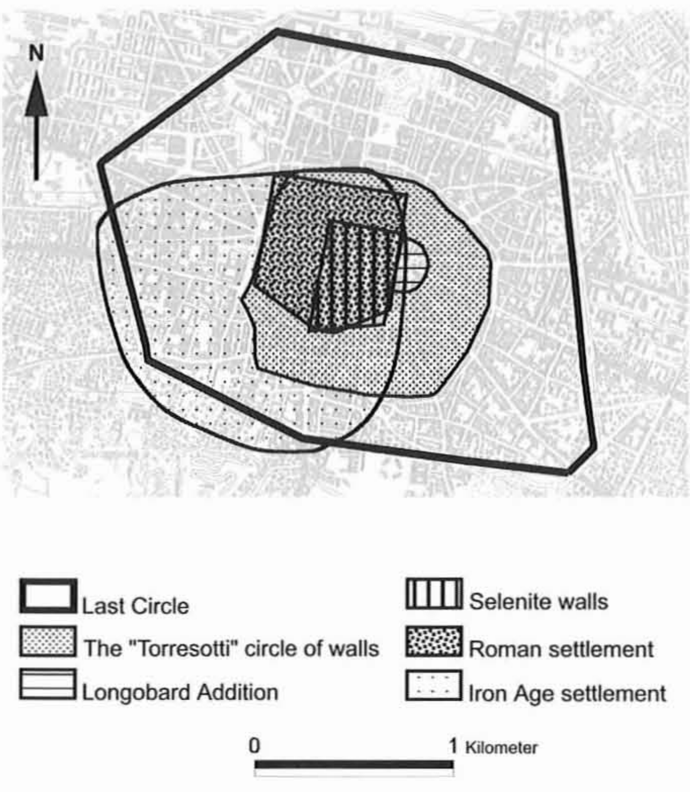

FIG. 3 - Historical settlements in the town area.

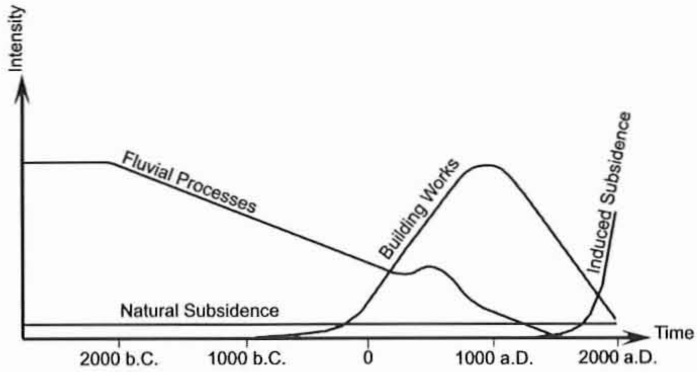

FIG. 4 - Intensities of geomorphological processes over the times.

Natural subsidence has been continual. The extent of lowering of the ground level is, though constant, limited for the period under consideration and estimated at an average of 2 mm/year. The highest lowering is found in the northern part while the rate of subsidence in the southern part is almost zero (Provincia di Bologna, 2001). We may reasonably suppose that the historic centre of Bologna, at least in the northern part, has subsided about 4 metres over the last two thousand years.

Continual building works, and the subsequent demolition and rebuilding on the ruins, has led to the raising, even by several metres, of the topographical surface. The intensity of this anthropic morphological factor has not had a linear trend over the years: it has gone on increasing from the first period of Bologna's history, which is to say around the 8th century BC, reaching a peak between the 5th and 12th centuries, a period in which no urban detritus or refuse was ever transported outside the city walls but was spread over the surrounding terrain. From the 14th century until the 18th century the earth removed for building was accumulated in the southern part of the city, little by little creating high ground which the Bolognese called «Montagnola».

THE DIGITAL ELEVATION MODEL OF THE HISTORIC CENTRE OF BOLOGNA

Study of the morphology of an inhabited centre involves special difficulties due to the fact that the terrain is almost completely covered by streets and buildings.

In order to define a basic altimetric level it was hypothesised that the road network was the closest reference to that which represents the study area surface. The level thus determined was also extended to the built-up areas, within which every vestige of the ancient surface has been largely cancelled out.

