Suppl. Geogr. Fis. Dinam. Quat.
III, T. 2 (1997), 105-121, 16 figg.

FOURTH INTERNATIONAL CONFERENCE ON GEOMORPHOLOGY - Italy 1997

Guide for the excursion

FUNDAMENTS FOR A GEOMORPHOLOGICAL OVERVIEW ON ROMA AND ITS SURROUNDINGS

P. BELLOTTI (1), C. CAPUTO (1), S. CICCACCI (3), D. DE RITA (2), S. DONATI (2), P. FREDI (1), R. FUNICIELLO (2),
G.B. LA MONICA (1), B. LANDINI (1), F. MARRA (2), S. MILLI (1), M. PAROTTO (2) & F. PUGLIESE (1)
Eds.: C. CAPUTO

INTRODUCTION
(C. Caputo)

In this synthetic guide the main aspects which distinguish the landscape of the area around Roma are described; it gives an easy geological and morphological description of the Eternal City and its surroundings, which can be visited during a short field trip.

The first of these aspects is represented by the landscape of the four large Quaternary volcanic complexes of Latium. It is mainly on the products of two of these volcanic complexes that Roma is built: they are the Monti Sabatini, to the NW, and the Colli Albani to the SE of the city. Roma and its morphological features, strictly connected with the Quaternary volcanic activity and the human presence since antique times, is the second outstanding landscape. Finally the third important landscape of the area around Roma is that of the flat region extending from the city to the Tyrrhenian Sea and forming, on the whole, the delta of the Fiume Tevere which had a prominent role in the history of Roma. Actually its waters have always represented a kind of umbilical cord between the «Mater Roma» and the Mediterranean Sea coasts along which the mighty Roman Empire rapidly developed and spread out.

The Monti Sabatini alkaline-potassic volcanic district had a prevailingly explosive activity from a great number of emission centres; they are mainly concentrated in the eastern sector and around the large depression holding the Lago di Bracciano and erupted a remarkable volume of volcanic products. Especially the emplacement of pyroclastic flows can be considered the main responsible of the generally flat morphology of the Campagna Romana (or Agro Romano). This area is 2,000 km^2 large and is bordered by the Monti Sabatini, the Colli Albani, and the south-western carbonate reliefs of the Latium pre-Apennines and is passed through by the lower course of the Fiume Tevere which, after having crossed Roma, flows into the Tyrrhenian Sea.

The expansion of Roma has been with no doubt linked to the many historical events which followed one another during more than 2,000 years. Nevertheless, many different factors controlled the development of Roma; among them the natural ones surely had a very important role. For instance, the unbalanced expansion of the city astride the Fiume Tevere, can be explained on morphological basis. In fact, on the hydrographical right side of the river the higher ridge of the Vatican hills acted like a blockage. On the contrary, the smoother Seven Hills and the infra-hill areas, on the river left sides, represented a more suitable place where a more harmonious expansion could take place. Moreover, especially the expansion of Roma has been conditioned by the existence of numerous creeks and marshes; however also the geological arrangement was important, as it determined which areas were more or less prone to sliding.

---

(1) *Dipartimento di Scienze della Terra, Università degli Studi «La Sapienza», Roma, Italy.*

(2) *Dipartimento di Scienze Geologiche, Università degli Studi Roma Tre, Roma, Italy.*

(3) *Dipartimento di Geologia e Geofisica, Università degli Studi di Bari, Italy.*

Work financially supported by: Ministero dell'Università e della Ricerca Scientifica e Tecnologica, Consiglio Nazionale delle Ricerche, Università degli Studi di Roma «La Sapienza» (Prof. E. Lupia Palmieri). The relative excursion has been patronized by the Regione Lazio and the Comune di Roma and financially supported by: Università degli Studi di Roma «La Sapienza», Consiglio Nazionale delle Ricerche, Ministero dell'Università e della Ricerca Scientifica e Teconologica.

If the above mentioned conditions have controlled the development of Roma «town of the living», the same must be said for the «necropolis», generally placed along the main consular roads and, according to Roman laws, outside the town walls. The most renowned sepulchral area is, perhaps, the Appian way (the famous Via Appia, «Regina Viarum» of the Romans) which winds, starting about 3 km from Porta San Sebastiano (to the South of Roma) on an important lava flow connected with the Colli Albani activity.

After Christianity gained the upper hand over paganism, other burial areas arose: the catacombs. One example may be the Catacombs of Priscilla, near the Via Salaria, which develop in hypogaea, cubicula and galleries of different length within the pyroclastic products of the Monti Sabatini volcanic complex.

Both the Sabatini and the Colli Albani volcanic complexes have conditioned in time the flowing of the Fiume Tevere which, with its solid supply, was gradually building up its delta through different stages: from a wide lagoon to a more and more well-marked delta body. During historical times the Tevere delta was affected by continuous - although at changeable rates - accretion; many archaeological witnesses testify to the great importance of this area in the Roman life. And these same witnesses offer a valuable aid for the study of the evolution itself; they are towns (Ostia Antica), burial areas (Necropoli di Porto on the Isola Sacra) or simply roads (Via Severiana). Also different testimonies come from the Classics. Among these worth of being mentioned is PLINIO IL GIOVANE (Pliny the Younger; I-II cent. A.D.); he frequently provides accounts of different natural phenomena with the utmost scientific exactitude.

The accretion of the Fiume Tevere delta lasted for a long time, but during the past 50 years changes into an opposite trend were observed and erosion processes affected the delta. This obviously caused serious troubles to the coastal centres and specifically to Lido di Ostia, an area which is by now integral part of Roma. As a consequence extensive defences had to be built.

In view of the above comments, the main morphological characteristics of a volcanic complex (Monti Sabatini), the City of Roma, and the Tevere delta with its shore will be described in following pages.

THE MONTI SABATINI VOLCANIC COMPLEX

(P. Fredi, S. Ciccacci & D. De Rita)

The Monti Sabatini volcanic district is located in northern-central Latium, about 20 km to the North-West of Roma and it is bordered to the North by the Vico volca-

FIG. 1 - Roma and its surroundings. At the centre of the picture is the meandering course of the Fiume Tevere, which, after having crossed the City of Roma, flows into the Tyrrhenian Sea through its typical delta. On the right side of the river, part of the Monti Sabatini volcanic complex with the Lago di Bracciano and the smaller Lago di Martignano. On the river left side the volcanic edifice of Colli Albani with the Albano and Nemi crater lakes (LANDSAT 4, 1983).

no, to the West by the Monti della Tolfa, to the South by the Tevere lower valley and to the East by the Monte Soratte-Monti Cornicolani structure. This volcanic district, together with the other Latian volcanic districts, Monti Vulsini and Vico (to the NW of Monti Sabatini) and Colli Albani (to the SE of Roma), is part of the «Provincia Romana», a K-alkaline volcanic province, which developed mainly during the Pleistocene and that has been active up to recent times. This volcanic province originated in an area characterized by the presence of a series of buried meso-cenozoic structural highs and lows elongated with an Apennine (NW-SE) direction. Such a trend is connected to a Plio-Pleistocene tectonic phase which affected the whole central Tyrrhenian area.

The structural setting of the area where the Sabatini volcanic complex developed can be sketched as a large Graben-like structure limited to the West by the Monti della Tolfa structural high and to the East by the Monte Soratte-Monti Cornicolani sedimentary structure; in the central-eastern sector of the main Graben there are secondary structural highs such as the Cesano-Baccano one (fig. 2). The areal distribution of the Plio-Pleistocene marine sediments shows that this structural setting was already existent before the volcanism started. The regressive phase, which is likely to have started during Lower Pleistocene, caused the emersion of marine sediments which was completed in Middle Pleistocene; from this time onward continental sedimentation was recorded (CARBONI & *alii*, 1993).

The Sabatini district was characterized by an areal volcanic activity ascribable to numerous eruptive centres widespread over an area of about 1,500 square kilometres, although a main central edifice was recognized in the eastern sector where the Sacrofano volcano developed. The volcanic activity started at the margins of the main Graben and then migrated to the centre following tectonic dislocations of regional importance; it caused the emplacement of a big amount of products (about 180 km^3) prevailingly made of pyroclastic flows, hydromagmatic products, lava sheets and pyroclastic fall products.

The first volcanism started less than 2.50 Ma ago in the Tolfa-Cerite-Manziate area, in the western sector of the Graben-like structure; it was characterized by differentiate chemism and is not considered part of the «Provincia Romana» but of the acidic «Tuscan volcanic Province» (LAURO & NEGRETTI, 1969).

In the eastern sector of the Sabatini district, the first volcanic activity began at the margin of the Monte Soratte-Monti Cornicolani structure. At present the most ancient eruptive centre is not morphologically recognizable, but it should have developed about 0.60 Ma ago, between the small towns of Morlupo and Castelnuovo di Porto. The products of this centre lay directly on the Plio-Pleistocene sediments; they consist of a trachytic lava flow followed by a thick sequence of fall and surge levels. The activity ended with the emplacement of a hydromagmatic pyroclastic flow which testifies for magma/water interactions.

During the last stage of Morlupo-Castelnuovo di Porto activity volcanism started also in the westward area, where the Sacrofano centre developed. This centre is one of the major volcanic features of the Sabatini district because of its long period of activity which lasted from 0.55 Ma ago until about 0.30 Ma ago, when the caldera collapse occurred.

In its first stage Sacrofano activity was mainly vulcanian and the first product was the «Sacrofano lower pyroclastic flow unit» (named Via Tiberina Yellow Tuff, from tephritic-leucitic to phonolitic-leucitic in composition) followed by pyroclastic fall products; this activity continued for a long period of time during which the volcanic edifice was built. In this same period intense volcanism occurred all over the Sabatini district, probably corresponding to a period of maximum regional disgiuntive stress which between 0.40 and 0.30 Ma ago caused the paroxysmal activity also of the other volcanic districts of Central Italy. Most of the pyroclastic and lava flow units of the Sabatini central and western sectors were also erupted during this time interval from fractures or centres located along fracture systems; contemporary the Bracciano volcano-tectonic depression developed and, in the eastern sector, the Baccano-Cesano structural high collapsed.

After this paroxysmal stage, volcanism came to an exhausting phase, probably connected to the progressive

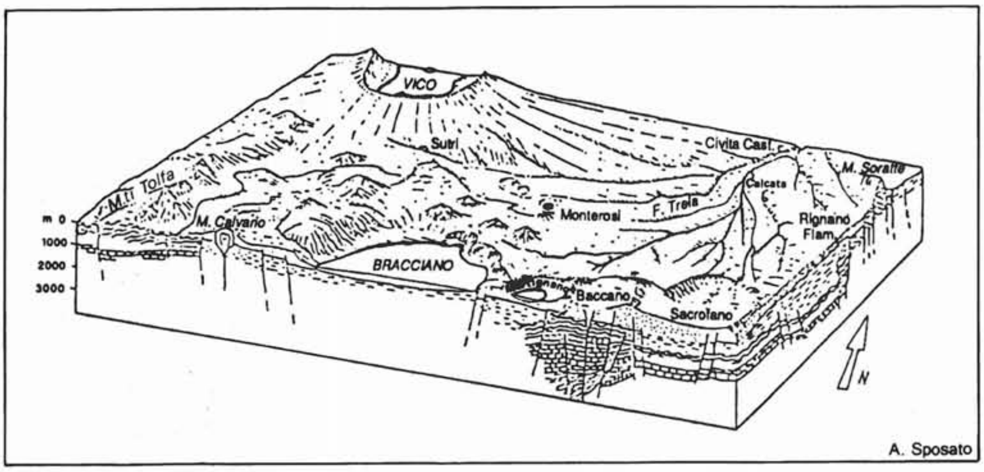


Fig. 2 - Block-diagram showing the location of the Monti Sabatini volcanic district and the geological and structural setting in which it originated.

diminishing stress. This situation may have allowed water to come to contact with magma, producing small single craters like the Monterosi one.

