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GEOMORPHOLOGICAL HAZARDS IN THE MUGELLO VALLEY (TUSCANY, ITALY) (****)

Abstract: GARZONIO C.A., MORETTI S., RODOLFI G. & ZANCHI C. - *Geomorphological hazards in the Mugello Valley (Tuscany, Italy).*

This work synthesises the results obtained from a series of researches carried out during the last decade in the Mugello valley, highly representative of a particular environmental situation very frequent in the interapenninic areas of peninsular Italy.

After a description of the climatic, geological, historical and social-economic characteristics of the area, the authors analyse and evaluate the different aspects of geomorphological hazards (soil erosion, mass movements, river dynamics) partly dependent on the recent development of the agricultural and industrial economy.

KEY WORDS: Soil erosion, Mass movements, Flood hazard, Mugello valley, Tuscany (Italy).

Riassunto: GARZONIO C.A., MORETTI S., RODOLFI G. & ZANCHI C. - *Rischi geomorfologici nel Mugello (Toscana).*

Il lavoro sintetizza i risultati ottenuti nel corso di una serie di ricerche effettuate nell'ultimo decennio nella valle del Mugello, altamente rappresentativa di una particolare situazione ambientale molto frequente nelle aree interappenniniche dell'Italia peninsulare.

Dopo una descrizione delle caratteristiche climatiche, geologiche, storiche e socio-economiche del comprensorio, vengono analizzate e valutate le varie espressioni del rischio geomorfologico (erosione del suolo, movimenti di massa, dinamica fluviale) in parte connesse con i recenti sviluppi della economica agricola ed industriale.

TERMINI CHIAVE: Erosione del suolo, Movimenti di massa, Rischio di esondazione, Mugello, Toscana.

INTRODUCTION

The depression of the Mugello, situated at about 30 km to the North of Florence in the direction of Bologna, coincides with the mid-upper part of the watershed of the Sieve R., the most important affluent of the River Arno. The basin lies between two parallel ridges of the Apennine system, with direction NW-SE: one which coincides with the Tyrrhenian-Adriatic watershed, and another which separates it from the adjacent Florence basin. The Calvana Mountains and the massif of the Mt. Falterona close this depression to the N and the S respectively. This depression, like other nearby ones, was formed during the extensive phase of the Apennine orogeny and, during the Villafranchian, was the site of a large deep lake.

Its geographical position as an intermontane basin situated in the centre of the peninsula of Italy, at an equal distance from both the Tyrrhenian and the Adriatic coasts, has had a considerable influence on the local climate. Even though it falls within the temperate climatic zone with a dry season (cfsa, according to Köppen) or the Mediterranean climate category, it also has some characteristics of a continental climate. The rigours of the climate and its isolated position with respect to the main road network conditioned the choice of agricultural crops and their commercialization respectively, thus relegating the Mugello area to an unfavourable economic situation for many years. Up to the 1950s the only productive activity was agriculture and this was regulated by the mezzadria contract (the farmworker and the landowner divided the produce) and it was carried out using rudimentary techniques based on the use of animals. Therefore, as a result, the farmland was divided up into many small plots with mainly mixed crops, grass and tree crops. A dense network of irrigation systems (surface channelling, drainage) assured sufficient control of the waters and consequently slope stability.

The industrial boom in the 1960s affected the adjoining Florence basin first: many farmers left their agriculture and their homes to go and work in industry where they earned more. They moved away to the neighbouring towns; this exodus was to leave the countryside virtually uninhabited. After a few years industries began to spring up in the

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Mugello too, thus enticing the few farmers left towards the towns. The expansion of the towns and the consequent sudden increase in the building industry was a direct result of this urbanization phenomenon. At the same time the road networks were improved, expecially with the construction of the Autostrada del Sole motorway. This provided a fast link between Florence and Bologna passing through the Apennines and it intercepted the road network of the Mugello at the head of the valley, thus helping to overcome its isolated position. This resulted in a further expansion of the industrial and urban areas on the valley plain.

At the same time agricultural activity returned to the hilly slopes once again but this time with different techniques: animals were replaced by mechanical methods. The use of machines was profitable, but it called for radical changes in the agricultural systems. Mixed crops (first of all the bare fallow) which allowed for complete mechanization of the operations; the plots were therefore extended and the morphological irregularities, both natural and artificial, were levelled.