For creation of the model it was necessary to gather 654 spot elevations, taken from the 1:2000 scale map produced by the Administration of the Comune di Bologna. A certain number of spots are located on bridges, campaniles etc. so were discarded because they do not represent ground height. Most of the altitudes are naturally located on the street network, some in courtyards or gardens. For data gathering we made use of a geographic information system (GIS) which permitted collecting, positioning and cataloguing the spot elevations. The methods employed to generate altimetric models can essentially be reduced to two types: *raster* and *Triangulated Irregular Network* (TIN). In this case I used the former type, applying the interpolation method known as *kriging*. The choice of this method was due to its capability of highlighting morphological structures, setting out from data distributed in a non-uniform manner. From the model thus obtained, the contour map with 1metre equidistance was drawn up (fig. 5).

MORPHOLOGY OF THE HISTORIC CENTRE OF BOLOGNA

The historic centre of Bologna, enclosed within the last walls, has a surface area of 409 hectares, a perimeter of 7.7 kilometres and the altimetric elevations are between approximately 78 metres in the southern part and 44 metres in the north-western part of the area examined. Lower elevations are found within the old port, artificially dug. It is possible to make out a sort of watershed line running north to south which divides the historic centre into two parts. The appearance of the contour levels is the typical fan-shape that marks the presence of an extended alluvial fan, located completely within the city walls and declining towards the north. In the central southern part of this alluvial fan there is a depression, originating from the over-excavation carried out by the running waters of the Aposa.

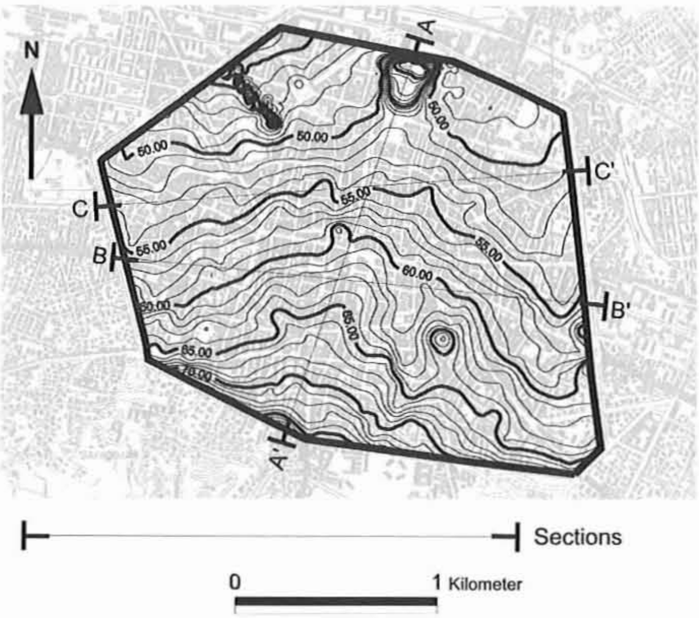

FIG. 5 - Contour lines.

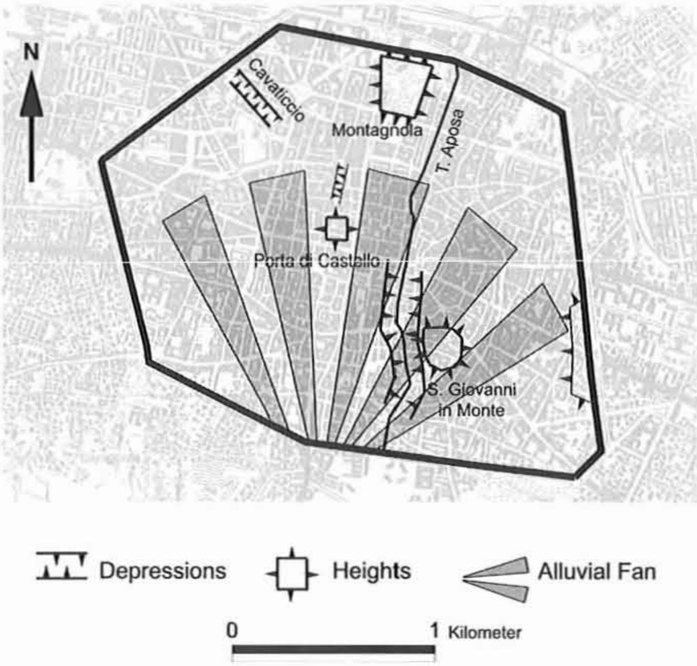

FIG. 6 - Geomorphology.