In the eastern Baccano-Cesano area, volcanism interacted many times with regional aquifers. At the Sacrofano centre this interaction caused the eruption of the «Sacrofano upper pyroclastic flow unit» (named Sacrofano Yellow Tuff), similar to the first one; this explosive event, dated about 0.30 Ma ago, was responsible for a volcano-tectonic phase of instability which produced the caldera collapse. The collapse faults intersected deep aquifers, rapidly mobilized the waters and opened a direct path for magma/water interactions. Inside the Sacrofano caldera the Monte Razzano tuff cone was built up. Afterward, the activity migrated westward and the Baccano centre was built on the western margin of the old Sacrofano caldera. This new centre had a very violent hydromagmatic activity; its explosions made the rise of magma in the conduit easier causing the emplacement, about 0.08 Ma ago, of the «Baccano pyroclastic flow unit». This event, together with the subsequent hydromagmatic explosions caused the caldera collapse and the migration of the activity westward.

The last volcanic activity in the Sabatini district occurred in the Cesano area and was characterized by hydromagmatic explosions from several local centres, like Martignano, Stracciacappa and Le Cese (DE RITA & *alii*, 1993).

GEOMORPHOLOGY

The morphological evolution and present arrangement of the Monti Sabatini area are the result of both the volcanic events and the exogenous processes, which in their turn have been strongly controlled by recent tectonics.

Morphotectonic studies testify for the complexity of the tectonic setting of the area (BIASINI & *alii*, 1993; CICCACCI & *alii*, 1989).

Many and interesting information about linear tectonic elements were derived from the analysis of stream preferential orientations and from the alignment of significant morphological features; on the base of this morphological evidence the existence of tectonic lineations N-S, NE-SW and NW-SE directed was supposed. The hypothesis that the morphological alignments and the channel orientations are the surface expression of regional tectonic lines is also supported by the location and shape of the main volcanic forms as well as by the results of more specific geological and structural studies. To evidence areal tectonic elements the areal variability of the morphometric parametres «drainage density» and «amplitude of relief» was examined. Such studies allowed the identification of three different morphotectonic sectors which are likely to have undergone differential uplifting and subsidence. More exactly, the eastern and western sectors resulted uplifted as respect to the central one where the volcano-tectonic depression of Lago di Bracciano is present. Moreover, differently displaced areas were singled out within each sector; such displacements took place along the above mentioned tectonic directions and testify for the existence of articulate and complex tectonic situations.

The landscape of the Monti Sabatini volcanic complex is marked by the contrast between the composite aspect of the central zones, where most of the positive and negative volcanic forms are present, and the smooth and regular trend of the peripheral zones, slightly dipping outward from the central zones.

The positive volcanic forms (mainly scoria cones) are responsible for the greatest elevation in the northern part of the central sector where, at Monte Rocca Romana, to the North of Lago di Bracciano, the maximum elevation is reached (612 m a.s.l.). The wide subcircular depression, occupied by the Lago di Bracciano is the most striking negative form of the whole complex; moving eastward the depressions of Martignano, Baccano and Sacrofano are found. The origin and evolution of these four main depressions followed different paths: the former had an essentially volcano-tectonic origin, while the others display the typical features of volcanic centres with predominantly explosive activity.

The morphology of the peripheral zones of the Monti Sabatini area is typical of all the volcanic areas of Latium; the repeated pyroclastic and lava flows caused the formation of surfaces slightly inclined from the eruptive centres outward which were then shaped by the exogenous processes. Among these the most evident are due to channelled running waters that cut the volcanic plateau into large shelves separated by deep valleys, drawing an overall centrifugal drainage network that varies in density from zone to zone (BIASINI & *alii*, 1993).

In the following pages the main geomorphological characters of particularly interesting areas will be described in more details; the aim is to show the most important aspects of the geomorphological evolution of areas which can be both representative of the whole volcanic complex and observable only in one day of excursion.

The Sacrofano-Baccano area

This area is located in the eastern sector of the volcanic district and is one of the most interesting of the whole volcanic complex as its geomorphological evolution was markedly affected by both volcanic and tectonic events in which the same valley of Fiume Tevere get involved. Thorough studies allowed to delineate the geomorphological evolution of this area, starting from the beginning of the volcanic activity. Such evolution took place through four main phases (CICCACCI & *alii*, 1988) .

The *first phase* started about 0.55 Ma ago with the emplacement of the most ancient products of the volcanic centre of Sacrofano; the products of this initial and mainly vulcanian activity (Sacrofano lower pyroclastic flow unit and pyroclastic fall products) built up the central volcanic edifice, while many scoria cones originated in the peripheral zones of the main volcano. On the newly created relief a radial centrifugal drainage developed which cut deep valleys mainly developed on the northern slope of the volcano while on the southern slope the crater was probably in direct connection with a main valley, where the Sacrofano products were preferentially channelled (fig. 3.1).

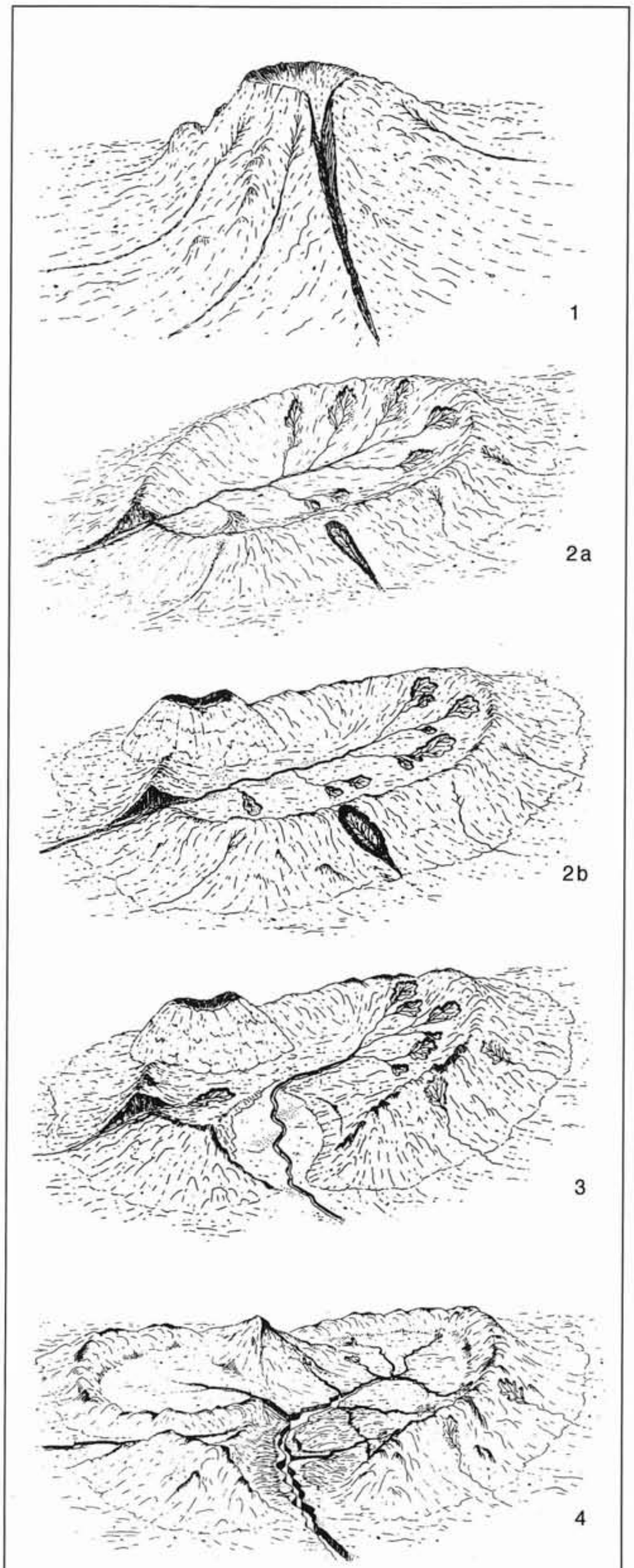


FIG. 3 - Geomorphological evolution of the Sacrofano and Baccano depressions. (From: CICCACCI & *alii*, 1988, modified).

The emplacement of the Sacrofano lower pyroclastic flow, in particular, was strongly controlled by the preexisting topography and was responsible for deep morphological changes also in the most marginal areas. To the North of the Sacrofano volcano, in fact, this flow was channelled in the ancient valley of Fiume Tevere which was dammed and forced to flow in the present and more eastern position (ALVAREZ, 1973). The ancient course of Fiume Tevere was then inherited by the Fiume Treia which presently flows on the northern slope of the Sacrofano volcano from South to North, i.e. in a reverse direction as respect to the Fiume Tevere (fig. 4). The possibility that the ancient Fiume Tevere might flow in a more westward position, broadly corresponding to the present course of Fiume Treia, is confirmed by the existence within the drainage basin of this river of a thick layer of fluvial conglomerates directly laying beneath the Sacrofano lower pyroclastic flow unit. This fluvial deposit, located close to the small town of Calcata, is made of well rounded calcareous clasts which testify to a prolonged fluvial transport and to the presence of calcareous reliefs in the source area. The deposit thickness as well as clast roundness and lithology apply to a river with a higher discharge and a more extended drainage basin, but cannot be applied to Fiume Treia that has a relatively small catchment, entirely emplaced on the volcanic units.

The first phase of the evolution of the Sacrofano-Baccano area ended when the Sacrofano upper pyroclastic flow unit was emplaced, about 0.30 Ma ago. This event was followed by the volcano summit collapse and the consequent formation of a wide elliptical caldera, having its major axis NE-SW oriented. This direction has been interpreted as a tectonic direction of regional importance, in fact it clearly controlled the morphological evolution of the eastern sector of the Sabatini volcanic complex as well as its volcanic history. As it is known that the volcanic activity of this sector migrated approximately from East to West, it is likely that the migration occurred just along this important tectonic direction. Consequently, the more ancient Morlupo centre, which presently is not morphologically recognizable on field, would have been located on the northeastward extension of the Sacrofano caldera major axis (fig. 5).

The *second phase* of the evolution of the Sacrofano-Baccano area was dominated by the presence of the Sacrofano caldera (fig. 3.2a). The collapse of the volcano summit cut off the radial valley headwaters, while the valleys themselves were partially filled with the pyroclastic flow. Solifluction-like processes in the unconsolidated volcanic products shaped the minor valleys, which still now show a trough-floored cross-profile. The major radial valleys, on the contrary, were deeply cut by rivers, as it is singled out by sharp fluvial erosion scarps. Within the caldera a new centripetal drainage network was emplaced which joined the main trunk flowing from NE to SW, following the caldera major axis and breaking the depression edge southwestward.