This new social-economic situation caused deep changes in the physical environment. The construction of the new infrastructures (road networks, civil and industrial construction) called for large quantities of aggregate. This was taken from the sites which were most readily available and at the lowest extraction cost possible. Taking advantage of the lack of adequate protection norms, the materials were taken directly from the river beds (especially the Sieve R.), thus causing a gradual lowering of their levels. At the same time increasingly large areas were built on, thus causing a significant increase in the runoff coefficient of the water courses. On the slopes in the central part of the valley which are mainly composed of clayey-silty deposits of the lacustrine phase, the new agricultural techniques altered the irrigation network and exposed greater areas to rainfall attack: a considerable increase in soil erosion occurred and the first mass movements appeared, or dormant ones became active again. The situation of increasing degradation contributed to a large extent to amplifying the effects of the flood disaster on 4th Nov. 1966 which hit the entire River Arno basin.

From then on, even though the soil-use typology remained unchanged, a growing awareness of the problems linked to the vulnerability of the physical environment led to the issuing of the first land management and planning measures: e.g. all riverbed excavations were stopped, but the inertia of the phenomenon which had previously been triggered off still continues to manifest itself in clearly visible bank erosion. As a result, applied scientific research was also keep to become involved: the finalized projects of the Consiglio Nazionale delle Ricerche (National Research Council) «Soil Conservation», completed in 1975 and the more recent «Productivity Increase of Agricultural Resouces» started in 1982 and finished not long ago, have contributed in highlighting, also in the Mugello Valley, the various geomorphological hazards and in evaluating their intensity, not only in relation to the natural dynamics but also in relation to the human activity.

Still on the same subject, we must take into account the fact that, in the near future, this region will see its vulnerability increased with the construction of important public facilities. In the higher part of the valley, work is currently underway on the construction of a reservoir, with a capacity of 80 million m^3 and a surface area of 500 ha, which will provide the city of Florence with water. The stretch of the

TABLE 1

MONTHLY AND YEARLY MEAN VALUES OF THE RAIN (in mm), NUMBER OF RAINY DAYS FOR SOME RAIN GAUGES IN THE MUGELLO VALLEY.

Station	G	F	M	A	M	J	J	A	S	O	N	D	Yearly mean
Casaglia (754 m a.s.l.)	142	137	123	121	120	76	40	47	115	182	180	158	1145
1925-1943/1952-1956	11	10	10	10	11	7	4	4	8	12	13	12	113
Razzuolo (635 m a.s.l.)	116	116	125	126	100	83	50	89	118	127	191	151	1395
1959-1975	11	10	11	11	10	8	5	7	8	9	14	11	115
Ronta (364 m a.s.l.)	97	113	93	99	92	78	45	57	96	109	152	123	1154
1937-1975	11	10	10	10	9	7	4	5	6	9	12	12	105
Borgo S. Lorenzo (193 m a.s.l.)	94	113	87	79	77	54	31	55	86	106	149	114	1047
1947-1974	10	10	9	9	9	7	4	5	9	8	11	11	102
Montesenario (815 m a.s.l.)	102	123	84	83	86	60	29	30	73	108	135	128	1041
1945-1962	—	—	—	—	—	—	—	—	—	—	—	—	—
Calvanella (707 m a.s.l.)	92	97	73	95	98	67	32	93	114	78	184	103	1126
1965-1974	10	11	8	11	9	7	4	7	8	8	12	9	104

Autostrada del Sole motorway which involves the Mugello will have to be doubled to cope with the heavy traffic between Florence and Bologna. A motorway connection which will provide a direct link between Bologna and Rome will cut across the valley and run parallel to the already planned high speed Milan-Rome railway. These works will involve an area which has a precarious equilibrium both in terms of the exogenic (geomorphological risks illustrated above) and to a lesser extent the endogenic (seismic risk) processes.

The aim of this work is to characterize, on the basis of the results of the research carried out in the last ten years, these processes and to evaluate their present intensity, with the prospect of contributing to the reduction of the impact that these planned works will have on the environment.

2. CLIMATE

The climate characteristics were established from data obtained from the weather stations present in the Mugello (Tab.1). Unfortunately there are few hydrographic survey stations operating in the area and so the analysis had to integrate the data available by taking into account some of the factors which influence the variability of the climate: e.g. altitude and exposure. In fact it is the configuration itself of the Mugello basin, which stretches in a NNE-SSW direction, that particularly influences the weather, both in terms of the appreciable differences in height and the exposure of the slopes themselves, and because of their sometimes very uneven morphology.