It was probably in part widened in order to diverting the water from the Savena, through the creation in 1221 of what was known as the Savena canal, with the intention of supplying the moat which surrounded the walls, and subsequently of powering factories, in particular silk-mills. Three prominences stand out in the historic centre, two of them of wholly artificial origin. The «Montagnola», consists of an accumulation of waste and rubble collected over the centuries from the 14^{th} onwards and with an estimated volume of around 500,000 cubic metres; today it is a public park, and its top is about ten metres higher than the surrounding ground. The prominence of Via Porta di Castello, which stands about five metres high, originated from the accumulation of rubble from the demolition of a pair of large temple buildings of the Roman period on which a stronghold was built in the middle ages, later destroyed in uprisings of the people. The third prominence, San Giovanni in Monte, about five metres high, is situated at the side of the Aposa depression and is at least in part of natural origin. Only the final three or four metres could have been artificially added (Cremonini & Zecchi, 2000).

In the northern part of the area there is a narrow and elongated depression, nine metres deep, running in a SE-NW direction. This is the area occupied by the Cavaticcio canal, built during the 16^{th} century, together with the new port of Bologna, to permit vessels to reach Ferrara and Venice by means of internal waterways.

Observing the contour levels one notes limited depressions which probably indicate incisions by torrents.

At the edges of the historic centre, near the city walls, there are morphological raised areas bearing witness to the remains of the ancient rampart embankments (fig. 6).

The surface terrain is clay loam (Bergonzoni & Elmi, 1999), with a prevalence of silty clays in the eastern portion and sandy clay loam in the west (Elmi & *alii*, 1984). Deeper down, the coarser fraction of sediment increases, especially near the eastern and western limits of the built-up area, at a depth of about 15 metres, where we find the first gravely levels attributable to the sedimentary bodies constituting respectively the Savena and Reno alluvial fans.

OLD LEVEL OF THE HISTORIC CENTRE

The old level is the surface corresponding to a period in which man had not yet stably occupied this territory, and has been reached by few drillings and archaeological stratigraphies. This makes it necessary to refer to another surface which is relatively close to that level. The surface identified is the Iron and Etruscan age ground level.

In order to reconstruct the old level of the historic centre it was necessary to gather data regarding the levels at which Iron Age and Etruscan finds surely in place were found. Since the archaeological data are only 89 (Taglioni, 1999), therefore numerically insufficient to determine the old level with a minimum of mathematical exactness, we had to make use of a further 141 finds from the Roman age (Bergonzoni & Bonora, 1976), supposing the altimetric differences between the levels corresponding to the two periods ought not to be too great (fig. 7).

Villanovian and Roman age finds are almost always in direct contact, or at the most separated by no more than fifty centimetres or so. The Etruscan level is often lacking where the Roman settlement is present. The reason for this absence may be explained by presuming that the Romans carried out levelling works in order to make the land more suitable for urbanisation (Bergonzoni, 1966; Ortalli, 1989). The position of the Villanovian and Etruscan levels in some cases coincides while in others they are separated by a few dozen centimetres of earth.

The stratigraphy of the terrain covering the Roman remains is characterised by the presence of «dark earths» (Macphail, 1981; Macphail & Courty, 1984), where there is an absence of continuity of inhabitation with the immediately subsequent periods, such as in the western part of Bononia. «Dark earths» are known from other towns and their origin remains debatable. This testify that between the late empire and the early middle ages every form of urban organisation had collapsed (Brogiolo & *alii*, 1988). The dark earths are absent in the part characterised by continuity of inhabitation to the present day, and there is a succession of rubble from the demolition and reconstruction of buildings (fig. 8).

