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Guide for the excursion

VOLCANISM, TECTONICS AND RECENT GEOMORPHOLOGICAL CHANGE IN THE BAY OF NAPOLI

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1 - PREMISE

This Field Trip has the double aim of illustrating (i) the recent geological and geomorphological evolution of the Gulf of Naples and (ii) the environmental and social impact of accelerated phenomena directly or indirectly related to volcanic activity. The trip starts from Naples (morning of Sept. 5) and arrives back at the same city (afternoon of Sept. 8) after a clockwise journey around the Gulf that is made partly on land - by bus - and partly on sea, by boat. The following Chapter 2 accounts briefly for the geological setting and the Quaternary evolution of the area around Naples. A short description of the field trip and its main points of interest is given in Chapter 3. More information and illustrations will be provided to the participants during the trip itself.

2 - GEOLOGICAL SETTING AND QUATERNARY EVOLUTION OF THE AREA
(L. Brancaccio, A. Cinque & A. Milia)

The Gulf of Naples lies in the southern part of a much wider tectonic depression (hereinafter referred to as the Campanian Depression, or CD) which also hosts the Campanian Plain and opens towards the Tyrrhenian Sea abyssal plain (fig. 1). Together with other similar features of the western flank of the Italian peninsula, said depression represents an effect of the back-arc extension that accompanied the NE verging accretion of the Apenninic thrust belt during the roll-back of the subducting foreland plate (Adria). As the growing orogenic wedge migrated towards the retreating foreland, the front of the Tyrrhenian extension also migrated northeastward, causing repeated truncations of the inner wedge and tectonic retreat of the coastline (i.e. submersion of slices of the wedge). As far as the Southern Apennine is concerned, the period of wedge accretion goes from Middle-Late Miocene to the end of Early Pleistocene, younging generally from the SW to the NE. In the area of the CD the first stage of lowering and submersion (Early Pleistocene in age) was probably controlled by a NE-SW extension, while a following one (Middle Pleistocene) responded mainly to a NW-SE extension. Normal faults inherited from both those stages were then reactivated during Late Pleistocene and Holocene phases of subsidence and uplift, especially in the zone affected by volcano-tectonics.

The reliefs that bound the CD reach up to 1,500 metres a.s.l. and are composed mainly of carbonatic rocks (Middle Triassic to late Cretaceous dolostones and limestones) organized in thrust-sheets piled up during the Late Miocene. Trapped along the thrust planes and, more rarely, on top of the highest carbonatic unit, relics of soft

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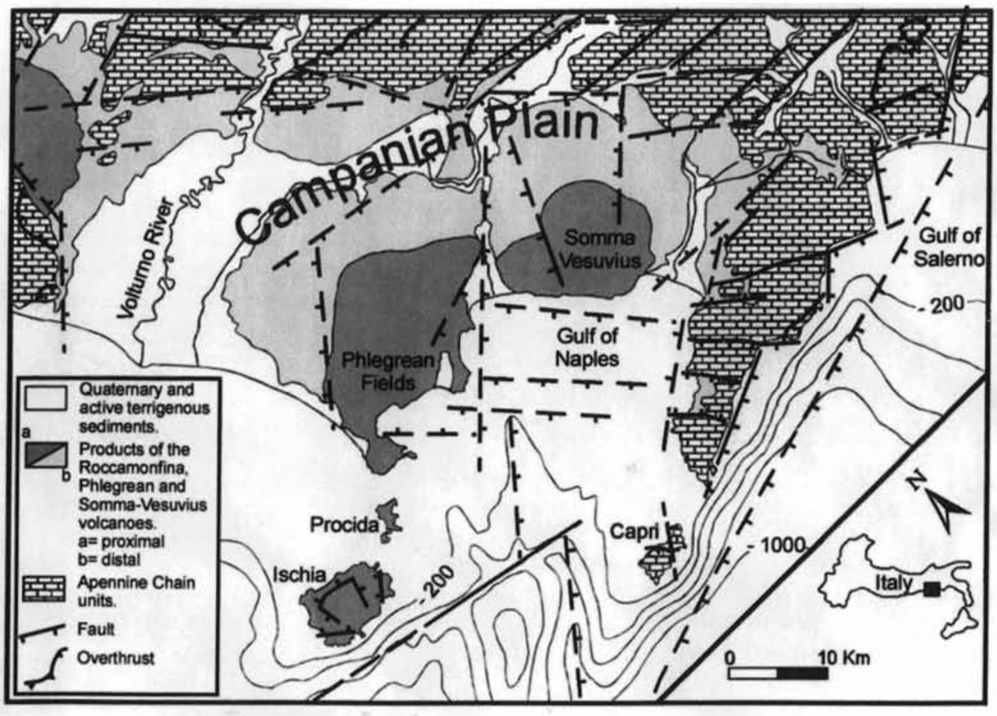

FIG. 1 - Schematic geological map of the Campanian depression.

syn-orogenic terrigenous formations (Miocene calcarenites and arenaceous flysch) are also found. Below the Piana Campana depression the above mentioned units are deeply buried under Quaternary sediments, reaching a maximum depth of about 3.5 km b.s.l.. Near the mouth of the Volturno River, sediments not older than the Emilian (a biostratigraphic stage ranging from about 1,45 to 1,15 Ma) were drilled up to 3000 m b.s.l.. A well drilled near the base of Vesuvius (were the chain units are depressed at 1,600m b.s.l.) encountered marine sediments of 0.9-1.1 Ma at 1,300 m b.s.l.. Based on these data, Quaternary mean rates of subsidence of 1.2 to 3 m/ka can be calculated for the CD.

High resolution seismic profiles taken within the Gulf of Naples clearly show that the sedimentary wedge forming the present continental shelf started growing at the beginning of Middle Pleistocene, when the floor of the CD (already occupied by Lower Pleistocene marine formations) was affected by NE trending normal faults and associate tilting of fault-blocks. Six glacial-eustatically controlled cycles of progradation are detectable within the Middle-Late Pleistocene sedimentary wedge.

The Pliocene-Pleistocene tectonic behaviour of the calcareous reliefs bounding the Campana Depression is difficult to reconstruct in detail because of the almost total lack of raised marine formations younger than the Late Miocene. However, it seems that their uplift started before the onset of subsidence in the coastal area, probably as a consequence of Pliocenic phases of contraction and duplexing of the orogenic wedge. Important phases of uplift and block faulting did probably occurr during the Early Pleistocene. After that, some sectors of the bordering mountainous region started subsiding and had their valley bottoms filled by thick alluvial and lacustrine deposits (e.g. the Volturno River and Solofrana River valleys). Other sectors, on the contrary, continued to rise -though at a slower rate- also during the Middle Pleistocene (e.g. the Caserta, Nola and Sarno Mts.; the Surrentine Peninsula). Starting from the Last Interglacial a substantial vertical stability characterizes all the structural highs that bound the CD.

The latter, on the contrary, has continued to subside also during the Late Quaternary, so that the entire Campanian Plain was transgressed by the sea during the Last Interglacial high stand. In fact, beach deposits of this age (Tyrrhenian Stage) have been drilled even near the base of the mountains bounding the Plain to the NE.

The first regressive peak of the Last Glacial resulted in about 30 km of south-westward advance of the coastline, which moved in fact near the present position of the shelf-break. This emersion was then reinforced by the growth of the first volcanic reliefs in the area around Naples and consequent pyroclastic aggradation of the surrounding plain. In particular, the eruption of the Campanian Ignimbrite (hereinafter CI) carpeted the whole plain with 20 to 60 meters of a welded grey tuff around 37,000 yrs ago. As some seismic profiles taken in the Gulf suggest, the CI was erupted also through a NW trending fault (i.e. the Napoli-Vico Equense Fault) that allowed the ou-

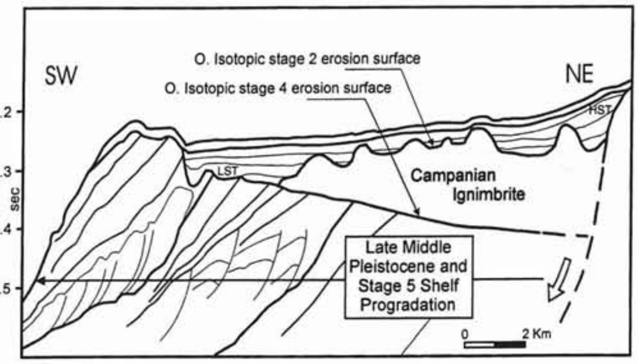

FIG. 2 Interpreted line-drawing of a seismic profile perpendicularly cutting across the continental shelf off the Vesuvius coast (modified after A. Milia, 1997).

ter portion of the coastal plain to tilt down toward the NE and accomodate a wedge of pyroclastics that has a maximum thickness of about 150 meters (fig. 2). This tilting block -which moved also after the CI eruption- was laterally limited by NE trending normal faults located along the northern coast of the stable Surrentine Peninsula and along the opposite side of the Gulf of Naples (e.g. the Acerra-Dohrn Canyon Fault). Field evidence and drilling data prove that this second fault has been active both after the implacement of the CI and after the eruption of the Neapolitan Yellow Tuff (hereinafter NYT), emitted from the Phlegrean Fields some 12,000 yrs BP.

Though modified by later volcanic, volcano-tectonic, erosional and depositional phenomena, the present plan outline of the Gulf of Naples still substantially reflects the sub-rectangular shape of the depression created by the above mentioned syn-post-CI tectonism. However, this depression (like the rest of the Plain) remained in subaerial conditions during the strong glacial-eustatic regression of the Oxigen Isotopic Stage 2. It was only upon the strong and rapid Post Glacial rise that the depression was deeply transgressed by the sea and the present gulf appeared.

3 - DESCRIPTION OF THE FIELD TRIP

3.1 - FIRST DAY

(A. Cinque, G. Robustelli, D. Sgambati & F. Russo)

3.1 a - *From Naples to Torre del Greco*

On leaving Naples we note that the historical part of this town (whose core dates back to Greek-Roman times) lies on a hilly landscape representing the faulted and eroded flank the Phlegrean Fields volcanic complex. (see # 3.4.a). The modern, eastern periphery of Naples lies, on

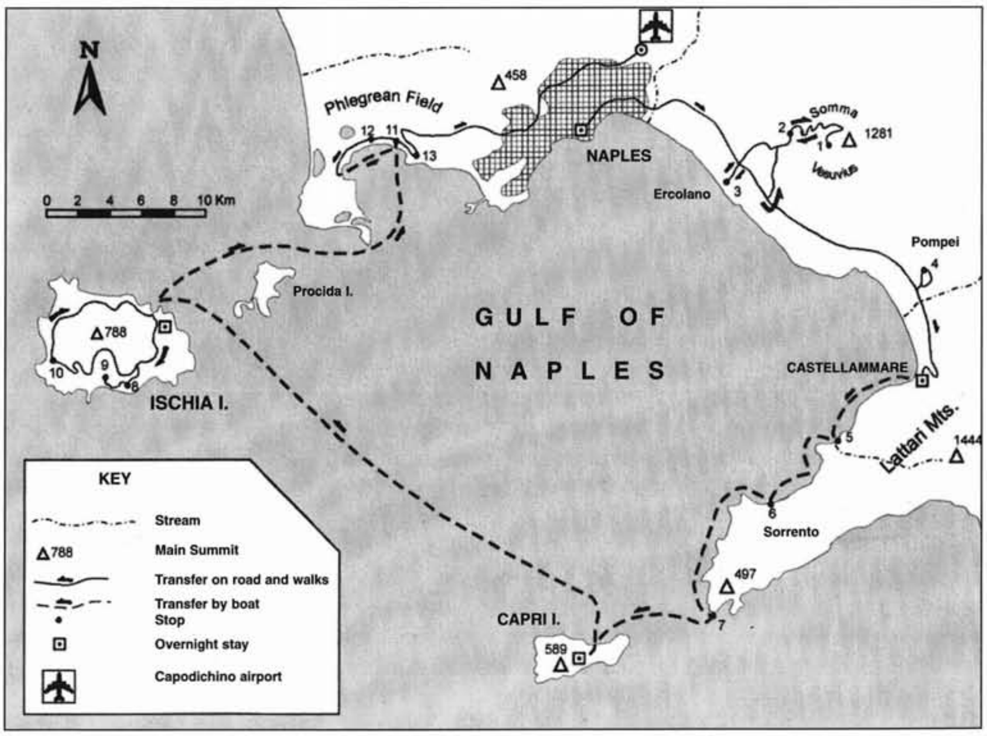

FIG. 3 - The route of the B8 Field Trip.

the contrary, on the flat coastal plain of the Sebeto River. The limit between these two contrasting landscapes is given by a NE trending normal fault (the on-land reach of the Acerra-Dohrn Canjon Fault; see Chap. 2) that has been active both after the emission of the CI (37 ka) and after the eruption of the NYT (12 ka). The related fault scarp has discontinuous and subdued evidence because it is covered by post-faulting pyroclastic mantles, dissected by water courses and re-shaped by sea-cliffs eroded during the Post-Glacial transgression.