As we can see, as far as rainfall is concerned, there is

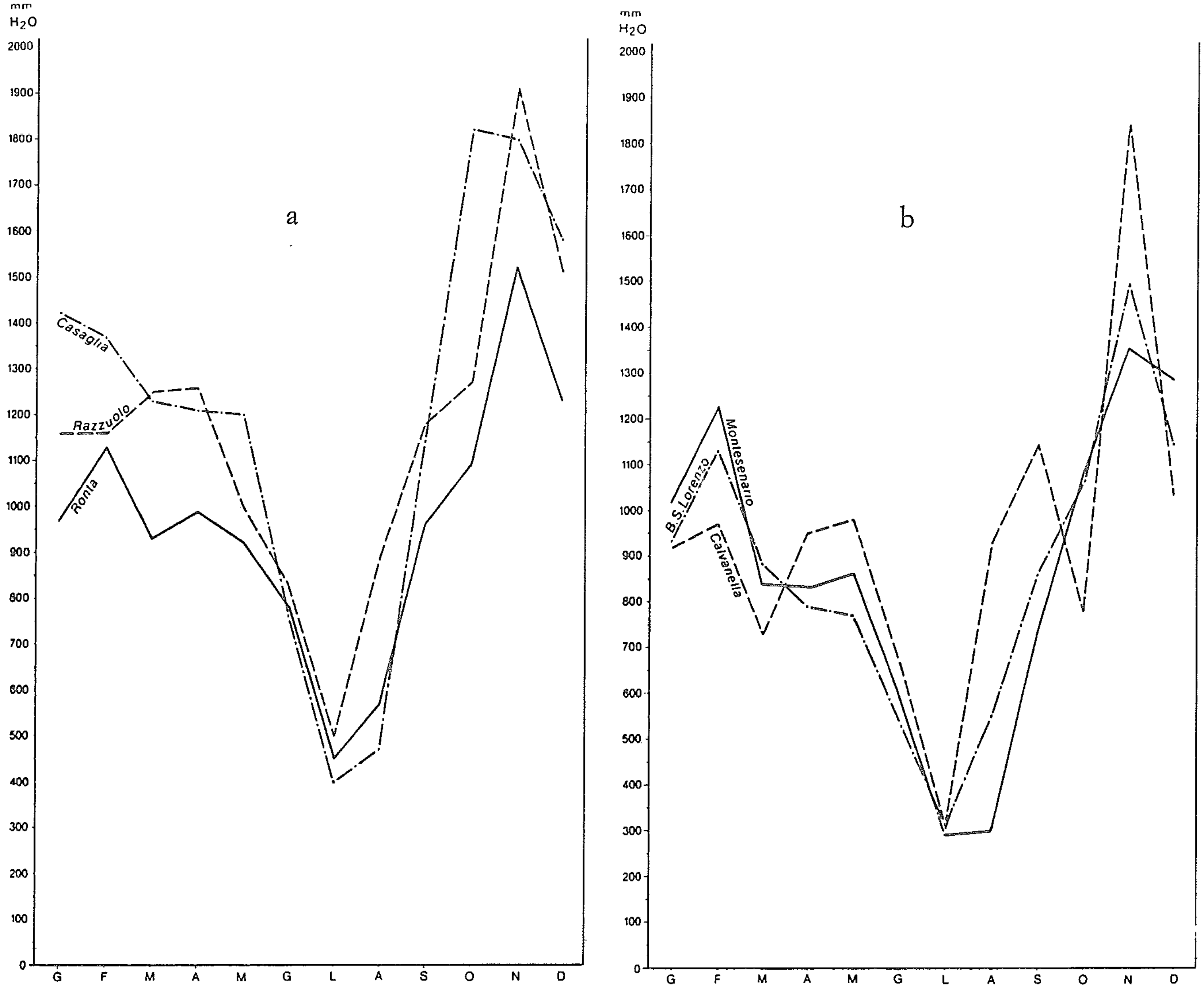

FIG. 1 a, b - Rainfall distribution (monthly mean) during the year: a) Raingauges on the northern piedmont and Adriatic slopes; b) Raingauges on the southern ridges and valley bottom.