It seems clear that the finds are irregularly distributed within the historic centre, and in fact they are concentrated in the central and south-western part. This is why it was

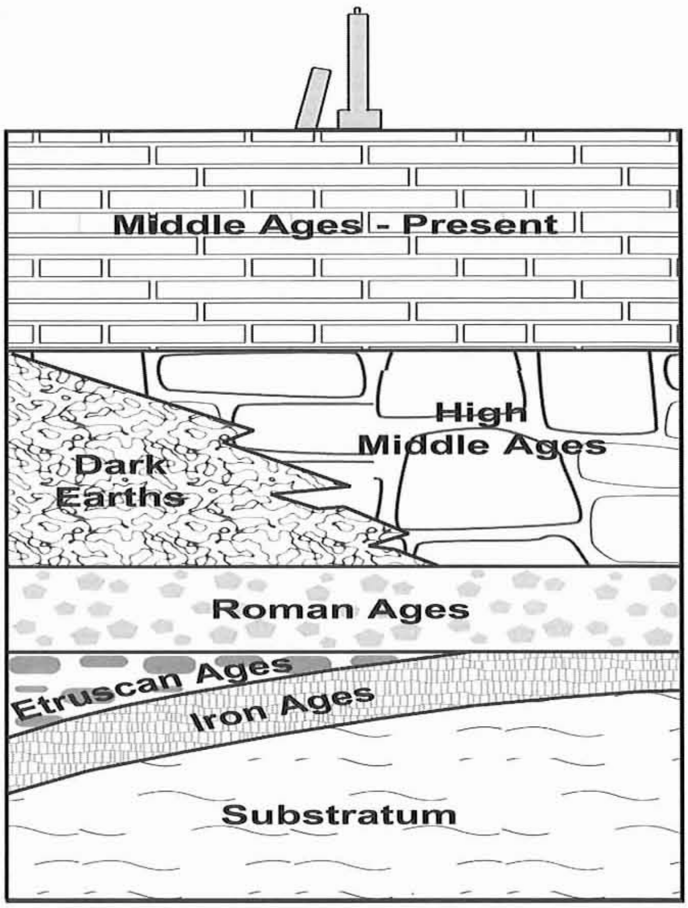

FIG. 8 - Stratigraphic sketch of Bologna subsoil.

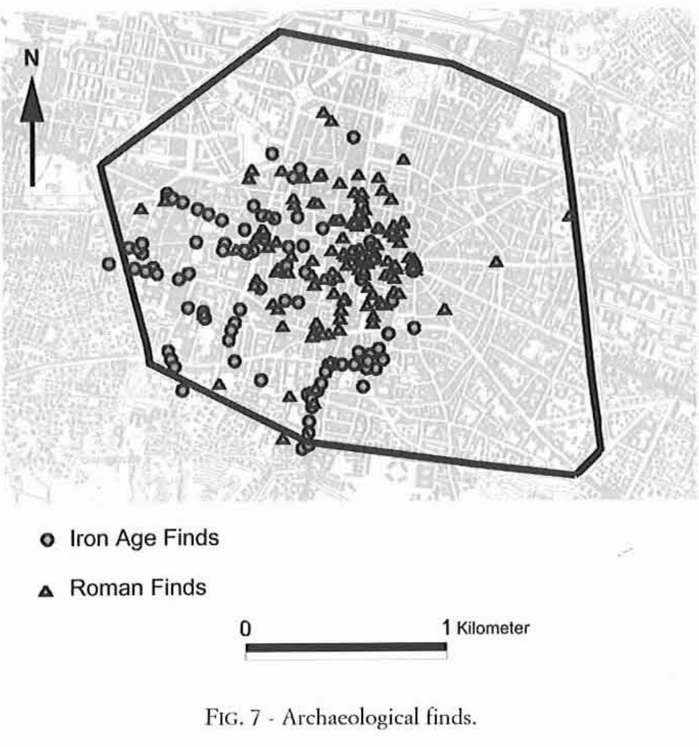

FIG. 7 - Archaeological finds.

necessary to reduce the surface for elaboration of the digital elevation model solely to the part of the territory featuring a high density of finds. The model thus created extends over roughly 138 hectares, equal to 34% of the area contained within the city walls.