The asymmetrical structural depression comprised of this fault scarp and the northern footslope of Somma-Vesuvius was partly invaded by the sea both before and after the NYT eruption (i.e. during the O.I. Stage 3 and the peaking phase of the O.I. Stage 1 transgression). Thanks to strong pyroclastic and volcanoclastic inputs, the Sebeto structural gulf became finally a fluvial coastal plain during the second half of Holocene, when aggradation prevailed on a subsidence of 1.75 to 2.5 mm/a (^{14}C datings of coastal marsh peat layers).

Moving southward on the Napoli-Pompei Highway, we leave the Sebeto plain and approach the base of the Somma-Vesuvius. The history of this composite volcanic relief comprises the buiding of a first cone-shaped volcano (Somma); the formation of a large summit caldera and, finally, the growth of a new large cone (Vesuvius) inside the caldera itself. The caldera's wall makes a half-circle in the NE part of the volcano, while its SW half is almost completely masked by the superimposed Vesuvian products (fig. 4). Some authors assume that this burial was made possible by a primary southwestward inclination of the caldera rim. Others have proposed that the southwestern part of Mt. Somma was depressed by faults during or soon after the calderization. As a matter of fact, there is one clear fault scarp (trending almost E-W) that depresses the caldera rim at the point where we see the 1944 lava flow come out from the crescent shaped depression separating the Somma remnant from Vesuvius' cone. Other faults of variable orientation are morphologically detectable along the outer flanks of the volcanic edifice (fig. 4). Some NW-SE trending faults depressing to the SW has been seismically proven in the immediate off shore of the Somma-Vesuvius coast, whose rectilinearity is also an effect of this recent tectonism (fig. 2).

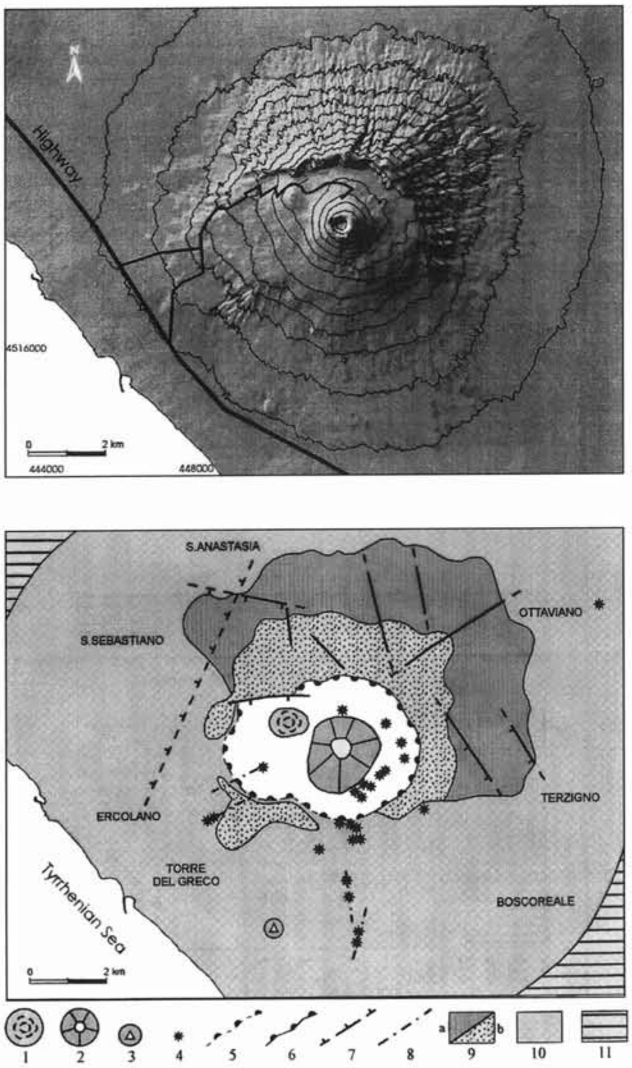

FIG. 4 - Dem-derived shaded-relief representation of the Somma-Vesuvius volcano (above) and Schematic Morphostructural Map of the same volcano (below). 1) lava-dome; 2) Vesuvius' Great Cone; 3) Camaldoli della Torre parasitic tuff cone; 4) secondary spatter cones and small lava domes; 5) convex break of slope probably marking the buried portion of the Somma's caldera rim; 6) exposed portion of the Somma's caldera rim; 7) morphologically detectable normal fault; 8) radial fracture; 9) remnant of Somma volcano (a: gently sloping, lower portion of the volcanic cone, mainly composed of pyroclastic flows, lahars and lavas; b: steeply sloping, upper part of the volcanic cone, mainly composed of scoria and lavas); 10) area covered by Vesuvius' products; 11) peri-volcanic alluvial plain.

THE HISTORY OF THE SOMMA-VESUVIUS

The Somma-Vesuvio is located almost on the same vertical of a much older volcano (now deeply buriend under the Campana Plain and revealed only by a deep borehole and several geophisical prospections) that has been active during Middle Pleistocene. Its activity was dominantly effusive and the lavas it emitted, often in a submarine environment, belong to the undersaturated, tefritic-fonolitic series. The nowadays visible Somma-Vesuvius edifice started forming during Late Pleistocene times, possibly after the eruption of the 37 ka old IC. Its products were initially saturated (trachybasaltic and trachytic) and then decisely undersaturated (leucititetefritic). The bulk of the Somma strato-volcano was built up before 25 ka BP thanks to voluminous emissions of lava and associated, local scale explosive activity. Between 25 and 15 ka the activity was mostly explosive with a series of Plinian eruptions alternating with periods of effusive and small-scale explosive events. After 15 ka there was a period characterized essentially by sub-Plinian eruptions separated by repose intervals of up to 4,000 yrs long. Not later than 3.6 ka ago the Somma Caldera appeared and the following activity (3.6 ka to A.D. 1944) can be divided into four eruptive cycles. Each cycle includes a major Plinian eruption (3.6 ka BP; A.D.79; A.D.472; A.D.1631) and the following small scale effusive-explosive events (interPlinian activity). It was during this last period of activity that the sothwestern half of the Somma volcano started disappearing under a thick cover of younger products, but the present Vesuvio's Great

Cone was probably formed during the inter-Plinian phase that followed the explosive eruption of A.D. 472.

For forecasting purposes, the volcanologists consider the current dormancy in terms of replenishment and differentiation processes. The future eruption could occur probably within 200-500 years, as suggested by the duration of the repose intervals of the two preceeding cycles.

3.1 b - *From Torre del Greco to Vesuvius*

At Torre del Greco we leave the Highway and take the road to Vesuvius. Along the way we observe the ropy surface of the 1858 lava flows and then the blocky surface of the 1944 lava flow, which reached and largely destrojed the town of San Sebastiano at the western base of the volcano. Further upslope we pass the lava-domes of Colle Umberto and Colle Margherita (accreted during the 1891-94 and 1895-99 eruptions respectively). From this point we can also observe the wall of the Somma Caldera exposing an alternation of lavas and scoria crossed by dikes and sills. The wall beheads numerous valleys that were radially incised on the outer slope of the strato-volcano prior to the calderization, when the Somma cone was between 1,600 and 2,000 meters high, according to various estimates. The amount of wall degradation (gelifraction plus rock falls) that has occurred in the last 53 years can be iudged from the size of the detrital cones grown on top of the 1944 lava flow.

3.1 c - *Vesuvius' Great Cone and summit crater (Stop 1)*

From the parking site at 1017 m a.s.l. we take the pathway that goes up to the top of Vesuvius' Great Cone (1281 m a.s.l.). This volcanic cone has experienced several phases of construction and explosive dismantling during the last 3.6 ka. Most of its present volume was probably accreted after the A.D. 472 Plinian eruption. As can be reconstructed by ancient drawings and descriptions, the summit of the cone was reduced by some 450 meters upon the blast associated with the A.D.1631 Plinian eruption and has finally rebuilt about 500 meters since then.

The steep angle of the Great Cone outer slope (up to 40° and more) is due to the welding of red-hot scoria ejected during phases of fountain-type activity. During the 1944 eruption, the tremors accompaining the eruption caused the scoria cover to slide downslope as hot avalanches and form several lobate tongues at the cone base.

The summit crater has an elliptical shape (480 x 580 m) and a depth of about 300 m. It formed upon the collapse that occurred after the last explosive phase of the 1944 eruption, which was responsible for the accumulation of the 20 meters of scoria and lapilli that are visible on top of the crater rim. The crater wall exposes the horizontally stratified lavas that filled up, between 1913 and 1944, the explosive crater left by the 1906 eruption. As the latter was little larger and more to the NE than the present one, in some parts of the crater the subvertical contact between the 1913-1944 lavic infilling and the analogous one formed between 1872 and 1906 can be seen.

From the top of Vesuvius we can also have a spectacular view of the entire Gulf of Naples (called *Crater* in the Greek times). The promontories that limit the bay are the Surrentine Peninsula to the SW and the Phlegrean Fields to the NE. The former is a WSW-ENE elongated structural high (maximum elevation 1444 m a.s.l.) made up of Mesozoic carbonatic rocks locally covered with Miocene flysch deposits. It continues westward with the island of Capri which has almost the same nature and is connected with the Peninsula through a submerged saddle not deeper than 75 meters (emerged during glacial low stands).

The Phlegrean Fields (maximum elevation 458 m a.s.l.) appear as a complex volcanic landscape composed of about 30 small volcanic centers (mostly tuff cones and tuff rings formed during the last 12 ka) superimposed on the faulted and calderized southwestern portion of a broad tuffaceous edifice: the so called Archiflegreo Volcano, which exposes volcanics as old as 47 ka mantled by both the CI (37 ka) and the NYT (12 ka). A residual of the caldera can still be recognized in the roughly semicircular bay of Pozzuoli, while the undisturbed NE flank of the Archiflegreo appears from here as a conical slope gently merging into the Campanian Plain north of Naples (see # 3.4.a). The volcanic islands of Procida, Vivara and Ischia constitute the maritime, SW elongated, continuation of the Phlegrean volcanic area, which also includes a number of submerged volcanoes. The eruption centres occurring on these islands range in age between 150 ka and historical times.

From the summit of the Vesuvio we can also fully appreciate the very dense and chaotic urbanization that characterizes both the volcano's flanks and the surrounding plain. The continuous belt of towns and villages that marks the Somma-Vesuvius footslope hosts some 700,000 inhabitants, while about two million are those living within a 15 km radius from the central crater of the volcano.

3.1 d - *The Vesuvian Observatory and the vigilance over Vesuvius (Stop 2)*

On the way back to Torre del Greco we stop at the old seat of the Osservatorio Vesuviano, the world's oldest scientific observatory built on an active volcano (1845). The list of former Directors of the observatory includes L. PALMIERI (who invented the first electromagnetic seismograph) and G. MERCALLI (famous for his scale of earthquake intensity). Nowadays this historical building hosts a volcanological library and a museum. We stop here to visit an exibition of posters illustrating the kind and distribution of volcanic hazards as well as the various types of geophysical surveillance presently in use.

3.1 e - *The buried Roman town of Herculaneum. (Stop 3)*

According to a legend reported by DIONE of ALICARNASSO, *Herculaneum* (Ercolano) was founded by the mythological hero Ercules. More probably its history was substantially the same as that of the nearby Pompei (see # 3.1.f). The town rose on a gently inclined terrace of the Vesuvius piedmont bounded by two valleys and truncated frontally (i.e. to the SW) by an active sea cliff. The products of the A.D. 79.D. eruption profoundly modified this topography aggrading totally the valleys and causing some 500 meters of coast line advance. Roman beach deposits recently exhumed near the base of the south-western walls of the town (fig. 5) demonstrate that the sea level of the 1st century A. D. lies between 4 and 5 meters below the present zero. It is not clear if this lowering was due to post-eruption deflation of the volcano or to a more generalized, tectonic subsidence of the Campanian Plain.