At the end of this second phase a hydromagmatic activity developed at an uncertain centre; the products of this

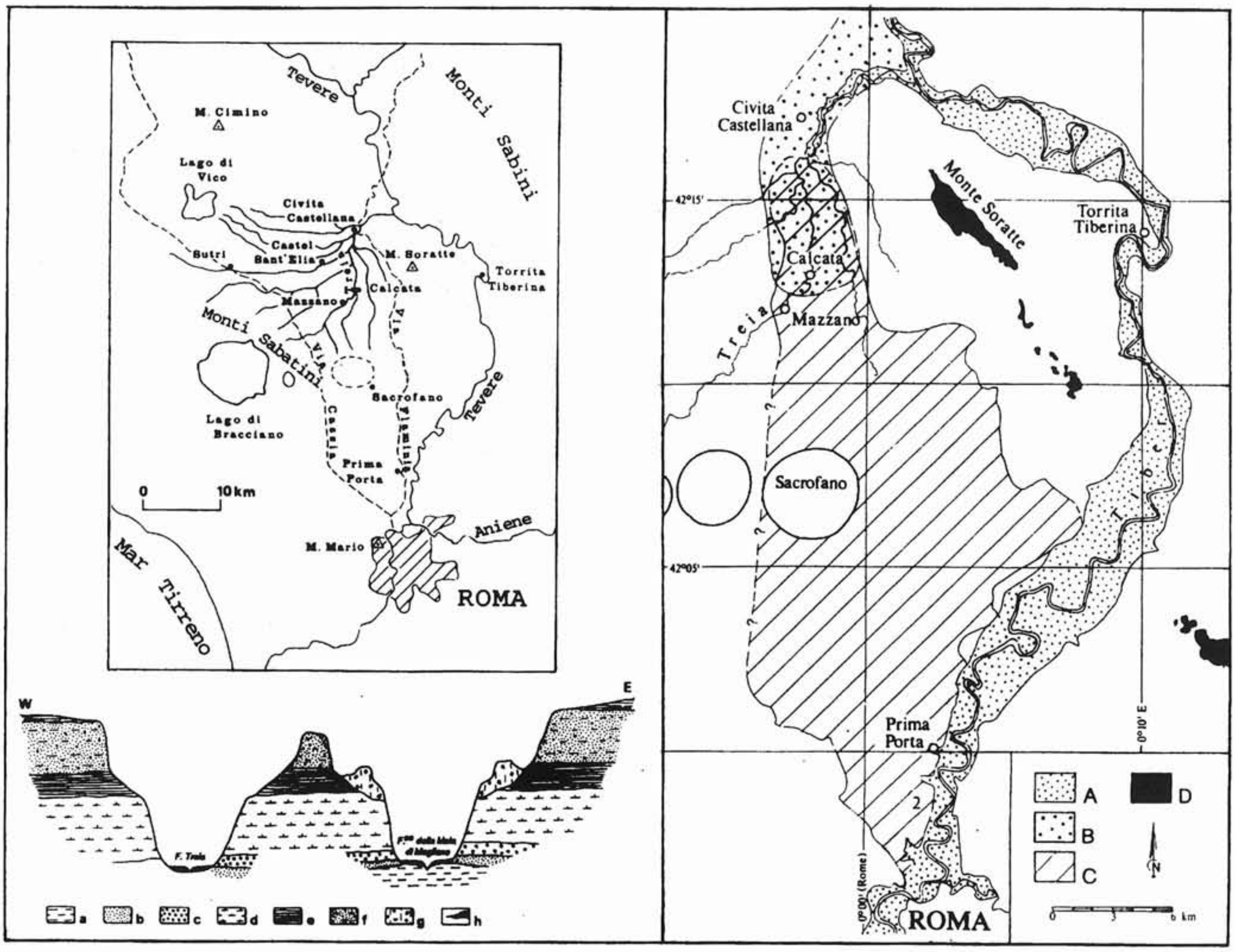


FIG. 4 - The Sabatini volcano area. The present drainage pattern is schematically shown up left. To the right, the probable course of the Paleo Tevere valley evidenced by the volcanic and lacustrine deposits which filled it: A - Flood-plain of the modern Tevere; B - Lake beds interbedded with Sacrofano pyroclastic fall products; C - Sacrofano lower pyroclastic flow unit; D - Mesozoic calcareous reliefs. (From: ALVAREZ, 1972, modified). The cross section on the left is approximately located between the towns of Calcata and Mazzano; it shows that the evolution of the valley of Fiume Treia was strongly controlled by the activity of both Sabatini and Vico volcanoes. a - Plio-Pleistocene marine clays; b - Plio-Pleistocene sands; c - Paleo Tevere conglomerates; d - Sacrofano lower pyroclastic flow unit; e - Sacrofano pyroclastic fall unit; f - Sabatian Red Tuff with black scoria from Sabatini volcano; g - Red Tuff with black scoria from Vico volcano; h - modern alluvial deposits. (From: CICCACCI & *alii*, 1990).

activity crop out on the northern and eastern rim of the caldera, where they give origin to scantily extended structural surfaces. The same kind of activity is responsible for the building up of Monte Razzano tuff-cone on the western edge of the Sacrofano caldera (fig. 3.2b). This event marked the end of the second evolutive phase and the beginning of the third one.

The *third phase* is marked by consistent modifications of surface drainage. The main trunk of the intracalderic drainage network, NE-SW oriented, is forced to flow southward inside the valley presently drained by Rio Cremera, but existing as an important valley in connection with the crater since the first evolutive phase. This deviation was probably due to the headward erosion of Rio Cremera which breached the southern rim of the caldera depression, near the present small town of Formello, and captured the intracalderic drainage network. This piracy was probably made easier by a volcanic event which would have interrupted the southern edge of the Sacrofano caldera (fig. 3.3). Such hypothesis is based on the existence of the Formello circular depression, the origin of which is still uncertain although it has been tentatively related to a volcano-tectonic event.

The *fourth phase* of the Sacrofano-Baccano area evolution started with the beginning of the Baccano eruptive centre activity (fig. 3.4). The volcanic events of this fourth phase deeply changed the previous landscape: the western edge of the Sacrofano caldera was firstly buried by the Baccano lower hydromagmatic unit and finally interrupted by the main collapse of the Baccano caldera, which occurred after the emplacement of the Baccano pyroclastic flow unit and of the Baccano intermediate and upper hydro-

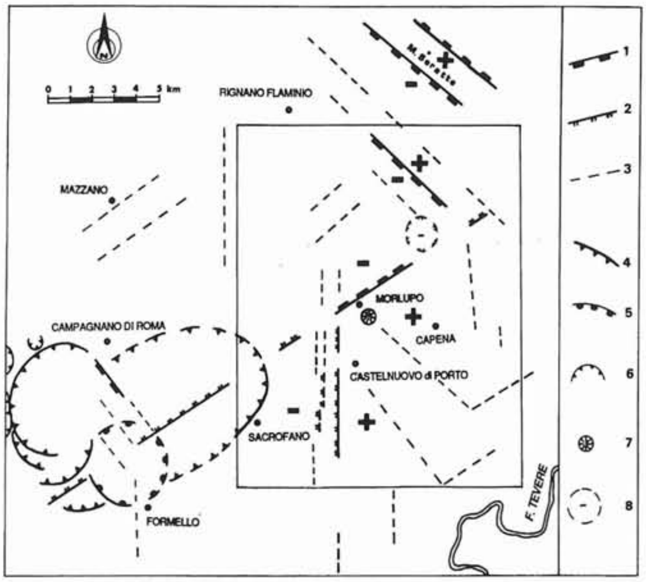


FIG. 5 - Morphostructural sketch of the eastern sector of Monti Sabatini volcanic complex. 1 - Faults; 2 - Supposed faults; 3 -Fractures; 4 - Caldera rim; 5 - Supposed volcano-tectonic depression rim; 6 - Crater rim; 7 - Trachitic lava outcrop; 8 - Depression of unknown origin. (From: CICCACCI & *alii*, 1989).

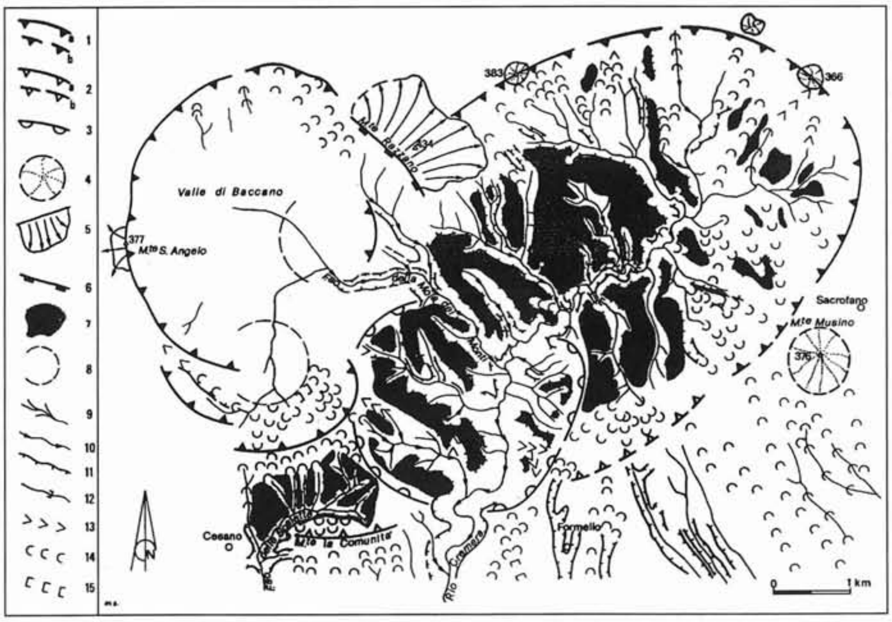
magmatic units (0.08-0.04 Ma). This collapse was accompanied by the faulting of the Monte Razzano tuff cone, the western downfaulted sector of which is now evidenced by the NW-SE trending fault scarp bordering the relief western slope. The Baccano products caused the progressive filling up of the Sacrofano depression; as a consequence, sub-horizontal structural surfaces originated which raised the caldera bottom and caused the drainage network rejuvenation. The evidence of the following phase of stream deepening is still recognizable in the fluvial erosion scarps which cut the Baccano products emplaced inside the Sacrofano caldera (fig. 6).

Inside the new caldera of Baccano a radial centripetal drainage network is likely to have developed. Moreover some lacustrine deposits at different heights, interbedded with fluvial and volcanic products, suggest that the calderic depression followed a complex evolutive path which available data cannot explain thoroughly. Certainly, in one stage of its evolution the depression was separated from the adjacent areas and became part of the Rio Cremera drainage basin only in a later phase. This latter event was probably made easier by the headward erosion of the Fosso delle Mola dei Monti which is likely to have emplaced along a NW-SE trending tectonic line. After this piracy event the drainage basin of Rio Cremera attained its present shape and extension.