Reconstruction of a level buried beneath the surface varies in function of the interpretative scheme adopted (Gualdrini & *alii*, 1997). One model assumes that the buried level has been covered in a sufficiently uniform way by materials of varied origin, even if the thicknesses differ from place to place. A second model considers non-homogeneous coverings, due, for example, to excavations and accumulations of materials. It is not easy to establish *a priori* which of the two approaches is most fitting for the local situation. Clearly, errors will be introduced in both cases. It is well known that, in the zone being studied, materials have been somewhere accumulated or removed while elsewhere the covering of the old level is fairly homogeneous. So an intermediate solution was adopted which therefore averages out any errors. It consists in creating both altimetric models from which a third is subsequently obtained, derived from the mathematical mean of the two previous ones (fig. 9).

From this model it was possible to draw a map of the isopachs (fig. 10), which is to say the depth of the old level in relation to the surface, and another representing the absolute elevation (fig. 11).

The overall volume of material, mostly backfill, which has been added over the past two thousand years, amounts to slightly more than three million cubic metres.

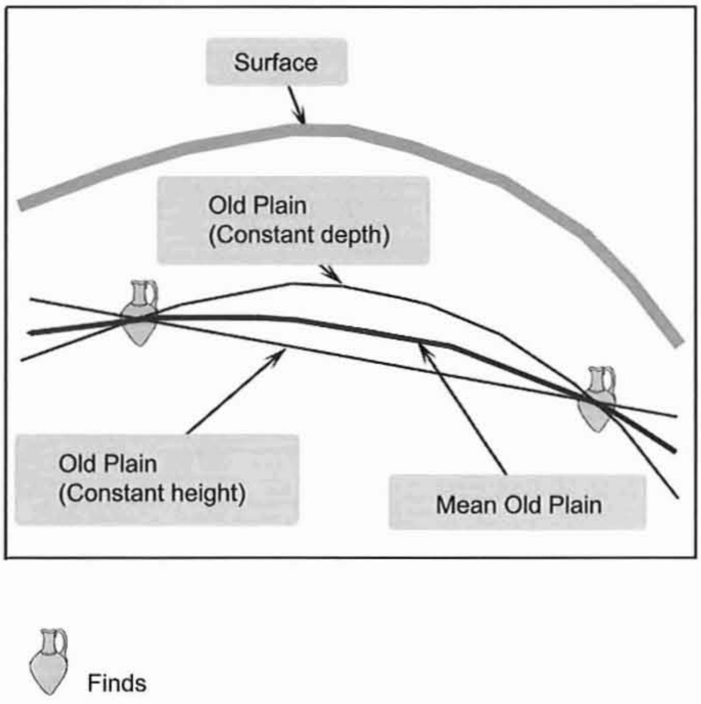

FIG. 9 - Model for old plain reconstruction.

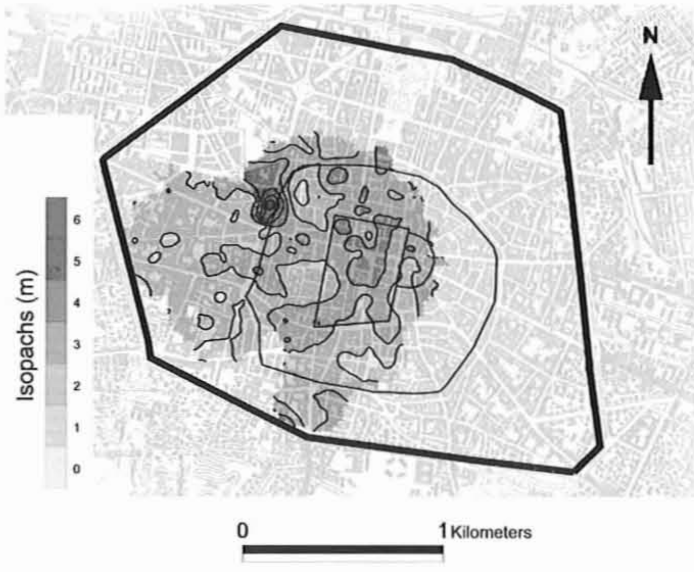

FIG. 10 - Isopachs map.