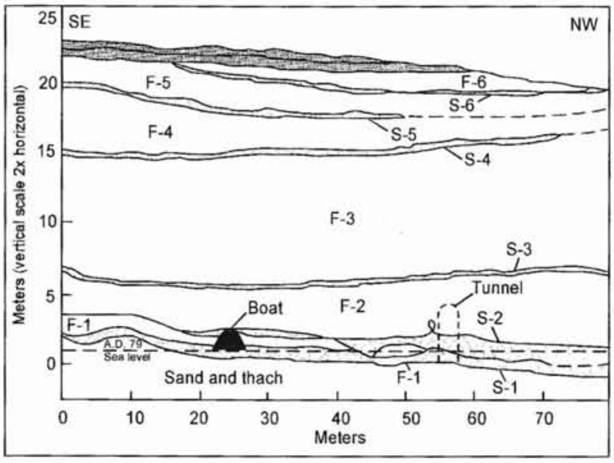

FIG. 5 - The A. D. 79 sequence of pyroclastic units exposed near the Suburban Thermal Baths of the ancient Herculaneum. Note that the vertical scale is based on datum that originates 5 meters below present sea level (after Sigurdson *et al.*, 1985).

We visit a recent excavation-site located near the Suburban Thermae, where the Roman waterfront is exhumed and the type stratigraphy of the A.D 79 burial can be seen (fig. 5). The prevailing wind direction (from NNW) during the Plinian phase of the eruption reduced the air-fall accumulation to a minimum (no more than 20 cm), but Herculaneum was subsequently inundated by a series of thick pyroclastic flows. Six individual flows (F1 to F6) can be detected along the 20 meters thick succession, each preceded by a basal surge layer (S1 to S6). S1 and F1 derived from a single *nuée ardente* and reached the town few minutes after the collapse of eruption column. The S1 swept through Herculaneum, while the following, denser F1 flowed around the town and emerged onto the beach through the lateral valleys of the terrace. As proved by the hundreds of skeletons found on the beach, all the Herculaneans that were still on the shore trying to flee the impending disaster were killed and buried by the surge S1, which was hot enough to carbonize dry wood but not fresh one. Quite hotter was the S2 surge, which was also the most destructive one. In fact, its deposit includes abundant bricks, roof tiles and fragments of walls up to 1 meter long. The F2 flow, up to 5 m thick, is massive, consolidated and pumice-rich. As this thick blanket of hot pyroclastics swamped the waterfront, it appears crossed by numerous steam pipes created by the boiling underlaying water. The upper part of the section is composed of four more couplets of surge and flow deposits. The S5 is characterized by large scale cross bedding.

3.1 f - *The buried Roman town of Pompei (Stop 4)*

Founded by the Opici people in the 7th-6th century B.C., Pompei experienced the influence of the nearby Etruscan, Greek and Samnitic colonies. In 80 B.C. it was conquered by Silla and became a Roman possession. Thanks to its

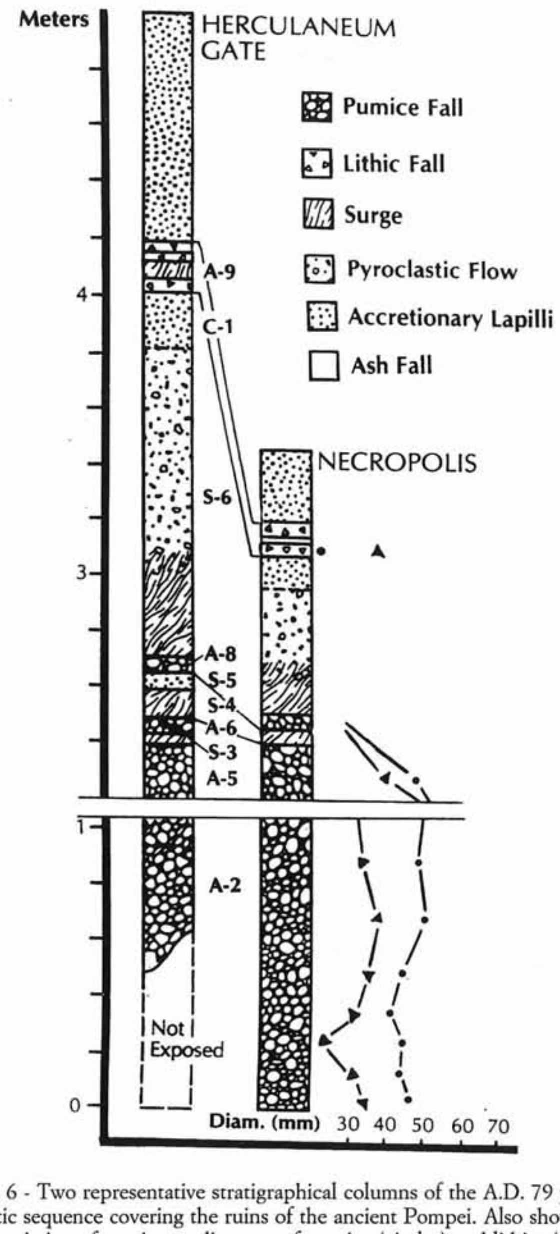

FIG. 6 - Two representative stratigraphical columns of the A.D. 79 pyroclastic sequence covering the ruins of the ancient Pompei. Also shown is the variation of maximum diameter of pumice (circles) and lithics (triangles) in the fall deposits (modified after Sigurdson & *alii,* 1985).

port near the Sarno R. mouth, Pompei was an important trade center that served all the fertile Sarno Plain and nearby areas. Pompei is supposed to have had not less than 12,000 inhabitants at the time of the A.D. 79 eruption. Unlike the case of Erculaneum, Pompei was buried mainly by air-fall and surge deposits reaching a maximum thickness of 6 meters. Visiting the ruins, we stop at an active excavation site (*Regio* 1st; *Insula* 22) to observe fresh sections across the A.D. 79 deposits.

At Pompei, the type sequence (fig. 6) includes a basal air-fall pumice layer, up to 2.8 m thick, followed by a succession of pyroclastic surge deposits. The air-fall phase of explosive eruptions is referred to in the volcanological literature as the Plinian phase, in honour of Pliny the Younger, who provided the first written eyewitness account of this type of activity in his letters to TACITO (*Epistolario*, VI, 16-20). The pumice layer was emplaced within 18 hours starting from 1 p.m. of August 24th. Due to strong winds these products were dispersed to the SE up to the Ionian Sea. DIO CASSIUS (*Epitome*, 66.23) reports that the ash from Vesuvius arrived as fas as the north coast of Africa and the Levant. In Pompei the roofs of most buildings collapsed under the weight of the air-fall pumices. It is worthy to note that in the excavation of *Oplontis* (Torre Annunziata) the basal pumices are interbedded with three surge layers (S 1,2,3) probably representing minor phases of collapse of the eruption column during the Plinian phase. Only the stronger surges which occurred on August 25th (S 4,5,6) reached Pompei, toppling many wall remnants emerging from the previous air-fall cover and aggrading the area with other 1 to 3 meters of deposits. The fine compacted ashes of these surges have preserved the detailed casts of bodies and garments of Pompeians. They were probably killed by the *nuée ardentes* S4 and S5 and then completely buried by the S6. This last surge was the agent of major destruction in Pompei. It arrived up to Stabiae (the modern Castellammare di Stabia) where PLINY the Elder remained killed. The dunes of the S6 surge are covered by dark gray ash with common accretionary lapilli (C1) that represents the transition to the final phreatomagmatic phase of the eruption (also characterized by two brief periods of dry lithic-fall separated by a minor surge. These layers are covered by a total of 60 to 80 cm thick, undifferentiated accretionary lapilli layers and thin surges.

On leaving the ruins of Pompei we stop at the base of the fossil sea cliff that marks the southern rim of the ancient town. It exposes some leucite-bearing foam-lavas that were emitted in prehistorical times (> 17 ka) by a nearby parasitical vent of the Somma volcano. These volcanics were marginally eroded by the sea during the peaking stage of the Post Glacial transgression, but the resulting sea cliff was then disactivated upon phases of sedimentary progradation occurred on the R. Sarno Plain during the second half of Holocene (fig. 7). As proved by many stratigraphical and archaeological data, the sea cliff at issue was surpassed by the advancing coastline not later than the 6th century B.C., when the coastal dune ridge of Bottaro formed. By the Roman period the shore had moved further to the SW so as to leave a costal plain almost one kilometer wide between the beach and the western foot of Pompei's hill.

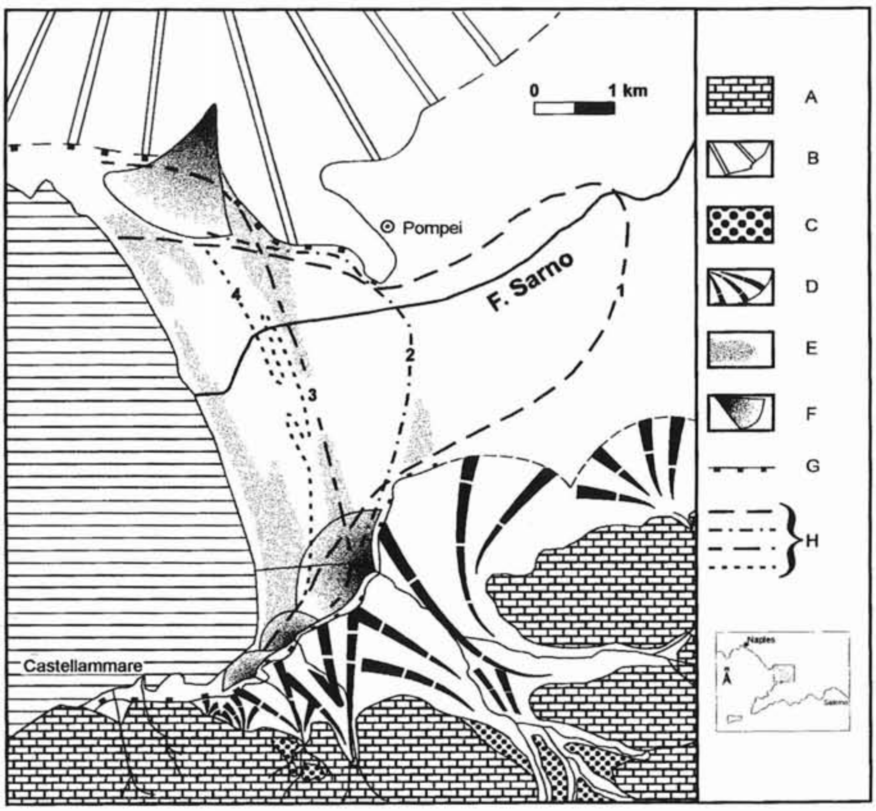

FIG. 7 - Geomorphological Map of the coastal portion of the Sarno River alluvial plain. A) Lattari Mts.; B) Somma-Vesuvius; C) Apex remnants of the First Generation of Alluvial Fans (Middle Pleistocene); D) Undifferentiated Second and Third Generations of Alluvial Fans (Last Glacial); E) Middle and Late Holocene coastal ridges; F) Late Holocene alluvial fans; G) Holocene sea-cliffs; H) Successive positions of the coastline during the Holocene [1: Post-Glacial Transgression maximum (5 ka); 2: Messigno stage (4.5-3.6 ka); 3: Bottaro-Pioppaino stage (>2.6 ka): 4: Pompei Port stage (1st century A.D.)].

3.1 h - *From Pompei to Castellamare di Stabia*

Moving by bus from Pompei to Castellamare di Stabia (*Stabiae* is another of the towns destrojed by the A.D. 79 eruption) we cross transversally the Holocene coastal-alluvial plain of the Sarno River. Thanks to the abundance of water, the fertility of soils and the mild climate of the area, this land is able to provide up to four harvests per year of high quality vegetables and flowers. The chaotic and mostly illegal urbanization which occurred after the Second World War (especially between 1960 and 1990) has largely compromised this resource. Moreover the Sarno is one of Europe's most polluted rivers owing to the inadequacy of sewerage-schemes and purification systems, both for urban and industrial outflows.

Our road runs very close to the place where the Roman coastline and the harbour of ancient Pompei were located. Chronological and stratigraphical data obtained from this area by means of drillings demonstrate that a subsidence of about 5 meters occurred after the A.D. 79 eruption. Approaching the town of Castellamare we see a Holocene fossil sea cliff cut at the base of a coalescing group of Late-Pleistocene alluvial fans descending from the Lattari Mts.. This cliff enters the coastal plain up to 2.6 km from the modern coast, where it joins the buried beach ridge of Messigno (4.5 to 3.6 ka). Similar to the one we have seen at the base of Pompei's hill, this cliff was also cut during the peaking stage of the Post Glacial transgression and then gradually abandoned into the prograding plain during the second half of the Holocene. The plan outline of this cliff evidenciates that the amount of retreat it suffered increases from east to west in relation to the length of time it remained active before being buried by the prograding coastal plain (fig. 7). Following this progressive disactivation, the streams descending from the Lattari Mts. (by then entrenched into the Late-Pleistocene fans) started to form new alluvial fans at the cliff base. Particularly strong was the magnitude of the alluvial phase that closely followed the A.D. 79 eruption, whose unstable pyroclastic products were rapidly stripped from the Mts. Lattari catchments (see also # 3.2.b).