The Bracciano depression area

The depression of Lago di Bracciano is the main feature of the central sector of the Monti Sabatini volcanic district. It cannot be interpreted like an emission centre but its origin has to be tied up to complex volcano-tectonic events which caused the progressive collapse of a wide area. The sinking of the depression started during the paroxysmal stage of the Sabatini volcanism, about 0.40-0.30 Ma, when the «Sabatian Red Tuff with black scoria» was erupted from NE-SW trending faults in the Vigna di Valle area to the South of the present depression (DE RITA & *alii*, 1996). Successively a widespread pyroclastic and lavic activity from several scoria cones occurred to the North of the present depression; moreover thick lava flows were erupted from feeding fractures, roughly oriented in the NE-SW and NW-SE directions.

FIG. 6 - Geomorphological map of the Sacrofano and Baccano volcanic depressions. 1 - Caldera rim: a = continuous, b = discontinuous; 2 - Caldera buried rim: a = evident, b = supposed; 3 - Subcircular depression edge of uncertain origin; 4 - Scoria cone; 5 - Tuff cone; 6 - Fault scarp; 7 - Structural sub-horizontal surface; 8 - Buried depression edge corresponding to thick volcanic breccias; 9 - Drainage network; 10 - River bed deepening; 11 - Fluvial erosion scarp; 12 - Knick along stream channel; 13 V-shaped small valley ; 14 - Trough-floored small valley; 15 - Flat-floored small valley. (From: CICCACCI & *alii*, 1988; modified).



During, or immediately after, the first phase of the Bracciano volcano-tectonic collapse, the Pizzo Prato, Vigna di Valle and Bracciano pyroclastic flow units were erupted from N-S and E-W fracture systems bordering the collapse area; these events took place approximately between 0.18-0.09 Ma and caused the further sinking of the depression. Successively pyroclastic fall and hydromagmatic products were erupted from local centres located to the North of the Bracciano depression (Monterosi, Trevignano, Monte Calvi). The final activity of this sector of the Sabatini volcanic district was mainly hydromagmatic and took place from the centres which border the eastern side of the Bracciano depression (Polline, La Conca and Lagusiello).

The morphological aspect of this central sector is surely dominated by the presence of scattered positive (scoria and lava cones) and negative (mainly explosive craters) volcanic forms, that exogenous processes have only slightly modified. Surface running waters are the most important of such morphogenetic agents; however their effectiveness is strongly reduced by the low relief energy observed throughout this sector. The crater rims, in fact, are often well preserved or easily reconstructable and the morphological boundaries of the volcanic products are still recognizable (fig. 7).

The shape of the lacustrine depression shows evidence of the control exerted on its collapse by the variously oriented tectonic directions; its roughly squared perimeter, 31.5 km long, is only locally interrupted by the circular rims of the most recent craters. The lake has a surface of 57 km^2 and a mean depth of 88 m; the maximum depth (–165 m) is attained in the south-eastern part of the depression. The isobath trend shows that the depression bottom is quite regular and that submerged volcanic forms are lacking (BARBANTI & CAROLLO, 1974). The drainage basin which contributes to the lake is 93 km^2 wide and is occupied by short and scarcely steep streams with a reduced solid load. The Fiume Arrone is the only effluent and comes out of the lake from its south-eastern side. The lake waters are presently scarcely polluted and are partly used for the hydric supply of the city of Roma.

REFERENCES

ALVAREZ W. (1973) - *Ancient course of Tevere river near Rome: an introduction to the Middle Pleistocene volcanic stratigraphy of Central Italy*, Geol. Soc. Am. Bull., 84, 749-758.

BARBANTI L. & CAROLLO A. (1974) - *Geomorfologia dei bacini lacustri.* In: «Indagini limnologiche sui Laghi di Bolsena, Bracciano, Vico e Trasimeno», Quad. Ist. Ric. sulla Acque, 17, 9-16, C.N.R.

BIASINI A., BUONASORTE G., CICCACCI S., FREDI P. & LUPIA PALMIERI E. (1993) - *Geomorphological characteristics.* In: «Sabatini Volcanic Complex», Quad. Ric. Scien., 11, 80-94, Cnr.

CARBONI M.G., CONTI M.A.. & ESU D. (1993) - *The neoautochthonous Cycles (Plio-Pleistocene).* In: «Sabatini Volcanic Complex», Quad. Ric. Scien., 11, 29-32, C.N.R.

CICCACCI S., DEL MONTE M. & FREDI P. (1990) - *Parco suburbano della valle del Treia: caratteristiche geologiche e geomorfologiche.* In: «L'ambiente della Tuscia laziale», 161-171, Università della Tuscia, Viterbo.

CICCACCI S., DE RITA D. & FREDI P. (1988) - *Studio geomorfologico delle depressioni vulcaniche di Sacrofano e Baccano nei Monti Sabatini (Lazio)*. Mem. Soc. Geol. It., 35, 833-845.

CICCACCI S., DE RITA D. & FREDI P. (1989) - *Geomorfologia quantitativa e Morfoneotettonica dell'area di Morlupo-Castelnuovo di Porto nei Monti Sabatini (Lazio)*. Geogr. Fis. Din. Quat., Suppl. 1, 197-206.

DE RITA D., DI FILIPPO M. & ROSA C. (1996) - *Structural evolution of the Bracciano volcano-tectonic depression, Sabatini Volcanic District, Italy.* In «Volcano Instability on the Earth and Other Planets», Geol. Soc. Special Pubbl. No. 110, 225-336.

DE RITA D., FUNICIELLO R., CORDA L., SPOSATO A. & ROSSI U. (1993) - *Volcanic units.* In: «Sabatini Volcanic Complex», Quad. Ric. Scien., 11, 33-79, Cnr.

LAURO C. & NEGRETTI G.C. (1969) - *Contributo alla conoscenza delle vulcaniti della regione Tolfetana, Cerite e Manziate. Il vulcanismo della Tuscia Romana: le manifestazioni vulcaniche del settore centro-occidentale*. Quad. Ric. Scien., 5, 1-39, Cnr.

THE GEOMORPHOLOGY AND THE SEISMIC RESPONSE OF THE CITY OF ROMA

(R. Funiciello, S. Donati, F. Marra & M. Parotto)

The historical centre of the city of Roma is characterized by the presence of two geomorphological domains: the alluvial plain of the Fiume Tevere and the topographic reliefs of the Colli Albani, where tradition indicates the first sites of the city foundation. In particular, the right river side is characterized by the outcropping of the regional bedrock along the Monte Mario-Gianicolo ridge, while the eastern reliefs are the remnants of the Sabatini and Albani volcanic plateau, deeply eroded by the articulated hydrographic network of the Tevere. These geomorphological domains are also characterized by a large difference in seismic response. The contrast in seismic response of the different sectors of downtown Roma is mainly linked to the impedance contrast between the geological units of the higher areas of the city and the coarse deposits of the lower alluvial plain of Fiume Tevere.

GEOLOGICAL SETTING

The geology of the area of Roma shows 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 Pliocene clays and the Pleistocene marine deposits (Monte Mario, Monte Ciocci and Monte delle Piche Units). Some regional structural features regulate the different outcrops of these sediments. During Upper Pleistocene, the intense tectonic activity and the climatic and paleogeographic changes related to the glacial and interglacial periods gave rise to a complex transgressive cycle characterized by the alternation of depositional and erosional phases. The sedimentation of Paleo Tevere units 1 and 2 is related to these phases. Starting from 0.6 Ma, Sabatini (NW of Roma) and Albani (SE) volcanic districts began to spread around their products. Tectonics, coupled to the widespread of a great amount of volcanic products, changed completely the geomorphology and hydrology of the Roman area, confining the Fiume Tevere to the present riverbed. In the last phase of the Würmian glacial period, the relevant eu-

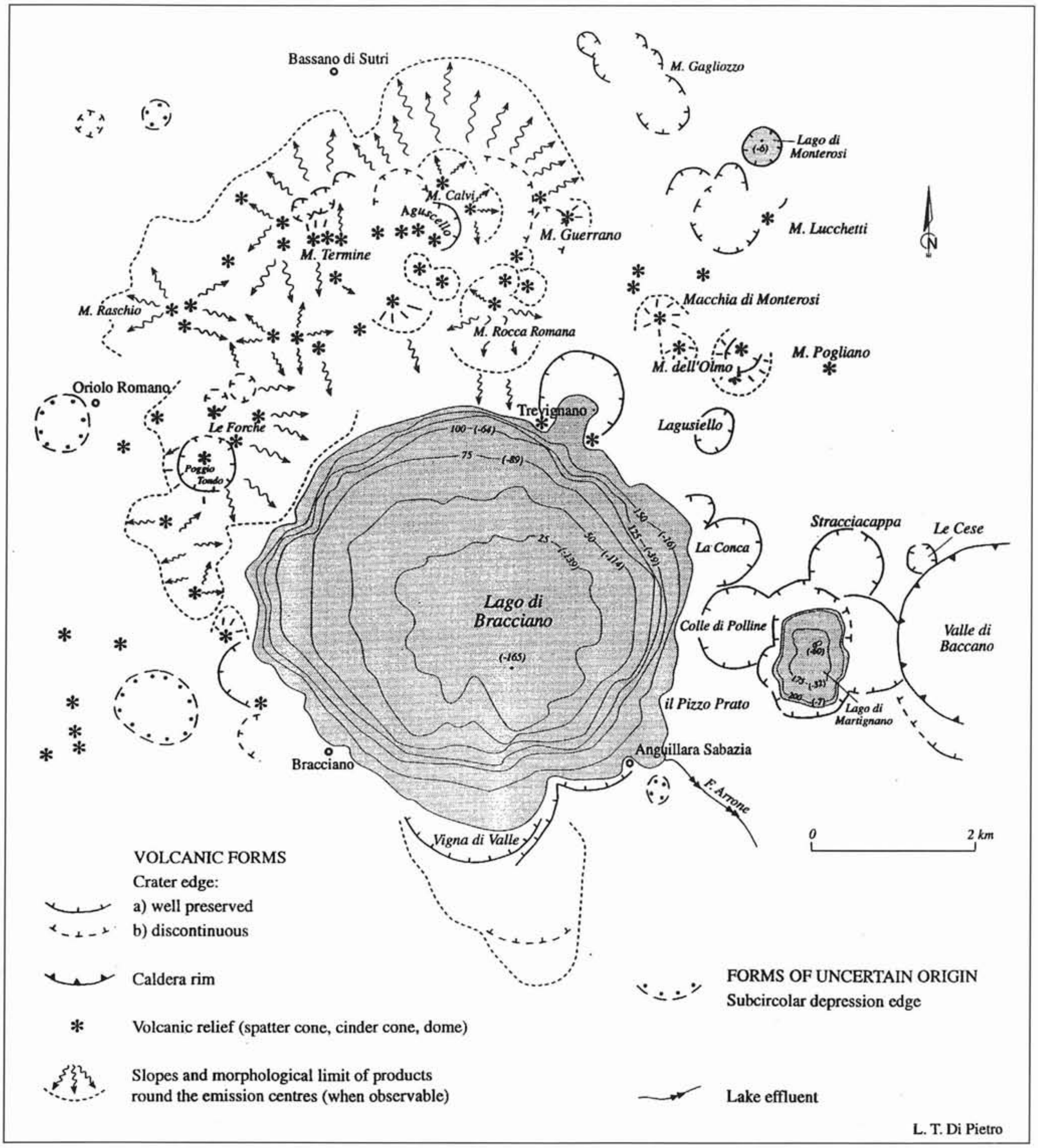


FIG. 7 - Map of volcanic forms of the Bracciano area.

static regression of the sea level accelerated the erosional process of the Fiume Tevere, excavating the Pliocene bedrock down to 50 metres below the sea level. During the subsequent rise of the sea level, the articulated network excavated by the Fiume Tevere 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 average).