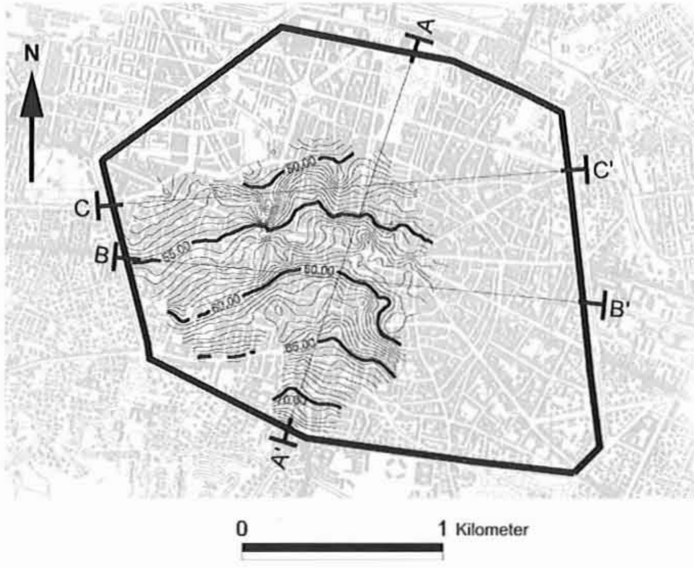

FIG. 11 - Old plain contour lines.

Three topographic sections were traced in which the old and current topographic surfaces are indicated (fig. 12). To better highlight the altimetric differences the scale of altitudes has been exaggerated 50 times in relation to the scale of lengths.

The first section A-A' has a NNE-SSW direction and is longitudinal in relation to the alluvial fan. It first meets the artificial rise of the Montagnola, after which it takes on a progression which gradually rises as it ascends the alluvial fan. The old surface is found at a greater depth in the

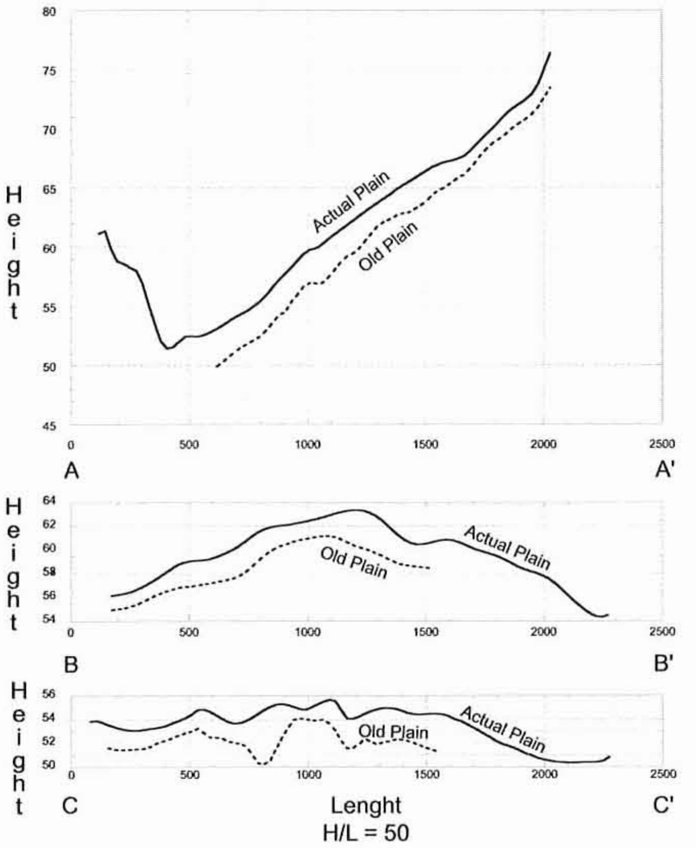

FIG. 12 - Sections.

northern part of the section whereas it tends to approach the topographic surface towards the south.

Section B-B' has a WNW-ESE direction and transversally cuts the alluvial fan, evidencing its appearance in an exemplary manner. Just over halfway, the slight incision made by the Aposa is evidenced. Proceeding west to east the old level tends to deepen.

Section C-C' is more or less parallel to the preceding one, with direction WSW-ENE, but is shifted northwards. It is practically in the terminal part of the alluvial fan where it mingles with the alluvial plain. In this case the form of the alluvial fan is not clear as in the preceding section. There are two deep incisions clearly evident in the old level of which the westernmost one is completely masked in the current topographic set-up, whereas the other is still visible also on the surface. The two depressions by contrast mark a morphologic high.