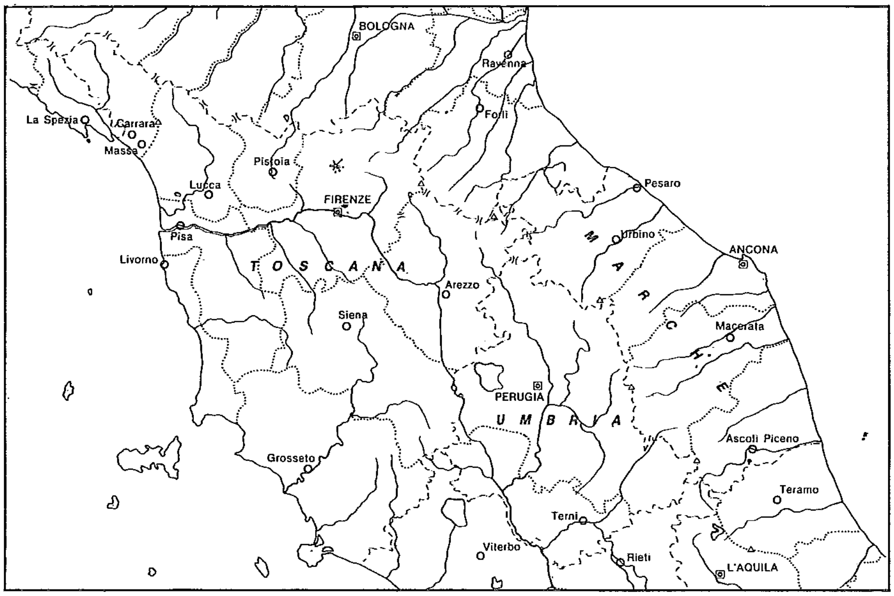

FIG. 2 - Location of the study area.

a certain homogeneity among the values for the northern part of Mt. Giovi-Mt. Senario and the valley plain, with the exception of the Polcanto stream. As we go up the opposite slope the values increase gradually until we reach Ronta at 1154 mm and Razzuolo at 1395 mm.

The general rainfall pattern during the year is characteristic of the Apennine rainfall régime (LANDI, 1976) with a summer minimum in July and two maxima, an autumn one in November and one at the end of winter (fig. 1a and 1b).

Therefore the climate can be classified, according to Köppen, as of «cfsa» type, i.e. temperate with a dry summer and continental characteristics.

Examination of the data allows us to make a forecast for the stations at higher altitudes (such as Barco, Pietramala and Traversa). These are, however, characterized by a considerably higher rainfall compared with the Giogo Pass and by a reduction or absence of the summer period of aridity with all the consequence which follow, especially from the agricultural point of view. Furthermore, examination of the rainfall has made it possible to evaluate the rainfall erosivity by means of the method indicated by WISCHMEIER & SMITH (1978). The average erosivity value for the area under examination came out as about 2010 MJmm/ha.h.y (megajoule millimeter/hectare.hour.year).

3. GEOLOGICAL SETTING

The mid-western part of the catchment basin of the Sieve river, an affluent on the right side of the River Arno, is called the Mugello valley (fig. 2). Its geological history coincides for the most part, and at least until relatively recent times, with that of the northern sector of the Apennine chain.

The first compressive stress caused by the Apennine orogenesis took place around the Middle Miocene. These phenomena provoked the emergence of the Tyrrhenian structures (i.e., Monti dell'Uccellina, Colline Metallifere, Montagnola Senese, etc.). Following subsequent pulses, other more recent structures were added to the previous ones. The more recent structures gradually emerged in the E and the result was a typically folded structure.

By the end of the Miocene, the principal framework of the Apennines had already appeared. It could be imagined as a series of ridges trending NW-SE, alternating with depressions running parallel to them. The early Mugello Valley coincided with part of one of these «valleys», contained between two ridges: one in the S separating it from the Florence-Prato basin and another in the N, corresponding approximately to one sector of the present main Apennine divide.

Fig. 3 illustrates the structural pattern of the Mugello. The most ancient geological formations outcropping belong to the Ligurian (Mt. Morello Unit and Chaotic Complex) and Sub-Ligurian (Canetolo) allochton structural units. The former is represented by predominantly shaly formations (Chaotic Complex) and by calcareous marly, calcarenitic and subordinately shaly formations. The latter unit is formed by the Canetolo Complex in arenaceous facies (Mt. Senario Sandstone).

Due to movements which started at the end of the Oligocene and continued up to the Tortonian, these units tectonically overlie the Tuscan units (autochton). The Tuscan units are formed by predominantly aranaceous flysch formations (Cervarola, Castel Gerino, M. Falterona sandstones) and by subordinately shaly formations (Pievepelago marls, Scaglia Toscana).