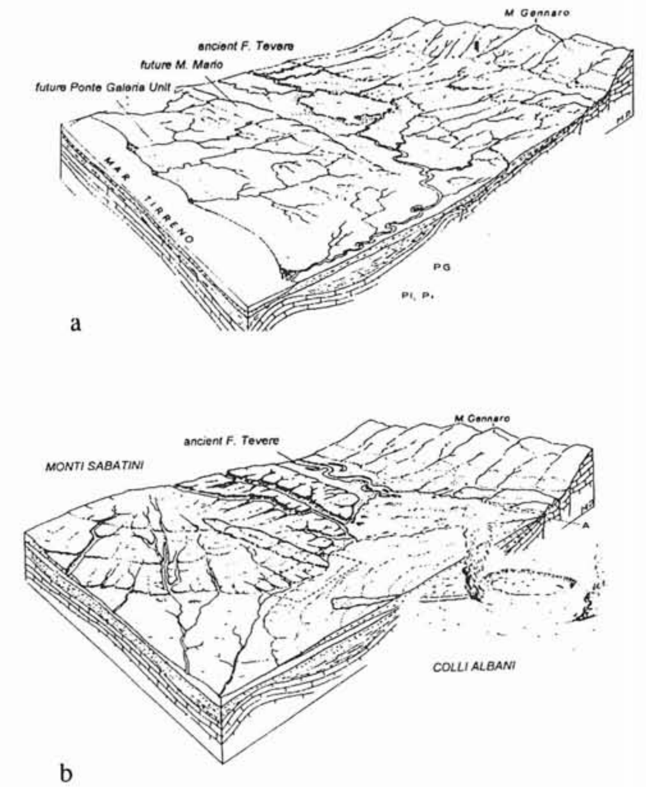


FIG. 8 - Paleogeographic evolution of the Roman area since Middle Pleistocene (800,000 years ago). a - The relief of Monte Mario comes out from a wide sedimentary mantle of sandy-gravelly deposits which is giving rise to the coastal belt. The ancient course of the Fiume Tevere has its mouth to the South of the oresent position (Pl, Pi = Pliocene and Pleistocene marine deposits; PG = Ponte Galeria Unit). b - Extent of Albani and Sabatini volvanic products and modification of the drainage pattern of the Fiume Tevere (A = Aurelia Unit). (In the dashed square is the area shown in fig. 9a).

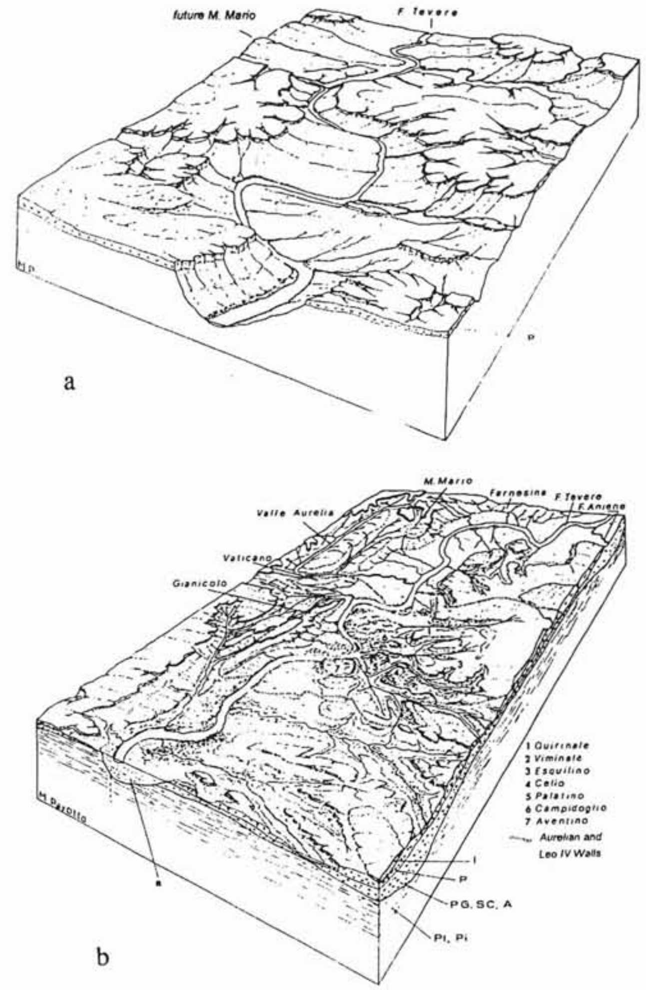


FIG. 9 - Geomorphological and geological sketch of the Roman area. a - Low stand of the sea level and deep erosion of the hydrographic network of the Fiume Tevere, confined in the present-day riverbed. The relics of the volcanic plateau represent the present day eastern topographic reliefs of Roma (P = Pyroclastic products). b - The Tevere valley is closed on the western margin by the Monte Mario-Gianicolo ridge, and, on the eastern portion of the town, by the relics of the volcanic plateau, the famous Seven Hills of Roma. During the Holocene high stand of the sea level, the recent alluvium fills the deep valley excavated by the FiumeTevere during the Würmian glacial period (a - recent alluvium; l = lava; SC = San Cosimato Unit).

SEISMOTECTONIC FEATURES

According to the Italian seismotectonic context, the seismicity of Roma is quite moderate. Nevertheless, during more than 2,500 years of history, it 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 record about ten events with intensity up to VII-VIII degree MCS, and more than 60 earthquakes felt by the population. Therefore, considering the existence in the urban area of both a priceless historical and monumental patrimony and extremely vulnerable old buildings, seismic risk cannot be neglected.

The city of Roma is mainly affected by the earthquakes associated with three different seismogenic districts: the Central Apennines area («regional seismicity»), the Colli Albani area («local seismicity») and the Roma area («urban seismicity»). The Apennine seismogenic sources, located between 60 and 130 km from Roma, produced the strongest intensity felt in the city (VII-VIII MCS). The Aquila 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, hypocentral depth between 5 and 10 km and felt intensity V-VI MCS. The urban seismogenic area, within a radius of 20 km, is characterized by a low frequency of occurrence, maximum intensity around VI-VII MCS, magnitude values probably less than 4 and maximum hypocentral depth around 12 km.

SEISMIC DAMAGE ANALYSIS

Many studies (AMBROSINI & *alii*, 1986; MOLIN & GUIDOBONI, 1989) had stressed the particular role of unconsolidated Holocene alluvial deposits in the areal distribution of seismic damage.

Thanks to the reconstruction of the geometry of the old hydrographic network of the Fiume Tevere, 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. 10). Almost 80% of the serious damage occurs in the Holocene alluvial area, tending to concentrate along the narrow bands close to the edges of the Tevere valley (edge effect), as well as near the major slope changes of topographic reliefs (topographic effect, see DONATI & *alii*, 1996). This percentage decreases to 60% for the weak damage, particularly influenced by the structural framework of buildings.

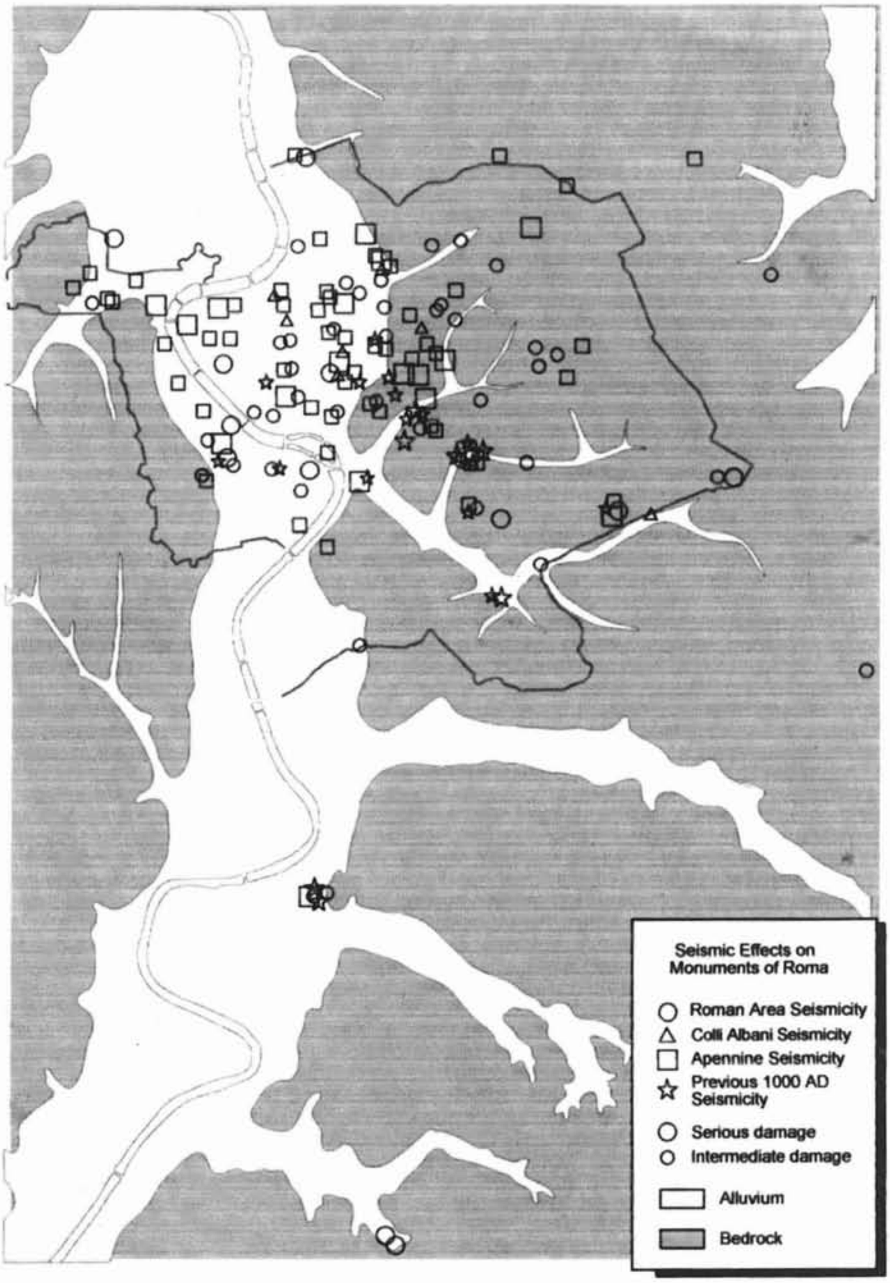


FIG. 10 - Distribution of seismic damage on the monuments of Roma for different seismogenic areas. The geological map of Roma (MARRA & ROSA, 1995) has been reduced considering exclusively the geotechnical heterogeneities of the outcropping units. According to this, marine and continental Plio-Pleistocene sedimentary units and Sabatini and Albani volcanic products have been unified in an undifferentiated unit (conventionally called bedrock).