The contour levels of the old level follow that of the current one fairly faithfully; in particular the ridge is confirmed which represents the axis of the Aposa alluvial fan already noted in the current morphology, even though it seems slightly shifted towards the west. There is also, though in incomplete form, the fan-like layout of the contour lines. The Aposa depression, being in a marginal position, is not completely highlighted. Some incisions zzalready present in the current morphology also persist in the old level, such as the one starting from the artificial raised part of Via Porta Castello. Farther west than the preceding one there is a clear and deep incision, up to six metres, which is not visible on the surface. Its position coincides with the western boundary of the Roman built-up area and may be interpreted as a moat, dug for defence of the city and subsequently filled in. Another limited zone in which the old level appears at greater depths, between three and four metres, corresponds with the accumulation of material from large buildings demolished in Via Porta di Castello.

The part of the city within the old selenite walls, having been continuously inhabited for a very long time, has the old level at an average depth of 2.6 metres with points that are well over three metres. The reason lies in the continual accumulation of rubble from the demolition of buildings in order to build new ones on their sites. Moving westwards but remaining within the Torresotti city walls, the average depth decreases to two metres. This area underwent a period of abandonment after the fall of the Roman empire. In the most recently urbanised part, outside the Roman inhabited area, the old level is found at an average depth of 1.8 metres.

On the basis of detailed study of the micro-morphology, using mathematical models that permit automatic tracing of the hydrographical network (Tarboton, 1991), it was possible to identify the traces of the incisions caused by the erosive activity of the ancient rivers, most of which are attributable to the Aposa (fig. 13).

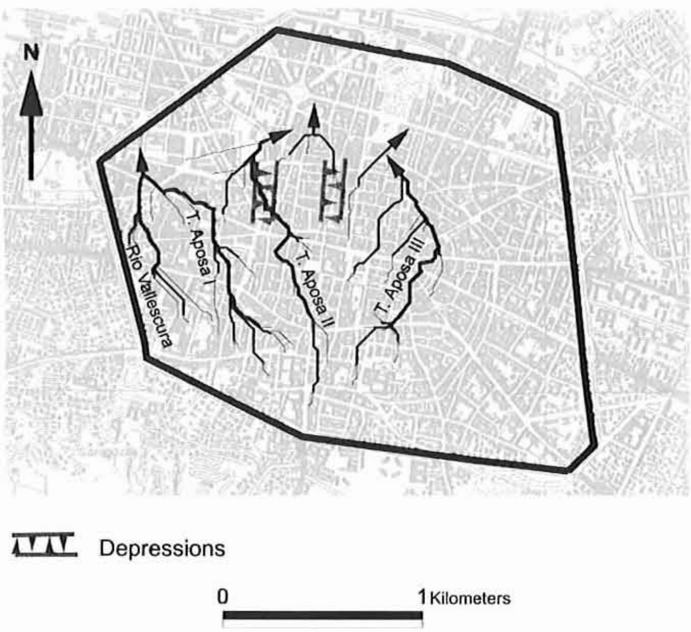

FIG. 13 - Old hydrography (from DEM).

The river traces have both north-west and north-east directions, although in the eastern part of the city the model is incomplete. The westernmost branch is probably referable to the Vallescura stream; the next one (T. Aposa I) ran to the west of the part occupied by Roman Bologna, receiving the water of the Vallescura itself, perhaps later converging with the Ravone torrent. Another ramification, originating from the apex of the alluvial fan (T. Aposa II), entered the western part of the Roman settlement and left it after having been at least partly redirected to protect the western boundary of the city, as suggested by the deep incision seen along the north-west boundary of the built-up area. This stretch also presents an optimal superimposition with the data from subsoil analysis which confirm the presence of a bed of the Aposa, starting from a depth of around 20 metres to about 10 metres (Artioli & *alii*, 1999). Having also identified it in the old level, where it had perhaps lost importance in comparison with the new western branch of the Aposa, means that a long life must be attributed to this watercourse. The subsequent stretch (T. Aposa III), which takes a direction towards north and north-east, is almost superimposable with the present day course of the Aposa.

The slope of the old level (fig. 14), though in a typical context of plain environments featuring sub-horizontal slopes, permits the evidencing of two distinct belts in which the slope is greater than one degree, while the remaining parts have lesser gradients. These slight variations allow the evidencing of two small morphological steps that may be attributed to two successive phases and/or different lithologic type which mark the proximal from the distal part of the alluvial fan. The strong inflexion involving the northern morphological step is due to the incision pointed out above.