The Tuscan unit is partially overthrust on the Umbrian-

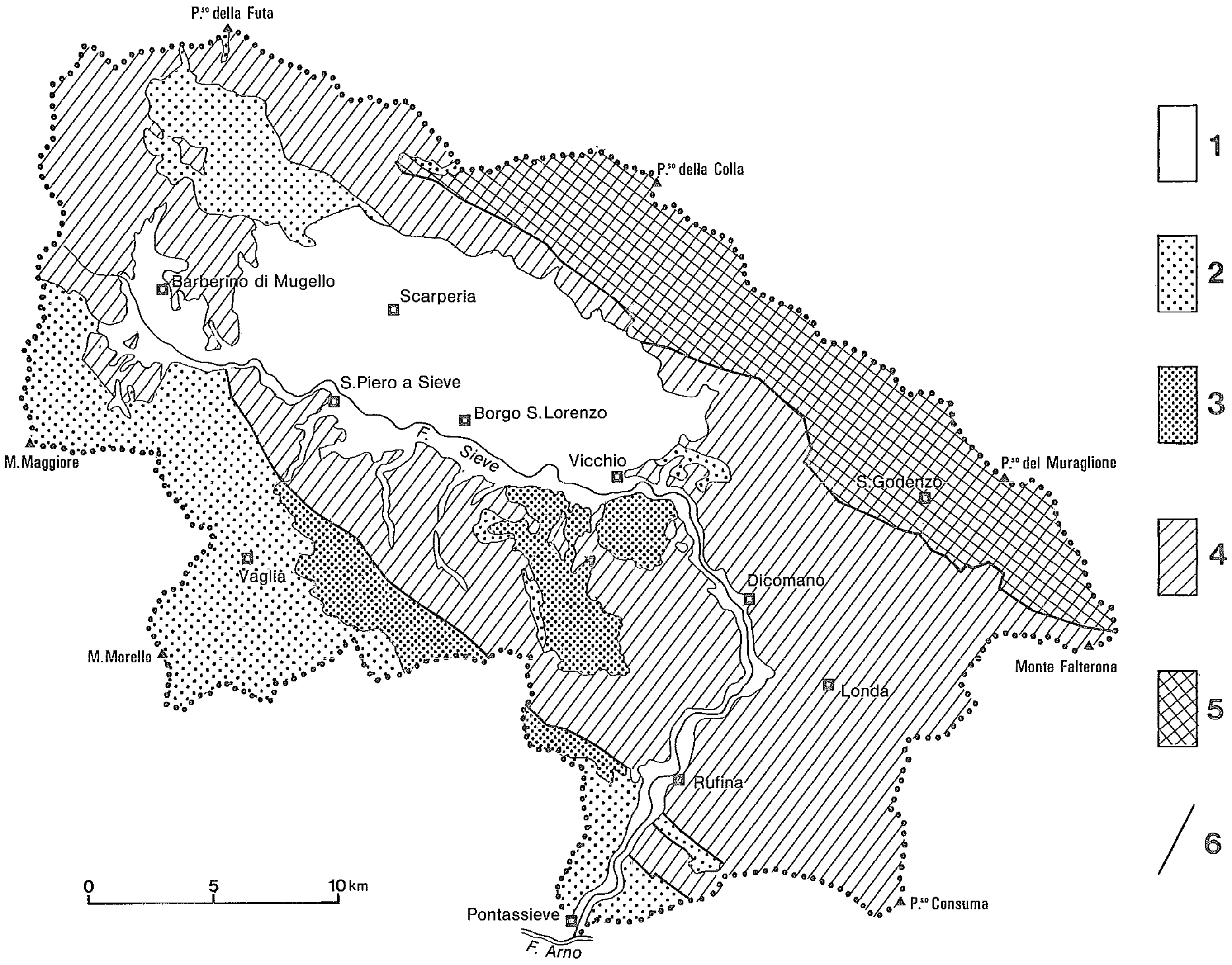

FIG. 3 - Sketch of the main structural features.
1) Lacustrine, Fluvio-lacustrine and alluvial deposits (Upper Pliocene - Quaternary).
2) Ligurian Units (Lower Cretacic - Paleocene)
3) Sub-Ligurian Units.
4) Cervarola Mt Units.
5) Marchigiano Romagnola Units.
6) Faults / Overthrusts.

Romagnola unit. The latter is represented exclusively by the marly arenaceous formation (arenaceous marly flysch). As far as the longitudinal dislocations are concerned, the most important lines correspond to the overthrust of the Tuscan unit on the Umbrian-Romagnola one in the north (from the Futa Pass to Mt. Falterona) and to the contact between the sub-Ligurian unit and the Tuscan one in the south (the northern slope of the Mt. Morello-Mt. Giovi ridge).