These results have been then interpreted in terms of source and site effects through seismological models, taking into account the main physical characteristics of both source and nearsurface geology (ROVELLI & *alii*, 1995). The synthetic accelerograms obtained have shown the largest ground motion in those geological situations where observations have indicated the maximum concentration of heavy effects.

In a few specific cases, the detailed study of the local geology allowed seismologists to estimate ground motion produced by earthquakes. For the sake of example, the different level damage suffered by the two most important honorary columns in Roma, those of Trajan and Marcus Aurelius, located 700 m apart, suggested the occurrence of strong variations of ground motion across a narrow zone due to changes in the local geology. The columns, in fact, are very similar in architecture, age, size and building materials. The study by BOSCHI & *alii.* (1995) has inferred 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.

Even considering the Colosseum, that suffered several types of damage related to earthquakes, the damage distribution shows a significant correlation with the local geology: the largest effects are concentrated in the southern sector of the amphitheatre, where geological features (FUNICIELLO & *alii*, 1995) point out the presence of a Holocene alluvial valley, the Fosso Labicano. A geological numerical modeling (MOCZO & *alii*, 1995) inferred the large differential motions at the basement of Colosseum, finding the largest shaking at the transition from Pleistocene units to Holocene sediments, in agreement with the highest damage zone (southern external ring).

REFERENCES

AMBROSINI S., CASTENETTO S., CEVOLAN F., DI LORETO E., FUNICIELLO R., LIPERI L. & MOLIN D. (1986) - *Risposta sismica dell'area urbana di Roma in occasione del terremoto del Fucino del 13-1-1915.* Mem. Soc. Geol. It., 35, 445-452.

BOSCHI E., CASERTA A., CONTI C., DI BONA M., FUNICIELLO R., MALAGNINI L., MARRA F., MARTINES G., ROVELLI A. & SALVI S.(1995) - *Resonance of Subsurface Sediments: an Unforeseen Complication for Designers of Roman Columns.* Bull. Seismol. Soc. Am., 85, (1), 320-324.

DONATI S., FUNICIELLO R. & ROVELLI A. (1996) - *Seismic Response of the Historical Centre of Roma.* Mem. Soc. Geol. It., (in press).

FUNICIELLO R., LOMBARDI L., MARRA F. & PAROTTO M. (1995) - *Seismic damage and geological heterogeneity in Roma's Colosseum area: are they related?* Ann. Geofis., 38, 927-937.

MARRA, F. & ROSA C. (1995) - *Stratigrafia e assetto geologico dell'area romana.* In: «La Geologia di Roma Centro Storico». Funiciello R. (ed.), Mem. Descr. Carta Geol. d'It., 50, 50-1188.

MOCZO P., ROVELLI A., LABAK P. & MALAGNINI L. (1995). *Seismic response of the geologic structure underlying the Roman Colosseum and a 2-D resonance of a sediment valley.* Ann. Geofis., 38, (5-6), 939-956.

MOLIN D. & GUIDOBONI E. (1989). *Effetto fonti effetto monumenti a Roma: i terremoti dall'antichità ad oggi.* In: «I terremoti prima del Mille in Italia e nell'Area Mediterranea». ING, a cura di E. Guidoboni, Bologna, 194-223.

ROVELLI A., MOLIN D., MALAGNINI L. & CASERTA A. (1995). *Variability of damage pattern in Roma: combination of source and local effects.* Proceedings of the 5th Internat. Conf. on Seismic Zonation, Afps-Eeri, Nice, France, II, 1359-1366.

THE EVOLUTION OF THE FIUME TEVERE DELTA

(C. Caputo, P. Bellotti, G.B. La Monica, B.Landini,
S. Milli & F. Pugliese)

The Fiume Tevere drains a wide area of the Central Apennines; in its basin (17,156 km^2), carbonate, siliciclastic, and volcanic rocks crop out. Its subaerial delta plain (about 150 km^2 large) extends inland for 13 km and along the coast (from NW to SE) for 30 km. Sediments cropping out in the hills bordering the plain have been carried by this river in the last 900,000 years. They were deposited in fluvial, coastal-lagoonal and marine environments.

During that time the geological evolution of the coastal sector was very complex and the stratigraphic organization of the sedimentary succession was controlled by two coeval processes: sea-level variations connected to Pleistocene climatic changes, and tectonic uplift due to the extensional tectonics of the Tyrrhenian margin. Variations occurred during Holocene are mainly connected with glacioeustatic sea-level rise, while those which followed during historical and present times are chiefly controlled by human settlement and activity.

ANCIENT TIMES

Facies and stratigraphic analysis of the Pleistocene deposits (MILLI, 1992, 1994) of the Fiume Tevere delta (fig. 11), made it possible to subdivide the sedimentary succession into nine stratigraphic-depositional units (depositional sequences), each with a duration of about 100,000 years and bounded by unconformity surfaces. The basal unconformities of these units are connected to glacio-eustatic sea-level falls and are correlated to oxygen isotopic stages 22, 18, 16, 14, 12, 10, 8, 6 and 2. The «Tevere Sequence» is the most recent one and its deposition is still ongoing. It began when the relative sea-level rise following the last sea-level fall (stage 2) started.

The best outcropping depositional systems belong to the first three depositional sequences, whose age is comprised between 0.87 and 0.55 Ma. They are characterized by facies and facies associations of fluvial, lacustrine-lagoonal and marine environment. The fluvial sediments are mainly represented by a sandy-gravelly lithofacies, and subordinately by a sandy lithofacies. Gravel shows a curved non-parallel bedding with surfaces of different hierarchical order. These sediments are the product of the deposition in a braided fluvial environment and both channel aggradation and lateral migration are responsible for their tabular geometry. The sandy lithofacies is characterized by small and gently curved non-parallel bedding due to ripples and dune (lower flow regime) and by an even-parallel bedding formed during upper flow regime connected to flood events. The sandy lithofacies overlays the sandy-gravelly one giving rise to fining-upward sequences which evidence channel infill. In other cases, sand is laterally associated with gravel; these deposits have been interpreted as due to overbank processes. In places, the gravel deposits show lateral accretion surfaces and are interpreted as gravelly point-bars. These deposits indicate the presence of meandering channels coeval with the braided ones and both occurring along a gently sloping coastal plain.

The lacustrine-lagoonal deposits are represented by lacustrine mud at the bottom and by lagoonal mud towards the top. This environmental change is evidenced only by micro- and macrofaunal variations. At the base, fresh-water ostracods and an oligotypic association of pulmonate gastropods are present. Upsection, they are substituted by an oligotypic Ammonia association typical of brackish water, and in the uppermost levels by an abundant fauna of brackish and marine environments.

The marine deposits are represented mainly by clinostratified sandy-gravelly sediments organized in progradational beach sequences. It was possible to distinguish four subenvironments: backshore, upper beachface, lower beach-faced and shoreface. Many quarries allowed to single out the dip angle of clinostratification surfaces and consequently the depositional strike (from NW-SE to NNW-SSE), i.e. the orientation of the paleo-shoreline which approximately is parallel to the present one.

The backshore deposits are rarely preserved and are characterized by two main facies. The first is constituted by pedogenized reddish sands interpreted as aeolian deposits. The second facies, mainly gravelly-sandy, is present inland from and close to the berm crest and has been interpreted as connected to overwash processes during storms.

The upper and lower beachface sediments constitute the clinostratified body of the beach. In the upper beachface the bedding dip angle is about 2°-3° and gradually decreases upslope and increases downslope (in the lower beachface) where it varies from 8°-9° up to 15°. In the upper beachface the sandy and gravelly sedimentation shows a remarkable segregation of clasts which are separated into different beds. Gravel shows a high sorting and a well-developed seaward imbrication. Beds are thin, parallel, laterally continuous and seaward-dipping. In the lower beachface sandy and gravelly beds are more discontinuous and are bounded by sharp and erosional contacts. The sandy beds show a landward-dipping lamination, while the graveley beds show a disorganized texture indicative of a transport mechanism connected with flows moving downslope and due both to the influence of gravitational force and backwash. Such flows were enhanced during storm events.

The shoreface environment may be subdivided into upper shoreface and lower shoreface. The upper shoreface sedimentation is characterized by an interfingering of layers of medium-fine sand and gravel. The sandy beds show mainly a landward-inclined lamination, while the gravel beds, more discontinuous, are texturally disorganized and characterized by an extreme variability of the pebble grainsize and shape. The lower shoreface deposits are mainly represented by fine and very fine sands showing a hummocky cross-stratification. These sands are locally highly bioturbated and completely homogenized.

Beach deposits are laterally and vertically substituted by lagoonal mud characterized by brackish micro- and macrofaunal assemblages. Sandy and shelly levels are interbedded in the mud; they have been interpreted as the product of storm events.

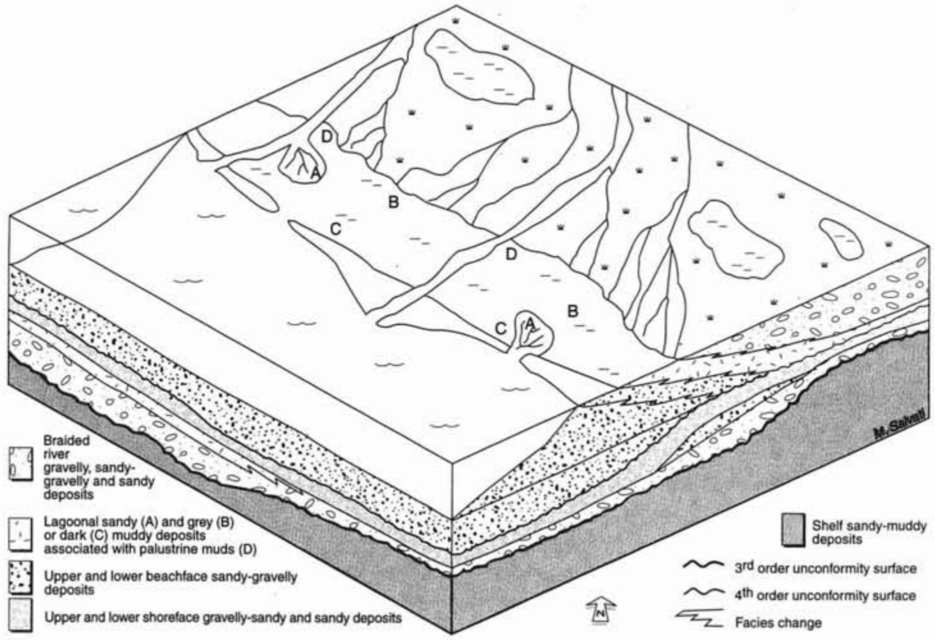


FIG. 11 - Paleogeographic scheme and depositional setting of the area surronding Roma during the Early-Middle Pleistocene.