3.2 - SECOND DAY
(P.P.C. Aucelli, A. Cinque, G. Robustelli & M. Russo)

3.2 a - *Sailing from Castellammare di Stabia to Vico Equense*

On leaving Castellammare's port we see once again the Holocene sea cliff cuts at the base of the Pleistocene alluvial fans that characterize the northern piedmont of the Lattari Mts.

THE PLEISTOCENE ALLUVIAL FANS OF THE MTS. LATTARI PIEDMONT

Three main Generations of alluvial fans have been recognized along this piedmont. Of the first one -which is Middle Pleistocene in age- only the cemented, apex parts are left near the exit of their feeding valleys (fig. 7). The outer portion of these fans is not visible both because tectonically downthrown and because dismantled by the sea during the Last Interglacial transgression. The fans of Second and Third Generations -formed during the Last Glacial- are due to both climatic causes (increase of gelifraction on the limestone cliffs of the catchements) and volcanological ones (mass wasting and washing of the thick pyroclastic covers repeatedly thrown onto the Lattari Mts. by the explosive eruption of Phlegrean and Somma volcanoes). They are separated by a phase of linear dissection which occurred after the emplacement of the CI (37 ka).

Between the eastern end of the Lattari's piedmont and Castellamare (where no strong lowering of base level occurred during the Last Glacial) the alluvial fans of the Third Generation are slightly entrenched into those of Second one and sometimes cover them entirely. Along the coast between Castellamare and Vico Equense, on the contrary, these two generations of alluvial fans are altimetrically well separated (e.g. the two orders of entrenched fan terraces of Pozzano) and both appear truncated by sea cliffs.

FIG. 8 - The landslide occurred at Pozzano on January 10, 1997 in a photo taken a few days after the event (courtesy of A. SANTO).

Near Pozzano we see the still clear signs of one of the numerous landslides (earth-fall or slide passing to a mudflow) that occurred in the Lattari Mts. on January 10, 1997 causing a total of six victims and great damages to roads, cultivations and buildings. Following an Autumn that had brought as much rain as the total rainfall of a normal year (844 mm in Naples), two days of continuous and heavy rain occurred on January 9 and 10, totalling 150 mm in Castellammare. This meteorological events greatly reduced the stability of the weathered pyroclastic cover that mantles the Lattari Mts. (usually few decimeters to few meters thick), triggering landslides on slopes of 30° or more, even if densely forested. In Pozzano's case, the slide started on the upper part of a valley side, at about 450 m a.s.l. (fig. 8). The resulting pyroclastic mud flow, charged with tree logs and limestone boulders, impacted the opposite flank of the valley and continued to move rapidly towards the coast. Along its final course, the flow killed 5 people as it partly destroyed a house and swept away several cars stopping on the coastal road because of another small landslide.

This recent event exemplifies the geomorphological hazard created by the presence of air-fall pyroclastic covers on the steep slopes of the calcareous mountains surrounding the Neapolitan volcanic district. This cover gives small slides almost every rainy season, while crises consisting of one or more landslides of the magnitude of the example shown here have a recurrence time of the order 10 to 20 years.

This area of the Lattari Mts. is also exposed to another kind of geomorphological hazard which is indirectly related to the vicinity of the Neapolitan volcanoes. It arises from the possibility that large collapse dolines open and extend in places were deep tectonic fractures favour the mixture of percolation waters with fluids of volcanic origin, resulting in underground hyper-karst. The presence of tens of mineralized springs along the normal faults that separate the Lattari Mts. ridge from the Campanian Depression is a proof that a deep-sited water circulation occurs along this coast. Between Pozzano and Vico Equense we see three large collapse dolines along the costal slope. One of them is associated with a 800 meters long and 90 meters deep tension trench (called Spacco della Iala) which is up to 4 meters wide. Radiocarbon datings of displaced calcite concretions, together with evidence from truncated stony agricoltural walls, indicate that the crack opened between the Middle Age and about 300 yrs B.P..

The Late Pleistocene terrace of Vico Equense

Passing in front of Vico Equense we observe the truncated and dissected relics of another alluvial fan of the Second Generation forming gently inclined terraces between 80 and 110 meters a.s.l. on both sides of the Rivo d'Arco valley mouth (fig. 9A). The terrace forming sequence includes a lower part made of fanglomerates rich in pyroclastic materials (both in the form of matrix and intercalations) followed by reworked pyroclastic sands and topped by a thick mantle of Campanian Ignimbrite. During its growth, the fan completely covered a minor calcareous block flanking the final reach of the valley. This block appears cut by a flat erosional surface that probably represents an abrasion platform formed during the Middle Pleistocene.

Similarly to other streams descending from the Lattari Mts. also the Rivo d'Arco probably produced a Third Generation fan after the emplacement of the CI. Such younger fan is not visible in outcrop, but the bathimetry of Vico Equense offshore suggests its presence under the sea-level. This is evidence that in front of this part of the Lattari ridge the coastal plain that emerged during the O. I. Stage 2 glacial regression was some tens of meters below the present zero, probably because the subsidence which affected this part of the Gulf of Naples during and soon after the eruption of the CI (see Chapter 2)

3.2 b - *The post-A.D. 79-eruption alluvial fan of Marina di Equa (Stop 5)*

The small embayment of Marina di Equa occupies the mouth of the valley that dissects the above mentioned Late-Pleistocene fan of the Rivo d'Arco Stream. The floor of this incision is flattened by recent alluvial deposits that are longitudinally dissected by about seven meters and frontally truncated by a sea cliff of almost the same height (fig. 9). We land near the eastern end of the bay to obeserve an interesting geo-archeological situation that helps in deciphering and dating the geomorphic events which occurrend in the area during the first centuries A.D..

At the point where the beach touches the limestones of the valley side we see the ruins of a flight of steps constituting the access to a villa built on the calcareous slope sometime between the 1st century B. C. and the beginning of the 1st A. D.. These stairs are buried under the products of the 79 A.D. eruption (air-fall pumice followed by fine ash rich in accretionary lapilli) followed in a continuity of sedimentation by sheets of alluvial deposits almost wholly made up of reworked but unweathered pyroclasts of the same eruption. These sediments include fragments of pottery, tiles, bricks and plaster taken mostly from buildings of the I century, and reach a maximum thickness of some 5 meters. As a whole this alluvial body represents a phase of aggradation which occurred soon after the A.D. 79 eruption as a consequence of the rapid wasting of the very unstable py-

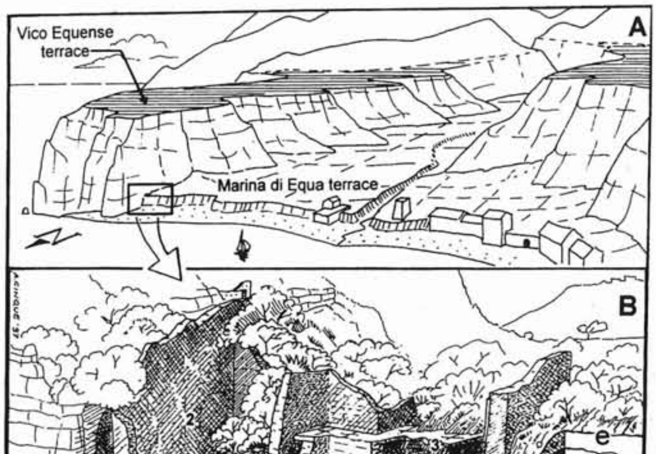

FIG. 9 - The Roman coastal terrace of Marina di Equa. A) General view from the NW. B) Simplified representation of the relations between the terrace forming deposits and the Roman ruins (a: beach deposits of the 1st century A. D.; b: A. D. 79 pumice fall; c: A. D. 79 ash; d: pyroclastic-alluvial deposits of the 1st - 2nd century A. D.; e: younger colluvium; 1, 2, 3: remnants of the three phases of building occurred between the 1st century B. C. and the 3rd century A. D.).

roclastic mantle that accumulated on the basin slopes. At the river mouth this aggradational phase corresponded to the growth of a fan that protruded into the sea at least 500 meters beyond the present coastline. It is likely that the lost, outer part of this body had a crudely developed deltaic structure.

The high rate of sedimentation that characterised this alluvial phase can be deduced from the fact that a few decades after the eruption (probably in the beginning of the 2nd century) the phenomenon had already calmed down, encouraging the reconstruction of the villa. In this second building phase the residence was also extended on top of the recently accumulated alluvial body. The foundations of these new rooms, today truncated by the sea cliff, appear laid into trenches excavated in the alluvial beds. At the time when the villa was restored and extended, the fan had already started to be dissected by the Rivo d'Arco and consumed frontally by a retreating sea cliff. But the latter had still to be far enough far from the villa to encourage its owner to build onto the coastal alluvial terrace. This was excessively optimistic because the sea cliff reached and damaged the second building not later than the 3 rd century, when a third building phase occurred. This consisted of protective walls leaning against the sea cliff and an inclined tunnel to connect the buildings left on the terrace with the beach formed in front of the sea cliff itself.

3.2 c - *Sailing from Marina di Equa to Sorrento*

Sailing toward Sorrento we pass the Punta Gradelle promontory: a homoclinal «horst» of Cretaceous limestones dipping some 15° to the NNW and bound on both sides by NW-SE trending normal faults active during the Early Pleistocene. As we round the cape we enter an embayment corresponding to a relatively depressed area (Meta-Sorrento depression) which is also limited on the opposite side by a NW trending fault. These two faults are associated with scarps showing subvertical basal segments up to 150 meters high, near the coast, and gradually decreasing in height towards the interior (i.e. SE). These basal cliffs are due to the exhumation of the fault mirrors caused by the erosional removal of the soft Miocenic formations occurring on the lowered block.

This differential erosion also helped the development of the Meta-Sorrento embayment, which was much more pronounced than today during Middle-Late Pleistocene. Marine deposits possibly belonging to the Last Interglacial have in fact been drilled on land, up to one kilometer from the present coast. They are covered by fluvial conglomerates probably belonging to the Second Generation of alluvial fans and then by the CI. This pyroclastic sheet reaches a maximum thickness of about 60 meters along the coast, where it is cut by a spectacular sea cliff up to 50 m high. The top surface of the CI (carpeted by no more than 6 meters of younger pyroclastic-fall loose deposits) forms the broad structural terrace where the towns of Meta, Piano, S. Agnello and Sorrento lie. The boundaries between these towns are traced along very narrow gorges with vertical flanks that have been cut into the welded tuff by streams coming from the hills of the interior, where Miocene flysch deposits of low permeability largely outcrop.

The Campanian Ignimbrite

This pyroclastic formation is a grey, poorly to moderately welded trachytic tuff that consists of rounded pumices and angular lithic fragments dispersed in a devitrified matrix containing sanidine, lesser plagioclase rimmed by sanidine, clinopiroxenes, biotite and magnetite. Recent high-precision datings (using single-crystal, laser fusion Ar/Ar methods) indicate that it erupted around 37 ka ago. Based on distribution and thickness of the residual outcrops it was calculated that the eruption covered some 30,000 square km of area and laid down about 500 cubic km of deposits (the largest eruption of the last 200,000 yrs in the Mediterranean region). The mechanism of emplacement was probably composed of: (i) a transport system given by expanded and decompressing turbulent currents that moved radially away from the source area and were more than 600 to 1,000 m thick when they reached the mountains surrounding the Campana Plain, and (ii) gravity driven depositional systems draining off ridges and down valleys in directions dictated by local topography.

Even though there is no doubt that the CI originated within the Campanian Depression (most probably in the southwestern part) the exact location and type of vent (or vents) is still controversial. Many authors locate it within the Flegrean Fields and some of them relate the emission of the CI with the first phase of collapse of the Flegrean Fields Central Caldera. Others suggest the hypothesis of fissural eruptions which occurred from fractures extending outside the Flegrean area with SE and, maybe, also NE directions.

Even though it has been noticeably drawn back by coastal erosion during the Post Glacial transgression, the Meta-Sorrento sea cliff is not a purely erosional form. Most probably it derives from a NE trending fault scarp formed by the tectonism occurred in the Gulf after the eruption of the CI. The tuff appears crossed by a network of vertical cooling joints (frequently irregular and one to several meters spaced) that play a major role in determining the rock falls through which the cliff recedes. The edge of the tuffaceous sea cliff was punctuated by luxurius villas during the First Imperial Roman age. Each of them had a private way down to the shore (i.e. the cliff base) cut into the solid tuff either in the form of inclined tunnels and/or external flights of stairs. At the sea level the most important villas also had one or more *ninfeos* and fish breading pools (*peschieras*), which were also into the tuff. The present conditions of these seaside ruins permit appreciation of the changes which have occurred since their construction.