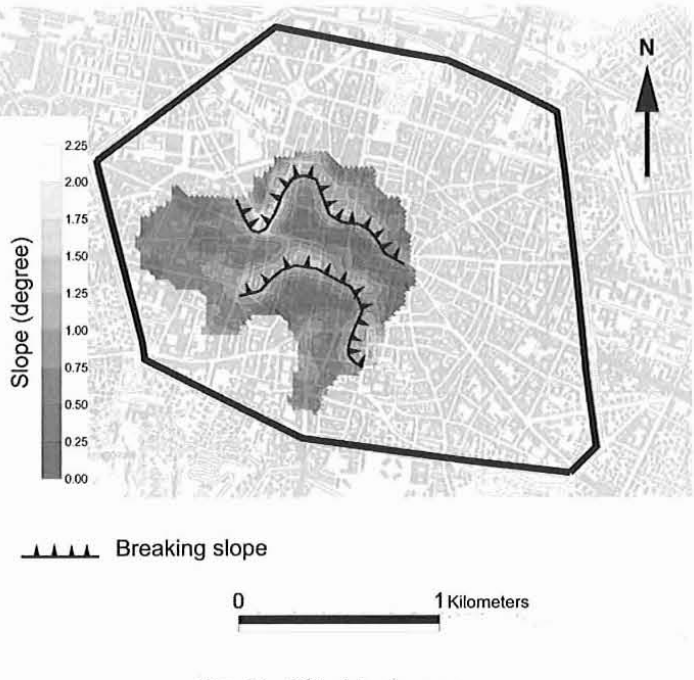

FIG. 14 - Old plain slope map.

CONCLUSION

The processes which have determined the geomorphologic evolution of the area within the historic centre of Bologna may be traced essentially to three factors:

1. The first regards erosion and depositing activities carried out by rivers, especially by the torrent Aposa. This activity took place mainly in the past and today is scant or non-existent due to the regulation of the watercourse which effectively impedes any depositing or eroding action.
2. The second is due to the works of man: in fact the urban construction of Bologna proceeded in phases of building, demolition and rebuilding on the previous rubble. These works in effect have raised the ground level of the historic centre almost to our own day. The area between the Ravone and the Aposa was continuously inhabited from the 8^{th} century BC to the 4^{th}-5^{th} century AD with the exclusion of the Celtic period. Subsequently the inhabited area was reduced for several centuries up to the 7^{th}, after which there was continual expansion until the 14^{th} century, in the course of which the city reached its maximum size which it was to maintain substantially unchanged almost to the beginning of the 20^{th} century.
3. The third factor is subsidence. Little can be said on this subject because it is impossible to know either the subsidence rate in the past or the areas chiefly affected by the phenomenon. Considerable information however is available with regard to the last few decades. The zone most affected by the phenomenon is the north-eastern portion of the area with subsidence rates that reached 4 cm/year. The subsidence in the south-western part is attenuated to the extent of almost disappearing. The high subsidence rate is chiefly due to anthropic causes, and especially to the draining of underground water. There is no doubt that in past centuries this lowering, though it existed, must have had lesser effects. It is in any case true that this aspect too must be taken into account in determining the ancient morphology of the historic centre. Unfortunately, not having data for an understanding of subsidence over the last three thousand years, one may only suppose that the north-east part of the area studied was relatively higher than what the current morphology leads us to suppose.

The surface geomorphologic features within the historic centre were inferred by reconstructing an altimetric model by means of gathering spot elevations. The model obtained permitted observance of the presence of an extended alluvial fan due to the sediments left by the Aposa torrent, of high ground of chiefly anthropic origin, and of incisions, also in this case prevalently connected with the works of man.

The geomorphology of the old level, reconstructed by means of the use of archaeological finds, dating to a period between the iron age and the Roman age, permitted partial identification of the Aposa alluvial fan and also the traces of ancient torrent beds, and two slight morphological steps that could mark the limits between two distinct and successive phases of the construction of the alluvial fan. Two small incisions were also identified, probably connected with works for canalisation of the rivers.

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