RECENT TIMES

The sedimentation of the recentmost stratigraphic-depositional unit (the «Tevere Sequence») and therefore the delta evolution during the last 20,000 years ca. has been reconstructed through the analysis of more than 200 cores and some radio-carbon datings. Stratigraphic reconstruction of the submerged part is based on a series of high-resolution seismic profiles (BELLUOMINI & *alii*, 1986; BELLOTTI & *alii,* 1994; BELLOTTI, 1994). This made possible to reconstruct the distribution in space and time of facies belonging to the delta body and thus to outline some evolutive steps (fig. 12).

About 18,000 yrs. BP, when the sea level was 120 m lower, the Fiume Tevere was flowing in a valley whose coastal stretch was trending NE-SW and not far from the modern water-course. This stretch is now below the present delta-plain sediments (60 to 80 metres thick). The river mouth was at about 10 km to the West of the present one. Changes occurred as from that time are mainly due to the glacioeustatic sea level rise and to the change in time of the river mouth position. The general subsidence of this area was negligible.

The first scenario dates back to about 12,000 yrs. BP, when the rising sea level (about 10 mm/yr) was at -70 m as to the present level. The sea flooded the end of this steep-sided valley forcing back the river mouth for several kilometres. It gave rise to a lagoon extending lengthways the palaeovalley axis and closed by a widely channeled narrow sandy bar. The river discharge was into the lagoon, but its load was inadequate to compensate for the sea level rise; therefore the mouth-lagoon-bar system was constantly moving back.

About 9,000 yrs. BP the sea level had reached -30 m; the divides of the paleovalley were overflooded and therefore the lagoon - much wider - changed its shape becoming parallel to the coast (NW-SE) and intercepting other less important streams. The lagoon was bordered seawards by a series of sand islands with channels allowing communication with the sea. Inside this large lagoon the Fiume Tevere was building up its delta which was allowed to migrate, yet being restricted to the lagoon. During the same period in the lagoon another delta was originating by means of a smaller river load, possibly the Fiume Arrone. Nowadays this river flows directly into the sea at about 10 km to the North of the Fiume Tevere. This small delta seems to have been active for about 3,000 years and, when no more active, it was rapidly submerged.

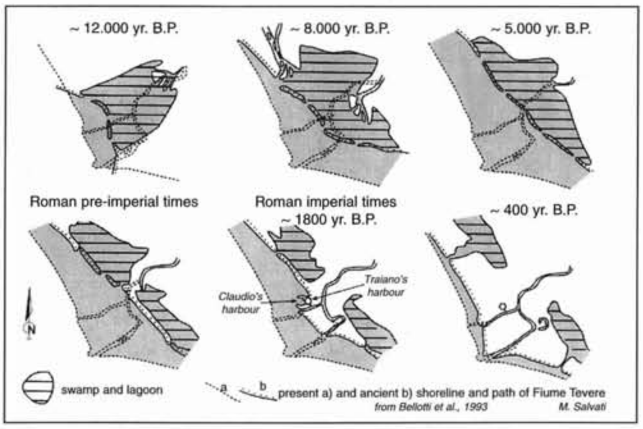


FIG. 12 - Evolutive scenarios of the Fiume Tevere during the rise and following stabilization of the sea level. Note the change in the lagoon orientation occurred between 12,000 and 5,000 yrs. BP, and its subdivision in pre-Roman times in two basins which lasted as relics up to recent times. The last scenario shows the small oxbow lake of the Fiume Tevere which originated in September 1557, after one of the most important floods in Renaissance times.

In the last about 1,000 years of this interval, the rates of the sea-level rise decreased more and more till the sea level stabilized about 5,000 yrs. BP. The relevant scenario shows a large lagoon well paralleling the coast, a well defined bar and the Fiume Tevere building up its delta inside the lagoon. Stabilization of the sea level changed completely the equilibrium. About 3,000 yrs. BP, with a sea level being almost stable, the lagoon fill with the Fiume Tevere load began and for this reason the lagoon-delta body rapidly prograded towards the bar. It is not well known when the delta body tied up to the bar so dividing in two the original lagoon, but in Roman times this surely had already occurred.

The early imperial Roman period sees a new scenario: the Fiume Tevere has a sea mouth and by that time the two lagoons were isolated from the river. The impressive harbour works of Claudius and Trajan date back to this period; the latter emperor seems to have opened the artificial canal which gave rise to the present mouth of Fiumicino. The ancient bar changed into a nearly continuous true barrier beach and both lagoons had only few and narrow outlets.

It is therefore that during the past 2,000 yrs. the Fiume Tevere has built up its sea delta. The delta prograded by alternating stages of erosion and accumulation throughout the Middle Ages, while progradation became continuous from the 16th to the 20th century. Archaeological remains and historical records allow a good reconstruction of different stages of post-Roman delta progradation. Following this progradation the original lagoons changed gradually into ponds farther and farther away from the sea, but still linked to the sea at least by one outlet. Reclamation of the pond area took place at the end of the 19th century and at present this area is artificially drained to avoid inundation of zones below the mean sea level.

The present-day delta (fig. 13) developed after the stabilization of the sea level and its subaerial area can be differentiated in two parts. The inner delta plain shows an extremely flat morphology and coincides with the ancient lagoons and ponds; sediment is mainly mud. The outer delta plain is characterized by sandy deposits arranged in beach ridges overlain by dune belts to evidence the delta progradation. The morphology of the delta plain and the distribution and texture of the sediments are typical for a wave-dominated delta. The submerged delta is nourished by the fluvial hypopycnal flow and is made of a delta front extending from the shoreline to –25 m, and a prodelta reaching –115 m. The delta front has a gentle slope (0.3°) and is wa-

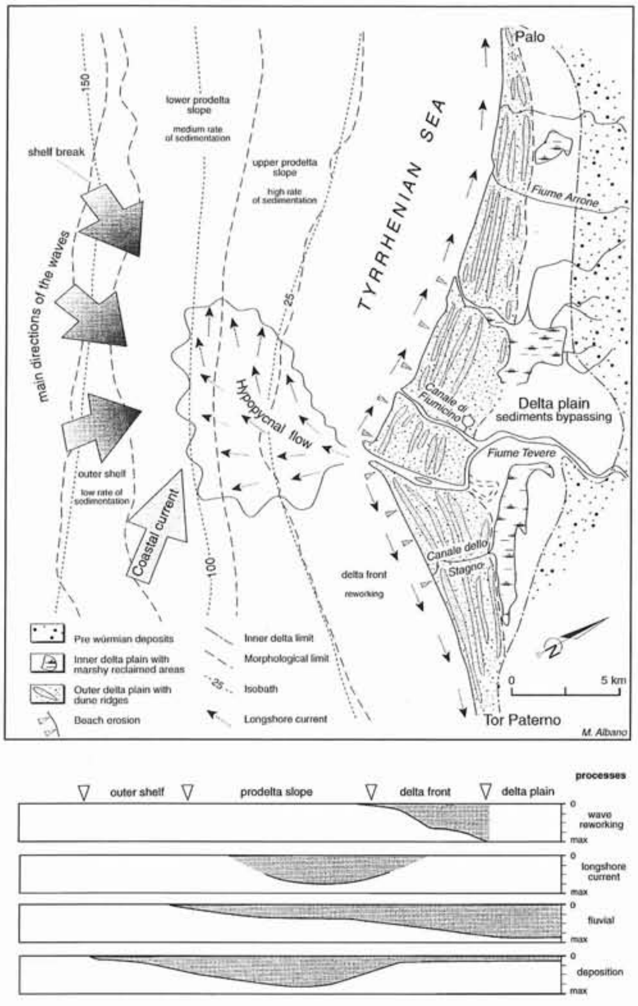


FIG. 13 - Morphological scheme of the Fiume Tevere delta. The ongoing sedimentary processes are evidenced. (After BELLOTTI & *alii*, 1994).

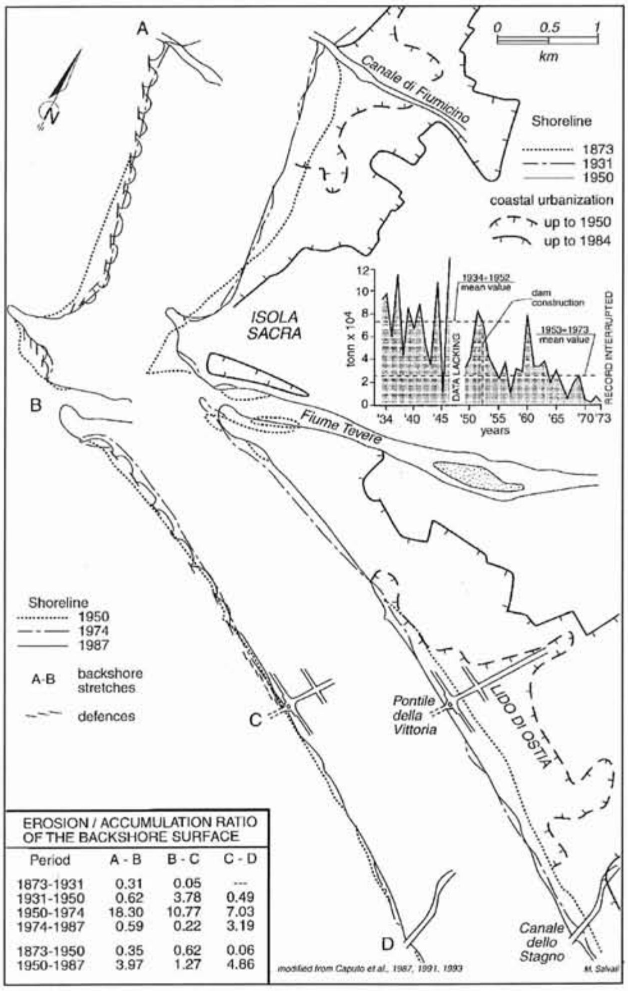
ve-dominated by longshore currents reworking and arranging the river sandy load. The prodelta slope reaches 1° and here the sedimentation is passive and due to the flocculation of the finest suspended materials.

PRESENT TIMES

During the past 100 years (fig. 14) the Fiume Tevere delta has undergone marked changes, evidenced by the delta apex shoreline shifting. The very detailed reconstruction of the beachline movement has been made possible by using large scale topographic maps edited by the IGMI (Istituto Geografico Militare Italiano) and by periodic aerial photographs.

Between 1873 and 1950, the prevailing process was the beach progradation, except for the two delta lobes which were affected by erosion. More in detail, maximum progradation (about 300 m) occurred close to Canale di Fiumicino, and to the South of Pontile della Vittoria (about 200 m). However it must be noted that in many places both the 1931 and 1950 shorelines have the same position. Between 1930 and 1950 period, while the sectors A-B and C-D (fig. 14) record an overall stability, marked erosion affected the beach stretching from the river mouth to Pontile della Vittoria.