Below the modern Villa Nicolini we see the ruins of two *ninfeos,* a *peschiera* and related ways down. The fact that inside the *peschiera* the peripheral platform is about 60 cm under the present sea level leads to the inference that a relative sea level rise of the order of a meter or so has occurred since the 1st century A. D.. At the site of the eastern *ninfeo*, and underlying *peschiera*, the sea cliff has practically remained at the same position it occupied in the Antiquity, probably because protected from wave attack by a platform cut into the tuff during the Roman age. On the contrary, the western ninfeo has been progressively damaged by rock falls that wore the cliff back at least a dozen meters.

Another stretch of cliff that shows a appreciable post-Roman retreat is the one near the Hotels Royal and Europa. The evidence here is the truncated ruins of the *calida-*

rium of a *therma* laying on the edge of the terrace (that witness many meters of cliff recession) and a huge rock fall talus accumulated at the cliff base.

3.2 d - *The ruins of Agrippa's Villa in Sorrento (Stop 6)*

We land at Marina Piccola (Sorrento) and visit the Roman ruins located below the historical Bellevue-Syrene Hotel. They represent the sea-side structures of a large villa (owned by Agrippa Postumo, Augustus' son in law) resting, as usual, on the terrace above the cliff. The villa had a number of ways down to the shore sculpted into the tuff. These works appear locally cancelled by post-Roman phases of cliff retreat. A backwearing of more than ten meters can be appreciated in front of the Major hollow *ninfeo* of the villa, whose original seaward extent is witnessed by the remains of the wall sustaining the ancient entrance arc (originally built against the tuff cliff and now emerging from the sea water. (fig. 10). Also in this area the amount of post-Roman recession of the sea cliff appears to vary considerably from place to place. This variability seems to be ascribed to local changes in the cliff-foot geometry (sometimes influenced by man) rather than to natural, lateral variations of the rock strength or differing exposure to waves. The whole set of geo-archaeological constraints available between Meta and Sorrento permits to conclude that the post-Roman retreat of the tuffaceous sea cliff has occurred at rates that vary - from place to place- between almost zero and about 6 mm/a, with an average value shifted towards the lower limit of the range. Much higher rates of retreat probably occurred during the first half of Holocene, when the sea level was lower than that the base of the tuffaceous bank and the waves were therefore attacking the much more erodable formations on which the CI rests.

The sea-side quarters of Agrippa's villa are interesting also because they permit to appreciate the relative sea level rise which has occurred since the Roman age. Laid down on the abrasion platform cut in the tuff and partly buried by the sand of the modern beach, there are the *in situ* ruins

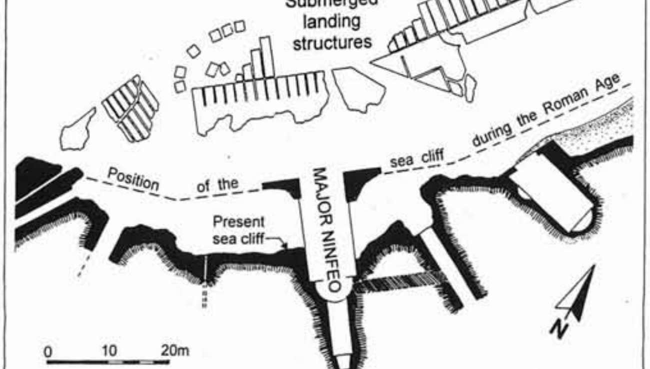

FIG. 10 - Partial plan of the coastal ruins of Agrippa's Villa in Sorrento (modified after MINGAZZINI & PFISTER, 1946).

of a complex landing system (typically made of hydraulic concrete poured into wooden cases) covered by about 70 cm of sea water (fig. 10). The exact amount of relative sea level rise cannot be calculated because we do not know (i) the thickness of the finishing top layer that have been eroded (or stolen?) from the concrete basament, and (ii) how much the jetties originally emerged from the sea level. However, the rise should be comprised between one meter and a meter and a half. A submergence of the order of one meter is also suggested by the situation shown in the nearby hollow *peschiera* of Agrippa's villa, which is similar to the one shown by the Villa Nicolini's *peschiera* (see # 3.2.c).

3.2 e - *Sailing from Sorrento to Punta Campanella*

From Sorrento to the headland of the Surrentine Peninsula the coast line tends to run parallel with the strike of the strata, which dip 10 to 20 degrees to the NNW. The coastal slope often shows structure controlled terraces along the contact between the easy erodable Upper Miocene flysch deposits and the resistant Lower Miocene calcarenites and/or Upper Cretaceous limestones. Differential erosion performed by storm breakers have also created emergent abrasion platforms where the contact between those contrasting rocks is exposed at a few meters above sea level. Where the calcareous sea cliff is more high and stable, it shows, at about 6 meters a.s.l., well preserved relics of a corrasion notch that is ascribed to the O. I. Substage 5.5 on the base of some U/Th datings on corals. This is an order of sea-level marks that occurs frequently on both sides of the Surrentine Peninsula (from Sorrento to Salerno) and all round the island of Capri mantaining practically the same elevation everywhere. As the maximum eustatic level reached by the Tyrrhenian Sea during the Last Interglacial was just between 4 and 6 meters higher than the present one, it can be concluded that the morphostructural unit embracing the Lattari Mts., the Surrentine Peninsula and the Island of Capri entered a phase of substantial tectonic stability not later than 125,000 years ago.

3.2 f - *Evidence of post-Roman sea level rise at the Athenaion (Stop 7)*

The cape of the Surrentine Peninsula (Punta Campanella) was known in the Antiquity as *Athenaion*, and then as *Promontorium Minervae*, from a famous temple that was built here during the 6th century B.C. and remained active till the 2nd century A. D.. Subsequently a Roman villa rose in its place to house a garrison during the presence of Emperor TIBERIUS and his court in Capri (27 to 37 A. D.). On each side of the cliffed promontory there was a flight of stair ascending from the shore to the temple. The southern one is better preserved because sculpted in the rock. In order to permit the visiting boats to come alongside near these stairs, a wide notch was excavated into the plunging cliff. Both the submersion of the basal steps and the insufficient height of the notch's roof prove that the sea level was about one meter lower than the present during the Roman times. This value of relative rise substantially equals the ones obtained from the *ninfeo* near Villa Nicolini and the ruins near the Hotel Bellevue-Syrene. As a number of geo-archaeological data converge to indicate that the eustatic level of the southern Tyrrhenian Sea was only 60 cm below the present one during the Roman period, some decimeters of subsidence is to be suspected for the coast of the Surrentine Peninsula. In any case, it is a very modest amount of ground movement if compared with the ones occurred along the opposite, volcanic side of the Gulf of Naples (see # 3.3 and 3.4).

3.2 g - *Sailing from Punta Campanella to Capri*

Moving from the Athenaion towards Capri we can note that this island is delimited all round by high and sub-vertical cliffs that correspond frequently on Quaternary fault scarps. The relief of the island is composed of two main blocks of Mesozoic limestones (namely Mt. Solaro to the west and Il Capo to the east) separated by a saddle were the Upper Miocene flysch outcrops. The carbonatic unit is overthrusted onto the terrigenous one, which comes to the surface in the saddle because here the thrust plane (dipping to the west) rises above the sea level. Fault scarps and sea cliffs exposing the plastic and erodable Miocene formations under the hard Mesozoic limestones evolved mainly through rock falls and deep seated gravitational movements. The Plio-Quaternary uplift of Capri is witnessed by a series of marine terraces (up to 350 meters a.s.l.) that are better expressed along the western flank of Mt. Solaro. This uplift was accompanied by downthrowing of peripheral blocks and formation of tectonic sea cliffs. Like in the nearby Surrentine Peninsula, also in Capri the last phases of uplift and block-faulting are not younger than the end part of the Middle Pleistocene.

3.3 - THIRD DAY
(R. Mele, P. Romano & N. Santangelo)

3.3 a - *Sailing from Capri to Ischia*

The island of Ischia has an area of 42 square kilometers and is dominated by the 787 m high volcano-tectonic horst of Mt. Epomeo. This relief is strongly asymmetrical, with the southwestern flank being much gentler than the northeastern one. It forms a quadrangular horst that is supposed to represent a resurgent block located inside an ancient caldera. The coast of the island is characterized by steep sea cliffs and an alternation of promontories and bays that appears influenced by the distribution of volcanic rocks having contrasting erodability.

As that of the Phlegrean Fields and the Somma-Vesuvius, the volcanism of Ischia is related to the Quaternary extentional tectonism that caused NW-SE and NE-SW-trending horst and graben structures along the Tyrheniam margin of the Campanian Appenine. The island is composed mainly of volcanic rocks belonging to the LK-series (alkalitrachytes with subordinate trachybasalts, latites and phonolites). Fossilifeorus marine deposits also occur at the top of Mt Epomeo and along its northern flank. Landslide deposits that are locally covered by younger volcanic edifices are also widespread around the central relief, especially along the northwestern and the southern slopes of the island (fig.11).

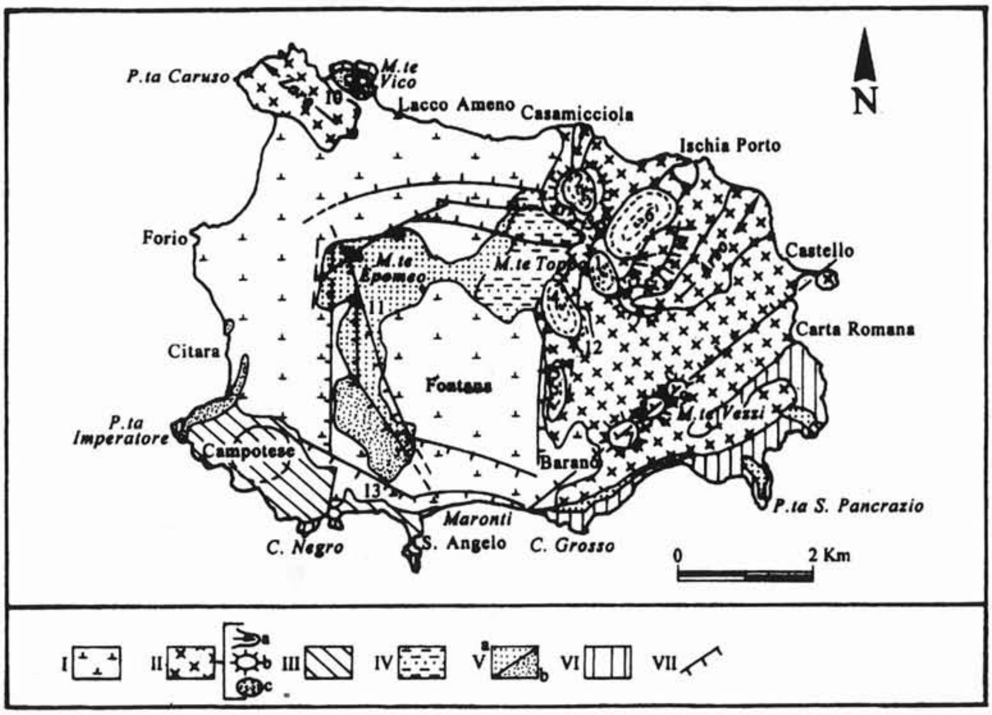

FIG. 11 - Schematic geological map of the island of Ischia. I) mud flow, debris flow and rock fall deposits; II) volcanics younger than 10 ka: a) lava flow, b) crater, c) dome; III) volcanics dated between 28 and 18 ka; IV) marine deposits of the Colle Ietto Formation (younger than 33 ka and older than 10 ka); V) volcanics dated between 55 and 33 ka: a) Mt. Epomeo Green Tuff, b) undifferentiated pyroclastic deposits; VI) volcanics older than 55 ka; VII) faults. Arabic numerals indicate localities: 1) Posta Lubrano; 2) Mt. Rotaro; 3) Fondo d'Oglio; 4) Trippodi; 5) Costa Sparaina; 6) Maschiata - Montagnone; 7) Vateliero; 8) Cava Nocelle; 9) Molara; 10) San Montano; 11) Pietra dell'Acqua; 12) Selva del Napolitano; 13) Caravana. (modified after Chiesa & *alii,* 1987).

THE VOLCANOLOGICAL HISTORY OF ISCHIA

The beginning of the volcanic activity of Ischia is probably much older than the 150 ka of the oldest dated rock of the island. The stratigraphically lowermost volcanics are, in fact, undated and are covered by trachytic and phonolitic domes, ranging in age between 150 and 73 ka (fig. 12). These domes are located on the edge of a central depression probably of volcano-tectonic origin . The dome-building activity was followed by a period of quiescence, which was interrupted, some 55 ka ago, by the eruption of the Mt. Epomeo Green Tuff. This trachytic formation partially filled the central depression covering also some marine deposits that had accumulated there during the previous period of quiescence. After the emplacement of the Green Tuff two other periods of volcanic activity followed, respectively comprised between 28 and 18 ka and 10 ka to A.D.1302. Both periods were characterized by hydromagmatic and explosive magmatic eruptions (forming tuff-rings and pyroclastic fall deposits) and by effusive eruption forming lava flows. At present the magmatic system of the island is still active as testified to both by the widespread fumaroles and thermal springs and by an intense seismic activity. Despite its still active volcanism, the island discloses a clear volcanic morphology only in the so called «Ischia graben», the structural depression located to the east of the resurgent block of Mt. Epomeo which host the products and landforms due to the last period of eruption activity.

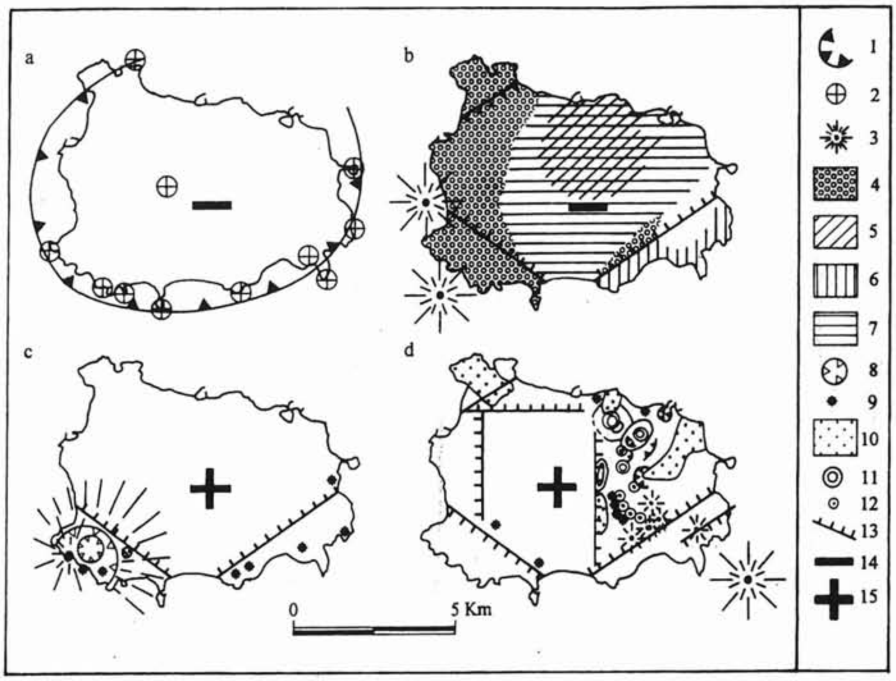

FIG. 12 - Volcano-tectonic evolution of Ischia island. a) domes and flows dated between 150 and 75 ka. Their distribution outlines the possible rim of a calderic depression; b) vents of the volcanic activity comprised between 55 and 33 ka and indication of the area interested by the emplacement of the Mt. Epomeo Green Tuff and by the deposition of the marine Colle Ietto Formation; c) distribution of the vents of the volcanic activity comprised between 28 and 18 ka. The Mt. Epomeo horst is lifting; d) distribution of the eruptive centers of the last phase of volcanic activity comprised between 10 ka and 1302 A.D. 1) caldera rim; 2) lava domes; 3) pyroclastic cones; 4) pyroclastic fall deposits; 5) marine deposits; 6) Mt. Epomeo Green Tuff pyroclastic flow; 7) Mt. Epomeo Green Tuff ignimbrite; 8) craters; 9) scoria and pumice cones; 10) lava flows; 11) recent domes and lava flows; 12) eruptive centres; 13) faults; 14) subsiding area; 15) uplifting area (modified after Vezzoli, 1988).

3.3 b - *From Ischia Porto to Maronti bay*

The circular bay hosting the harbour of Ischia derives from a crater lake that was artificially connected with the sea in 1854. It belongs to a volcano whose deposits overlay a paleosoil containing archaeological findings of the VI-V sec. B.C.. Moving from the port to the southern side of the island we enter the so called Ischia Graben, that is bordered weastward by the lava domes of Mt. Rotaro and Montagnone (formed between the 8th century B. C. and the 3rd A. D.). The almost flat area extending eastward is covered by the A. D. 1302 lava flow of Arso, that is the last eruption occurred in the island. Reaching the central part of the graben we see, to the south-east, the Torone - Mt. Vezzi ridge exposing some of the oldest volcanics of the island (the Mt. Vezzi eruptive centre is about 126 ka old). Toward the graben, the ridge is limited by a NW trending fault scarp. This fault has been active also during historical times, feeding the Molara and Vateliero craters (3rd century B. C.). The opposite flank of the Ischia Graben is marked by a N trending fault on which the lava domes of Mt. Trippodi (2nd century B. C.) and Costa Sparaina (4.3 ka) lie. Further ahead we see the Mt. Barano and Mt. Cotto reliefs that are made up of lavas covered by the pyroclastic flow deposits of the Mt. Epomeo Green Tuff (55 ka) and white ashes of the Piano Liguori Formation (5-6 ka).

3.3 c - *The southern slope of Mt. Epomeo (Stop 8)*

We stop at Belvedere to have a general view of the Maronti bay and the southeastern slope of Mt. Epomeo. Until 1965 the Maronti beach extended as far as the S. Angelo peninsula, but the recent construction of structures able to interrupt the eastward directed littoral drift has resulted in the complete erosion of the beach from the western sector of the bay, with consequent reactivation of the sea cliff.

The southeastern slope of Mt. Epomeo exposes different vulcanic and sedimentary formations. Its upper part is made up of the Epomeo Green Tuff (55 ka) overlayed by two marine formations of Late Pleistocene age: the Mt. Epomeo Tuffite and the Colle Jetto formation. The former is 50 meters thick , conformably covers the Green Tuff and is regarded as the suacqueous equivalent of the

Citara pyroclastic formation (43-33 ka). The Colle Jetto formation (up to 100 meters thick) consists of an alternation of silt, clay, sand , marl and tuffite beds that are locally rich of both micro and macrofossils. As suggested by the fossil content, it was deposited in a nearshore marine environment that reached a maximum depth of about 70 meters. Its highest, residual outcrop occurs at an elevation of 620 metres, but it is reasonable to assume that this marine formation covered originally up to the upper edge the tilted, resurgent block of Mt. Epomeo, which is today at 787 m a.s.l. (fig. 13). Therefore, it can be concluded that an

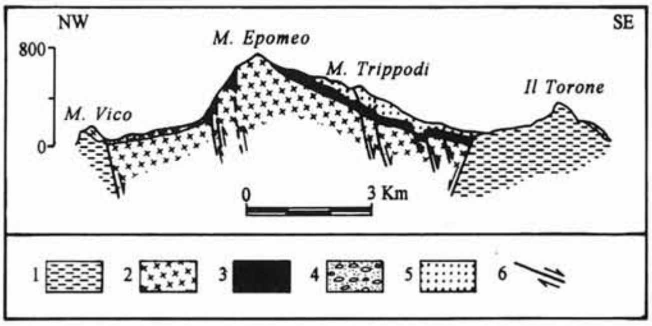

FIG. 13 - Schematic geological cross-section of Ischia island. 1) volcanics dated between 150 and 75 ka; 2) volcanics dated between 55 and 33 ka; 3) Upper Pleistocene marine deposits (Colle Jetto Frm.); 4) rock fall deposits; 5) volcanics dated between 10 ka and 1302 A.D.; 6) fault (modified after Orsi & *alii.,* 1991).

uplift in excess of 800 meters has affected the central part of Ischia in no more than 43 ka. Most of this uplift occurred probably before about 10 ka, when some of the Mt. Epomeo marginal faults were sealed by new volcanic reliefs.

The lower part of the Mt. Epomeo's south-western slope is extensively mantled by a problematic formation (hereinafter referred to as Mud Flow formation, or MF) which is up to 100-150 meters thick and has been differently interpreted by various authors. The hypotheses made range from that of a pile of landslide products (debris flows and mud flows) that would have occurred during and after the uplift of the Mt. Epomeo block, to that of a huge «debris avalanche» associated with a strong explosive eruption. As a matter of fact, some field characters suggest that this formation includes rock-fall deposits coming from active fault scarps, massive mudflows and debris flow as well as localised alluvial bodies showing a certain degree of sorting and crudely developed stratification. As we shall see at the next Stop, there is evidence that this compound formation was at least partly emplaced under the sea water and then uplifted.

The discontinuous nature of this uplift is evidenciated by well evident sub-horizontal terraces cut in the MF at various elevations. Both the morphological characters of these surfaces and the presence of beach deposits on some of them prove that they represent ancient abrasion platforms formed during three distinct phases of relative sea level stability (fig. 14). The terraces belonging to the first generation are displaced by normal faults that scatter them between 100 and 340 m a.s.l.. On the contrary, the second and third order terraces mantain a constant elevation all long the shore of the Maronti bay, resting at 50-60 and 20-25 meters a.s.l. respectively.

The 50-60 m terrace has a wide extension also out of the S.Angelo bay, reaching as far as the Campotese area. Also in the western part of Ischia there are traces of terrracing at altitudes comprised between 50 and 60 meters, always hanging above a younger paleo-sea-cliff. Near Mezzavia, in the northwestern sector of the island, fossiliferous beach depo-

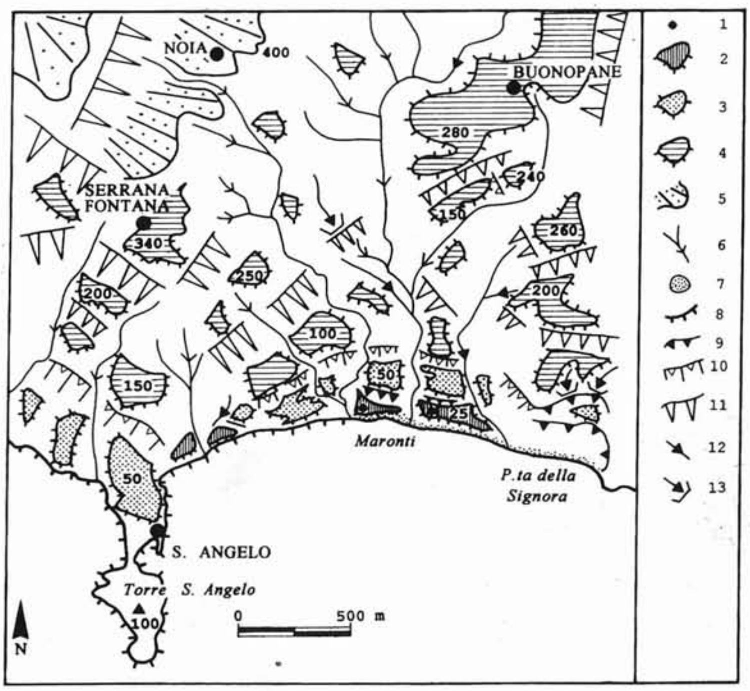

FIG. 14 - Schematic geomorphological map of Maronti area. 1) beach deposits with rounded pebbles of Roman age ; 2) First order of wave-cut terraces (20-25 m. a.s.l.); 3) second order of wave-cut terraces (50-60 m. a.s.l.); 4) third order of wave-cut terraces (>100 m. a.s.l.); 5) «mud flow» glacis; 6) gully; 7)) present beach; 8) active sea cliff; 9) palaeo-sea cliff; 10) structure controlled palaeo-sea cliff; 11) fault scarp; 12) subsequent valley; 13) hanging valley.

sits associated with a terrace resting at almost the same elevation has been radiometrically dated around 6 ka.

The 20-25 m terrace is to be referred to the Roman Age because fragments of pottery and roof tiles of that period have been found in the beach deposits (see # 3.3.d). With this regards, is worthy to observe that historical sources report that a sudden uplift of some ten meters affected the beach of Maronti during a strong earthquake occurred in the second century A.D.. Also to be stressed is the fact that the volcano-tectonic, vertical behaviour of Ischia has been fragmentary not only during the resurgence of the Mt. Epomeo block, but also during more recent times. This appears quite clear by contrasting the uplifted Roman terrace of Maronti with the Roman ruins of the first century B. C. found submerged at depths of up to 7 meters near Carta Romana and near Mt. Vico. Measurements taken in the last years also demonstrate that the southern part of Ischia (especially the sector comprised between the Mt. Epomeo and S. Angelo village) has been depressed of some centimeters with respect to the northern part of the island.