During the following period (1950-1974) erosion prevailed along the shore from Canale di Fiumicino to Canale dello Stagno; maximum beachline retreat has been recorded close to the Fiume Tevere mouth (up to 250 m). Taking into account the ratio between eroded and accumulated areas, it turns out that during this period erosion has been from 7 to 18 times higher than accretion (table in fig. 14). Among main causes of this severe erosion the heavy mining of the Fiume Tevere bed and the decrease of its load undoubtedly may be considered. It is significant that, starting from 1952, the suspended load decreased of about 40% owing to the dam at Castel Giubileo to the North of Roma (fig. 14). Erosion of the shore caused heavy damages especially to the coast roads and to the



EROSION / ACCUMULATION RATIO OF THE BACKSHORE SURFACE

Period	A - B	B - C	C - D
1873-1931	0.31	0.05	---
1931-1950	0.62	3.78	0.49
1950-1974	18.30	10.77	7.03
1974-1987	0.59	0.22	3.19
1873-1950	0.35	0.62	0.06
1950-1987	3.97	1.27	4.86

FIG. 14 - Shoreline changes from 1873 to 1987. The table shows values of the erosion/accumulation ratio of the backshore surface for the different periods considered.

many bathing establishments; therefore, as from the end of the Seventies, it was tried to face this critical situation by offshore breakwaters. Between 1974 and 1987, the so protected A-B and B-C sectors recorded a stop of the erosion followed by a shore progradation in the breakwater's shadow area. At the same time, downdrift the protected area the beachline adjustment lead to severe erosion along the sector C-D (from Pontile della Vittoria to Canale dello Stagno), where beaches were already very narrow and low. Also owing to some severe storms, during the second half of the Eighties, heavy damages to bathing establishments as well as to the coast road have been recorded.

To complete the framework of the shoreline variations of the Fiume Tevere delta it is worthy to take into account the shore modifications also along the delta wings not shown in fig. 14 (CAPUTO & *alii*, 1991). Most important changes have been recorded along the area about 20 km to the North of Canale di Fiumicino and 10 km to the South of Canale dello Stagno. Between 1873 and 1950 both sectors recorded a prevailing beach progradation, slightly more pronounced along the northern stretch (linear average accretion of about 145 m in 75 years) than along the southern one (about 126 m). During the following 1950-1987 period accretion was the prevailing process along the shore to the North of Fiumicino, even if during the last years of this period an evident erosion started, then spreading more and more to the North. The crisis should be connected with the building of shore defences immediately to the South. For the same 1950-1987 period the shore stretching to the South of Canale dello Stagno records a beach progradation, even if during the 1950-1974 period erosion was active along its northern end.

At the end of the Eighties the beach retreated so far inland to destroy the beaches to the South and close to the river mouth. This situation induced the Office of the Civil Engineers for Maritime Works to plan the restoration of the beach SW of Roma (Lido di Ostia) through a nourishment improved by a submerged breakwater.

The beach restoration started in May 1989 and lasted one year. The beach that has been restored is 3 km long and stretches from 500 m West of Pontile della Vittoria (where the offshore breakwaters start, ending at the river mouth) to Canale dello Stagno.

The protective beach was designed also on the ground of results supplied by an one-line mathematical model which was considered as a valid tool for short/medium forecasting time (1 to 10 years), thus suitable for the time-space scale of the work to undertake.

The beach (fig. 15) is open to seas from 132° to 304° and effective fetches range from 185 km to the West to 370 km to the South. The most frequent winds are from West (16.3%) being also the speediest; other wind directions are from South (11.4%), SW (10.3%) and SE (7.5%). Statistic wave direction falls within the sector 220°/250°. The longshore drift is to SE and rapidly decreasing moving away from the river mouth.

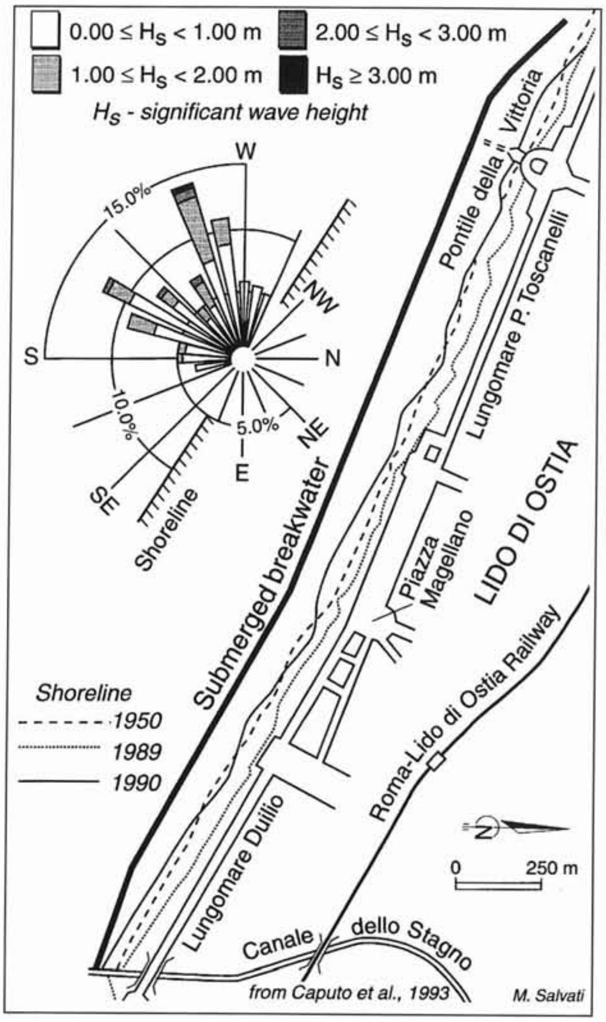
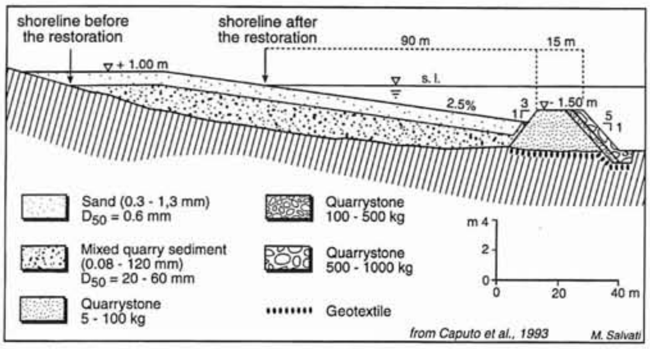


FIG. 15 - Map of the nourished beach. Recent changes in the shoreline position are represented together with wave-climate data recorded during 1990/91.

In the nearshore zone the slope decreases from 7% at the foreshore to 3% at a depth of –2 m ÷ –4 m, to 1% at the outer shoreface. Mean grainsize at the foreshore is 0.35/0.40 mm, 0.10 mm at a depth of –10 m.

The intervention was innovatory and experimental for the Italian shores; it was designed to restore and widen the existing beach and to improve the artificial filling by a submerged breakwater as long as the protective beach, acting as a natural bar and able to dissipate some of the energy of the incoming waves. This artificial bar (fig. 16) has been built about 160 m far from the beachline and at a depth of about 4 m. It has been built with natural stones varying in weight from 5 to 100 kg; seaward it is covered by 100 to 500 kg stones underlying the 500 to 1,000 kg stony armours. The top of the bar is at –1.5 m and is 15 m wide.

The filling behind this bar is made of a double layer. For the lower one, natural quarry gravelly-sandy sediment with grainsize varying from 0.08 to 120 mm (D_{50}=20-50 mm) has been used. The upper layer is 1 m thick and is made of a natural quarry sand with 0.3 to 1.3 mm grainsize



from Caputo et al., 1993

M. Salvati

FIG. 16 - Beach nourishment at Lido di Ostia: design cross section.

(D_{50}=0.6 mm). The gravelly-sandy as well as the sandy borrow material comes from quarries opened in Pleistocene marine and fluvial deposits cropping out at the border of the delta plain (fig. 13). The lower layer leans on the landside of the bar acting as a filter to prevent loss of the overlying finer sediment through the voids between the larger stones.

The one-line mathematical model and the qualitative diagrams «shoreline retreat vs. time» forecasted a fundamental dynamic equilibrium to be reached by this structure already within its first 5 operating years.

The planimetric trend after 10 years provides for an adjustment with a small clockwise rotation of the beach which is retreating sensibly off the Pontile della Vittoria, where it acts as an undernourished beach. The central part may be considered as fundamentally stable, while the section leaning on the downdrift jetty at Canale dello Stagno is prograding and its orientation is normal to dominant waves.

Stability experiments using a two-dimension physical model (scale 1:15) have evidenced a good static stability of the bar armour units, and a limited erosion of the beach profile with an increase of the foreshore slope. The computed loss of the borrow sediment has been 6 m^3/m of beach-line during the first year, but is quickly decreasing in time. Monitoring showed a behaviour consistent with the results of modelling. During the severe storms of December 9-10, 1990 (H_s=4.2 and recurrence interval of 10 years), the backshore was raised about 0.5/1.0 m and the foreshore slope reached 7-8%.

REFERENCES

ALESSANDRO V., BARTOLINI C., CAPUTO C. & PRANZINI E. (1990) - *Land use impact on Arno, Ombrone and Tiber deltas during historical times.* In: «Littoral 1990, Compte rendue du 1er symposium international de l'Association européenne Eurocoast», 261-265, Marseille.

BELLOTTI P. (1994) - *Sedimentologia ed evoluzione olocenica della laguna costiera presente un tempo alla foce del Tevere.* Atti 10° Congr. A.i.o.l., Alassio 4-6 novembre 1992, 633-642.

BELLOTTI P., CHIOCCI F.L., MILLI S.,TORTORA P. & VALERI P. (1994) - *Sequence stratigraphy and depositional setting of the Tiber Delta: Integration of high resolution seismic, well logs, and archeological data.* Journ. Sedim. Res. B64 (3), 415-432.

CAPUTO C., CHIOCCI F.L., FERRANTE A., LA MONICA G.B., LANDINI B. & PUGLIESE F. (1993) - *La ricostruzione dei litorali in erosione mediante ripascimento artificiale e il problema del reperimento degli inerti.* In: «La difesa dei litorali in Italia» (a cura di AMINTI P. & PRANZINI E.), 121-151, Edizioni delle Autonomie, Roma.

CAPUTO C., D'ALESSANDRO L., LA MONICA G.B., LANDINI B. & LUPIA PALMIERI E. (1991) - *Present erosion and dynamics of Italian beaches,* Zeit. Geomorph., N.F. Suppl.-Bd. 81, 31-39.

FERRANTE A. (1988) - *La ricostruzione della spiaggia del Lido di Ostia. Criteri metodologici e risultati della modellistica.* Giorn. Genio Civile, 10, 11, 12, 239-257, Poligrafico e Zecca dello Stato, Roma.

MILLI S. (1992) - *Analisi di facies e ciclostratigrafia in depositi di piana costiera e marino marginali. Un esempio nel Pleistocene del Bacino Romano.* Unpublished «Tesi di Dottorato di Ricerca», Università degli Studi di Roma «La Sapienza», 215 pp., Roma.

MILLI S. (1994) - *High-frequency sequence stratigraphy of the Middle-Late Pleistocene to Holocene deposits of the Roman Basin (Rome, Italy): relationships among high-frequency eustatic cycles, tectonics and volcanism.* In: «Second High-Resolution Sequence Stratigraphy Conference, Tremp, Spain 20-27 June 1994», (convenors POSAMENTIER H.P. & MUTTI E.), (Abstract volume), 125-129.