3.3 d - *Uplift induced forms of dissection and + 25 m marine terrace of Maronti (Stop 9)*

From the beach of Maronti we take a pathway that goes to the hot springs localized inside the Olmitello and Cava Scura gullies. Along the road we observe the lateral contact between the Green Tuff and the Mud Flow formations. The latter shows here its rock fall facies, characterized by large blocks and attaining a thickness of more than 50 metres (the base disappears under the sea). Towards the centre of the bay this facies is covered by finer grained deposits having centimetrical clasts dispersed into an abundant sandy-clayey matrix. The debris flow facies is exposed in the active sea cliff that occurs at the rear of the Maronti beach. Some of the boulders contained in the flow come from the marls and siltites of the Colle Jetto marine formation. Entering the Olmitello gully we can observe a stratified facies of the MF formation tilted down towards its original source area (i.e. the Mt. Epomeo). The upper part of the formation (that reaches here a total thickness of more than 100m) appears normally inclined toward the sea. Some sedimentological characteristics of the formation and the presence of a thin intercalation of microfossiliferous silty-clayey deposits suggest that it was deposited under the sea level. As we shall see also in the Cava Scura gully, the very steep flanks of these incisions are actively eroded and locally develop steep badland forms and pinnacles. The current tendency of these gullies to further extend and enlarge constitute a serious hazard for the houses and baths recently constructed along their beds and edges.

After Olmitello gully we visit the one of Cava Scura. We ascend its bed up to the point were the contact between the MF formation and the underlying Mt. Epomeo Tuffite is exposed. In this place the western flank of the gully preserves the ruins of some spa cabins that were excavated in the rock between 1600 and 1750, when the bed of the incision was about ten meters higher than todays. This permit to calculate that the gully downcuts at a rate comprised between 3 and 4 meters per century.

On the way back to Maronti we stop at an outcrop of the beach sediments that cover the 20-25 meters raised wave-cut platform. They are made up of well rounded pebbles and small boulders with some sandy matrix. Rounded fragments of Roman age pottery are also present in the deposit.

3.3 e - *Geomorphology of Mt. Epomeo's western slope (Stop 10)*

From Maronti we move by bus toward Panza and Forio, coming in view of the western slope of the Mt.Epomeo. Its upper part corresponds on N and NW trending fault scarps that are up to 70° steep and expose the Green Tuff formation. Both the lower parts of the slope and the almost flat area interveining between its base and the coast appear covered by landslide deposits including some very large blocks of green tuff. These deposits are a consequence of the high instability experienced by this sector of the island after the uplift of the Epomeo horst. The rockfall phenomena have been favoured by the cooling joints that crosses the Green Tuff with a spacing ranging from 0.5 to 5 meters, isolating blocks that can reach up to hundred cubic meters. By applying back analysis methods the cinematic mechanism of these rock fall phenomena was reconstructed leading to the identification of the influence areas and the most probable paths followed by rolling blocks. This work showed that a considerable portion of the island of Ischia is exposed to hazards derived by slope instability phenomena, including urban areas and zones used by man.

As proved by several historical written sources and scientific reports, ther is a strong causal link between volcano tectonic activity (e.g. the earthquake that destrojed Casamicciola in 1883) and the occurrence of large landslides. The analysis of the available data shows that events between the VII and VIII degree of the modified Mercalli scale can induce rock falls from the cliffs of The Mt. Epomeo and that earthquakes of higher energy (M>4) can also cause debris slides. Moreover, periods of intense rainfall can promote, besides new mud flows and debris flows, the reactivation of old landslide bodies. It seems that also the evolution of the Prehistoric, Greek and Roman settlements of Ischia reflects the occurrence of periods of intense volcanic and morphodynamic events. Some of them are also described by authors of the Antiquity as, for example, the great 460 B.C. earthquake mentioned by STRABO, which probably triggered the landslide that covered an ancient settlement near Forio. At the back of this coastal area, the slope descending from the Mt. Epomeo shows scarps, trenches and depressions to be interpreted as the results of recent deep-seated gravitational movements.

3.4 - FOURTH DAY

(P.P.C. Aucelli, A. Cinque & F. Russo)

3.4 a - *Sailing from Ischia Porto to Pozzuoli*

The transfer by ferry from Ischia to Pozzuoli gives us occasion to observe the well defined volcanic morphology of the western Phlegrean Area. As a whole (islands and submarine volcanoes included) it forms a SW-NE elongated high that bounds to the NW the Gulf of Naples structural depression (see Chapter 2).

THE PHLEGREAN FIELDS

Phlegrean (i.e. burning) Fields is the name given by the Greeks to an area extending beyond what geographers and geologists today call Campi Flegrei. It probaly included also Naples territory and Vesuvius. This was one of the places where the Greek mythology placed the battle between the Giants (living underground and responsible for earthquakes and eruptions) and the Olympic gods. As no volcanic eruption is known to have occurred during the Greek times (excluding the activity of Ischia), it is probable that the Greeks adapted a legend of the former Italics inhabitants to their own mythology.

The P.F. are an area were volcanism has been active since at least 50 ka, but most of its present morphology is to be referred to events which occurred after the implacement of the Campanian Ignimbrite (37 ka) when the area probably experienced a first phase of calderization. Another major event was the eruption of the Neapolitan Yellow Tuff (12ka) which substantially reshaped the topography of the area with its 40 cubic kilometers of products. Upon this eruption a second, smaller caldera formed which is some 12 km wide and centered on the town of Pozzuoli. All the volcanic activity which occurred after 12ka is located within this second caldera, which was also invaded by the sea during the Post Glacial transgression. In the middle of the Holocene, the northern half of the caldera was uplifted, while the southern half remained under the sea level to form the present bay of Pozzuoli (see # 3.4.c).

The morphology of the P.F. is characterized by a gently inclined outer slope (the so called Archiflegreo volcano), which is preserved in outcrop only N and NE of the caldera area; elsewhere it is downfaulted and disappears either under the Tyrrhenian sea or under the Campana Plain. On the other hand, the caldera area shows a complex pattern of mutually intersecting tuff-cones and tuff-rings some of which host (or hosted in the past) lakes and marine embayments (fig. 15).

Even though volcanic activity has been gradually decreasing during the last 10 ka, the volcanic risks are very high in this densely populated area, especially around Pozzuoli. Particularly to be feared is the possibility (suggested by the past behaviour of the area) that future eruptions will more probably occur along new vents, rather than inside pre-existing craters. Other problems arise from the possibility of crisis of ground movements, which can occur even at rates of many millimeters per day and sum up to several meters in few years.

We first pass the Ischia Channel, whose bottom is punctuated by remains of eruptive centers (La Catena, Formiche di Vivara, Secca d'Ischia, Ruommoli) which are not precisely dated, but not younger than 40 ka. Then we pass near the islands of Vivara and Procida, whose relief is almost entirely made of trachybasaltic pyroclastics emitted

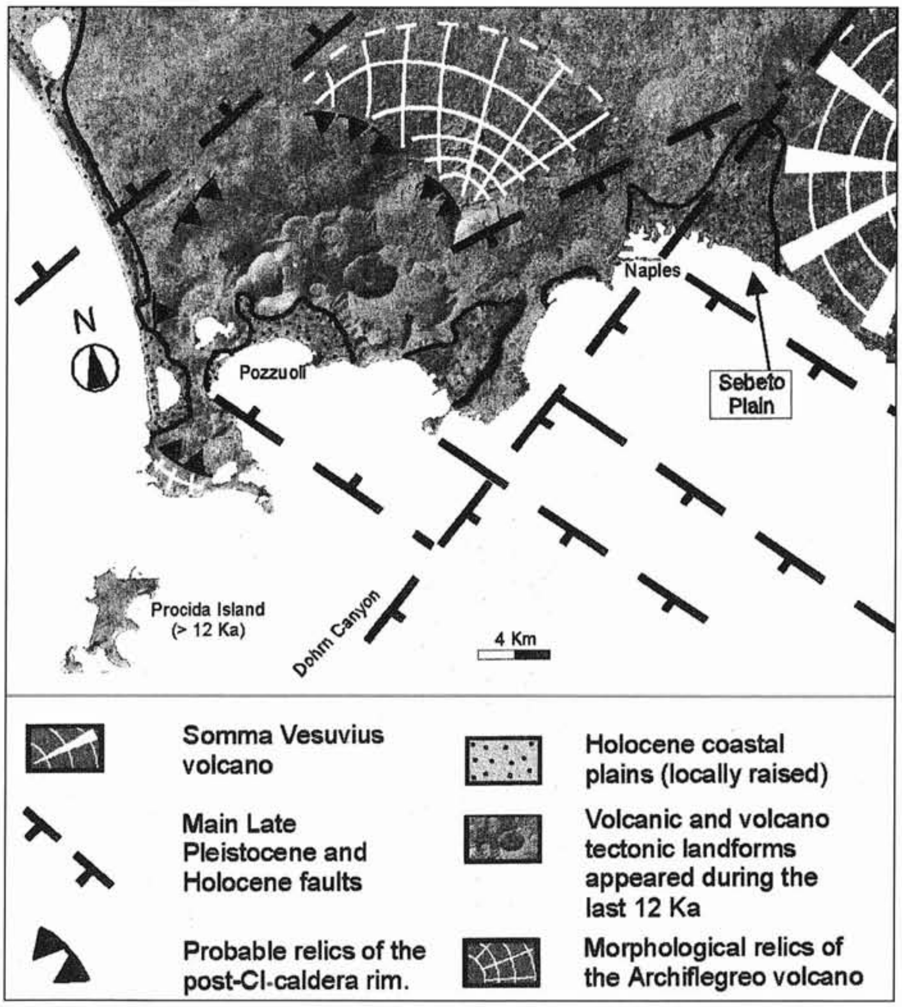

FIG. 15 - Major morphostructural units of the north-western portion of the Gulf of Naples.

by seven local vents active beetween 40 ka (Vivara volcano) and 27 ka (Solchiaro volcano). The occurrence of submarine pyroclastic units proves that this area too experienced some volcano-tectonic uplift during the end part of the Late Pleistocene. Due to the centripetal marine erosion which occurred during the Post Glacial transgression and following high stand, Procida appears as a sort of *mesa* characterised by a gently rolling top surface bounded all round by steep coastal cliffs. At Vivara and Punta Serra the Olocene marine erosion has open two ancient crateric depressions forming semicircular bays. After passed Procida, we move toward the mainland coming in sight of its Monte di Procida promontory. The sea cliff here exposes a sequence of pyroclastics emitted between 27 and 14 ka by various nearby centres (Miliscola, Torrefumo, Torregaveta and S. Martino) as well as by two volcanos of Procida (Fiumicello and Solchiaro). Soon after we round the promontory of Miseno, which is composed of a terminal tuff cone (eroded by the sea and thus showing perfectly its internal structure) which is connected to the mainland through a Late Olocene tombolo. Similarly to what can be reconstructed for the area of Pozzuoli (see # 3.4.b), also near Miseno cape there are submerged and emerged geo-archaeological evidence that a subsidence of about 13 meters occurred between the Roman period and the Middle Age, followed by an uplift of about 5 meters. After Miseno we enter into the Bay of Pozzuoli, which is host by the relict depression of the complex Phlegrean Fields caldera. Around the bay are a number of mutually intersecting volcanic reliefs (mostly tuff cones and tuff rings) formed during the last 10ka above the calderized remnants of the relief created by the Neapolitan Yellow Tuff (12 ka). The bay has a flat floored central depression that reaches 130 m b.s.l. and is limited also southwards by a roughly semicircular alignment of submerged volcanic reliefs (i.e. the banks of Miseno, -26 m; Pentapalummo, –44 m; Carenella, –108 m; Secca del Pampano, –98 m; Nisida, –72 m).

Along the coast between Capo Miseno and Pozzuoli a dense sequence of submerged Roman ruins exist up to a depth of about 10 meters. Approaching the port of Pozzuoli we note that the northern part of the caldera floor is occupied by the marine terrace of La Starza, raised 40 to 60 meters a.s.l. and limited by an inactive sea cliff. The terrace corresponds to the top surface of a succession alternating beach deposits and pyroclastic beds. It was uplifted almost to its present elevation between 4.6 and 4 millennia ago. During the Roman age (when *Puteoli* was one of the Empire's most important ports) a coastal plain much wider than the present one occurred at the base of the La Starza marginal cliff. This coastal strip was occupied by the harbour and commercial quarters of the town, whose residential part extended on the terrace and the nearby tuffaceous promontory of Rione Terra.

3.4 b - *The history of vertical ground movement narrated by the Serapeo (Stop 11)*

Among the numerous Roman ruins discovered at the foot of the La Starza marginal cliff, the Serapeo is certainly the most interesting one. Among the geologists it is worldwide famous since it appeared on the cover of LYELL's classical textbook of Geology in 1880. This fame is due to the fact that the columns of this building -acting as a sort of tide-gauge- recorded the ground movements which occurred in Pozzuoli during the last two millennia. The Serapeo was probably a temple devoted to the Egjptian God Serapide in the second century B.C.. Later it became a macellum (i.e. a pubblic market). At the beginning of the third century A.D. it needed some restoration because it had been severly damaged by the sea. As those restoration works involved the costruction of a second pavement about two meters higher than the former one, we infer that it was because of ground subsidence that the building had come in reach of storm breakers. For similar reasons we suppose that the second pavement - today emerging a few decimeters from the sea water- was very few meters above sea level (likely 2 or 3) in the third century. A stronger phase of subsidence occurred during the Middle Age, probably peaking between the 10^{th} and 12^{th} centuries. At that time the building was already ruined and the second pavement was already covered by about one meter of continental sediments. As we can judge from the litophagus perforations occurring on three survived marble columns of the market, the maximum flooding level reached 6.8 meters from the second pavement. A period of remarkable uplift occurred then during the first decades of the 16th century, probably in relation to a phase of caldera inflation precurring the eruption that constructed the Monte Nuovo («new mountain») scoria-cone some 2 km west of the Serapeo. From 1538 to 1969 the coast of Pozzuoli experienced a gradual lowering (with a documented mean rate of 14 mm/yr from 1822 onwards).

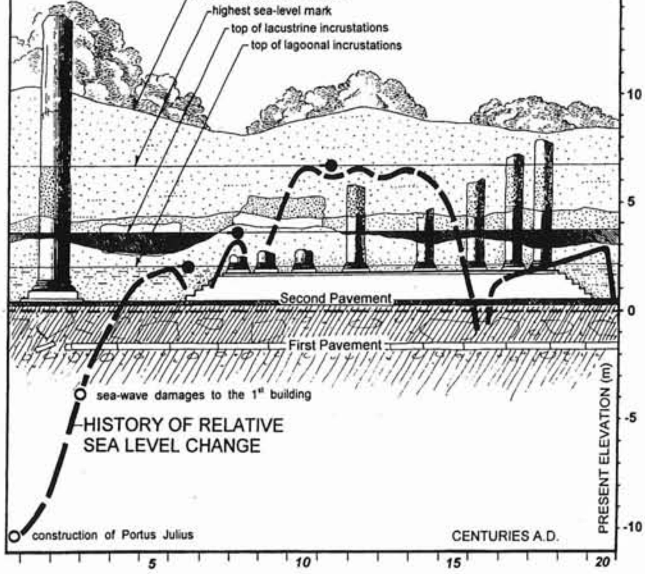

FIG. 16 - Curve of relative sea level change occurred in Pozzuoli since the Roman Age plotted on a section of the Serapeo ruins taken from C. BABBAGE (1847).

The recent bradyseismic events

Starting from the summer of 1969 the area of Pozzuoli was again affected by volcanic uplift (probably due to inflation of the thick and porous infill of the caldera) that reached a maximum of 1.70 m by December 1971. It was accompanied by a moderate seismicity that concentrated in the northern part of Pozzuoli bay and in the area between Averno and Agnano. Between mid-1972 and the end of 1974 the ground subsided 0.22 m, while for the next 8 years there was no significant change in elevation and almost no seismicity. At the beginning of 1982 a new intense uplift began with a low seismicity up to the end of the year. By the end of 1984, the maximum uplift was 1.8 m. Added to the 150 cm left by the 1969-74 events, this new uplift made unusable the piers of Pozzuoli's port, which had in fact to be raised urgently. From 1983 to the end of 1984 the seismicity was very intense (magnitude up to 4) with hypocentres located at shallow depth (no more than 4-5 km) in the northern part of Pozzuoli bay and its immediate hinterland. This seismic activity caused severe damages to the town and 40,000 inhabitants were evacuated from Pozzuoli. A large part of them live now in an entirely new village (planned during the 82-84 crisis) resting outside the caldera rim (Monte Ruscello Village). Since the end of 1984 the ground has generally subsided with small, scattered uplifts. The subsidence has never been accompanied by earthquakes, while seismicity did accompany the small uplifts.

3.4 c - *The Holocene marine terrace of La Starza (Stop 12)*

Along the road to Baia we stop at the base of the abandoned sea cliff that bounds the Holocene marine terrace of La Starza (fig. 17). The succession exposed in this cliff corresponds on the upper portion of a sequence that continues also below the present sea level. It rests on a volcanic substratum made of the 12 ka old Nyt and includes fossiliferous litoral deposits (sandy and gravel beaches plus water laid cinder beds) in alternation with subaerial pyroclastic deposits and paleosoils. The lowest marine interval exposed in the cliff has been radiometrically dated 10.5 ka; an overlying paleosoil gave an age of about 8 ka and the uppermost beach deposits an age of about 4.6 ka. The continental intervals of the succession are interpreted as due to periods of uplift at rates higher than sea level rise. The first transgressive episode was able to invade most of the Phlaegrean Fields caldera, while the following ones had their penetration contrasted by newly appeared volcanic edifices and fault scarps. In the outcrops visible along the coastal cliff the highest marine interval is at about 30 m a.s.l., but further inland beach deposits have been found up to a maximum elevation of about 50 m.

The fact that La Starza surface was already deeply dissected when it was covered by the Monte Spina Pyroclastic-flow and Monte Olibano lava dome (4 ka) permits the

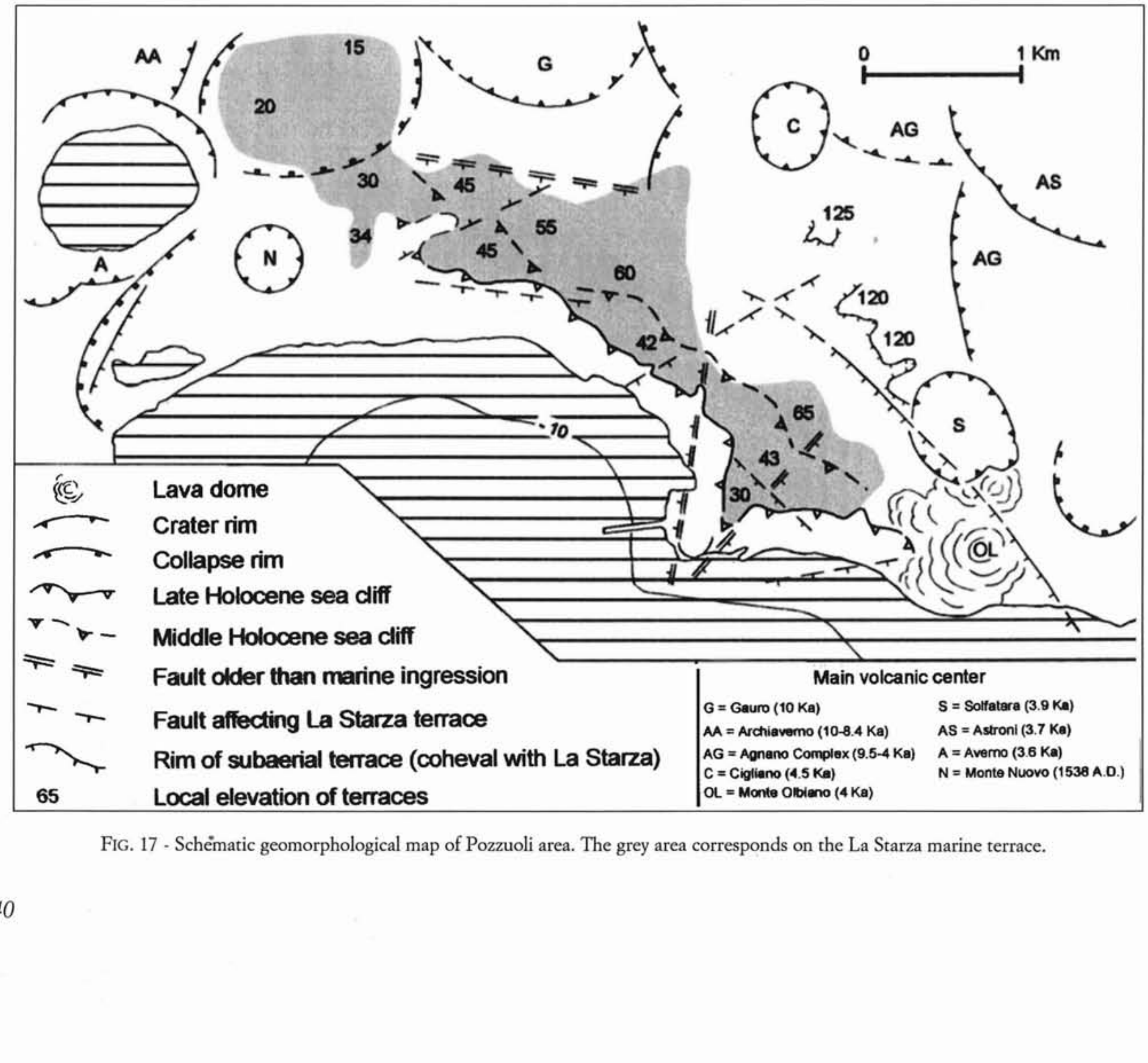

FIG. 17 - Schematic geomorphological map of Pozzuoli area. The grey area corresponds on the La Starza marine terrace.

inference that the terrace was already uplifted to almost its present elevation when those eruptions occurred. This strong and fast final uplift (about 30 meters in few centuries) was probably related to the resurgence of a portion of the caldera that accompanied the onset of a new period of strong volcanic activity of the Phlegrean Fields. The said uplift did not homogeneously affect the whole post-12 ka caldera and the conditions for magmas to rise to surface were enstablished only in those parts of the caldera floor subject to an extensional stress regime.

3.4 d - *From Pozzuoli to Baia*

Along the road to Baia we encounter the 150 meters high volcanic cone of Monte Nuovo, the very youngest of the above 30 monogenic volcanic centres identificable within the Phlegrean Fields. Most of the cone formed between September 29 and 30, 1538 by superimposed low temperature, muddy pyroclastic flows. After five days of rest there was a final resumption consisting of two days of Strombolian activity that covered the edifice with a mantle of scoria. On October 6th a scoria-flow associated with this activity surprised and killed 24 people that were there to observe the eruption.

3.4 e - *Sailing from Baia to Pozzuoli*

The boat *Cymba* takes us back from the port of Baia to that of Pozzuoli. Through the transparent keel of the boat we can observe the submerged archaeological remains that punctuate the near shore strip of the bay. The first ruins we see represent the submerged prosecution of the ancient *Baiae*, whose upper part is witnessed by the ruins exposed along the steep coastal slope (e.g. the magnificent Imperial Villa of Baia, also known as Cesar Palace). The so called Venere, Mercurio and Diana Temples, whose basal parts disappear under the sea level, lay originally on the elevated, inner part of a relatively wide coastal plain interveining between the shoreline of that time and the foot of the hill.

Off the Punta Epitaffio cape the remains of other Roman villas, ninfeos and roads are visible at about 7 m b.s.l. Between Lucrino and Pozzuoli all the strip comprised between the modern beach and -10 meters is punctuated by remnants of houses and roads which remained emerged at least till the third century A.D.. Near Pozzuoli we also note the submerged remnants of the large Portus Iulius (constructed in 36-37 B. C.) and the adjacent commercial quarter of the ancient *Puteoli*. On the base of geomorphological and archaeological evidence the coastline of the of the period when Portus Julius was built has been recognized at about 10 meters below the present sea level. Coupling this evidence with that available from the Serapeo and other emerged ruins, it can be concluded that a total subsidence of 16-17 meters has affected the Pozzuoli area between the 1st century and the 10th-12th century. This period of prevailing subsidence was interrupted by a phase of rest during the early Middle Age and was followed by 6-7 meters of uplift in the period comprised between the Renaissance Age (15th-16th century) and 1969 (fig. 16).

3.4 f - *From Pozzuoli to Naples (Stop 13)*

On the way back to Naples we stop at the Solfatara volcano (active since 3.9 ka) to visit the fumaroles and the boiling mud pools located inside its crater. The ring around the crater exposes a basal phreato-magmatic breccia overlain by pyroclastic-flow deposits. The composition and temperature of some fumaroles (up to 157 °C) are monitored by the Osservatorio Vesuviano as part of the Phlaegran Fields surveillance. During the 1983-85 seismic crisis the Solfatara area has been shaken by the most energetic earthquakes (magnitude 4+) and new fractures opened on the crater floor. Near the fumarolic vents incrustations of Realgar (AsS) forms that weather rapidly into Orpimento (As_2S_3).

After the visit to the Solfatara we return to Naples along the Tangenziale highway, which offers us other views of the volcanic and volcano-tectonic features that charactेrizes the landscape of the Phlegrean Fields.