An important normal fault with an Apennine trend, linked to the recent widespread tectonics, had developed where the lacustrine deposits and the Tuscan units come into contact. There is also the hypothesis of the presence of a considerable dislocation on the southern side of the basin, buried under the fluvial-lacustrine sediments, with a NE dip (SANESI, 1965).

From the main anti-apennine traverse, dislocation lines, which can be identified in some cases by their hydrographic characteristics (FAZZUOLI & GUAZZONE 1971), the «Livorno-Sillaro», can be plotted and according to some authors the same holds for the «Piombino-Pontassieve-Faenza» line (BARTOLINI & *alii*, 1981). These lines border the lacustrine basin on the west and on the east respectively. The presence of two tectonic disturbances in the central part of the basin results from the drillings. Furthermore, from analysis of the substratum pattern and from some surface observations, there is the hypothesis of two tension faults (BERTELLO, 1984) which have broken the graben into a series of blocks which get progressively lower from W to E, as is testified by capture phenomena among the most easterly water courses and by the greater

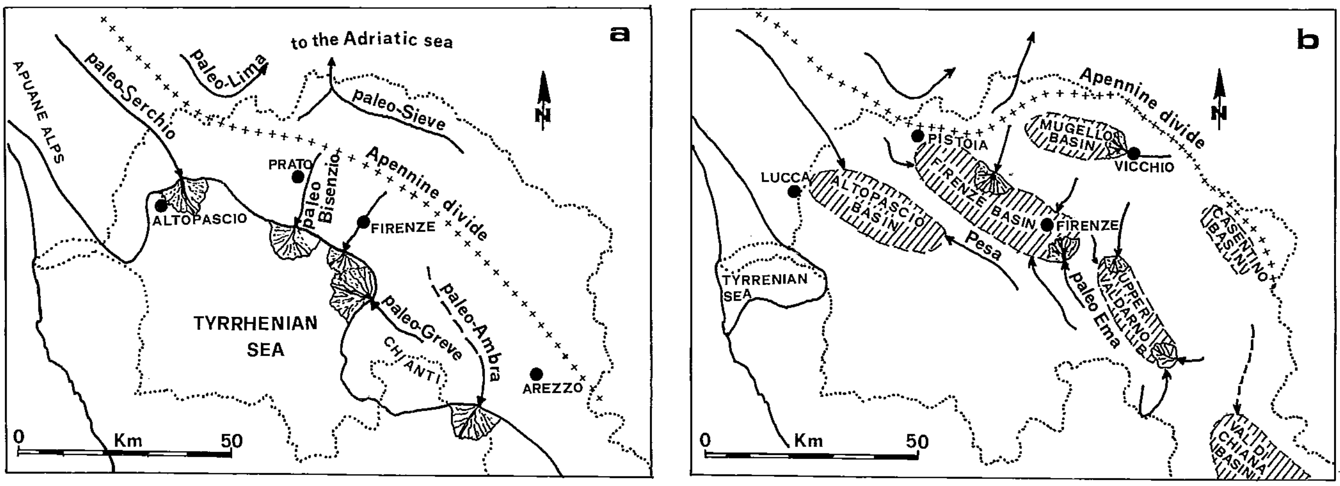

FIG. 4 - Evolution of the Arno River and Serchio River basins (from BARTOLINI & PRANZINI, 1981). a) Middle Pliocene drainage; b) Upper Villafranchian drainage.

thickness of the fluvial lacustrine sediments.

At the start of the Pliocene (fig. 4a), a second orogenic phase began. In this phase, extensive tectonic activity replaced the compressive activity, with stress directed in the opposite direction. Some parts of the previous depression underwent further collapse along fault planes trending in the same direction as that of the older structures. Secondary faults, perpendicular to the previous ones, interrupted this graben in some spots, thereby creating isolated areas of more limited extension which started to undergo gradual subsidence.

With the occurrence of this latter phase of orogenic activity (which is still in progress, e.g. seismic activity), the main characteristics of the valley emerged even more clearly. The continuance of the earlier depression in a NW-SE direction was interrupted in the N by the Calvana relief and in the S by the Falterona massif. In this manner, an extensive lacustrine basin was created (fig. 4b) which occupied the valley until the end of the earliest known glaciation (SANESI, 1965).

During this period, and perhaps in more recent times

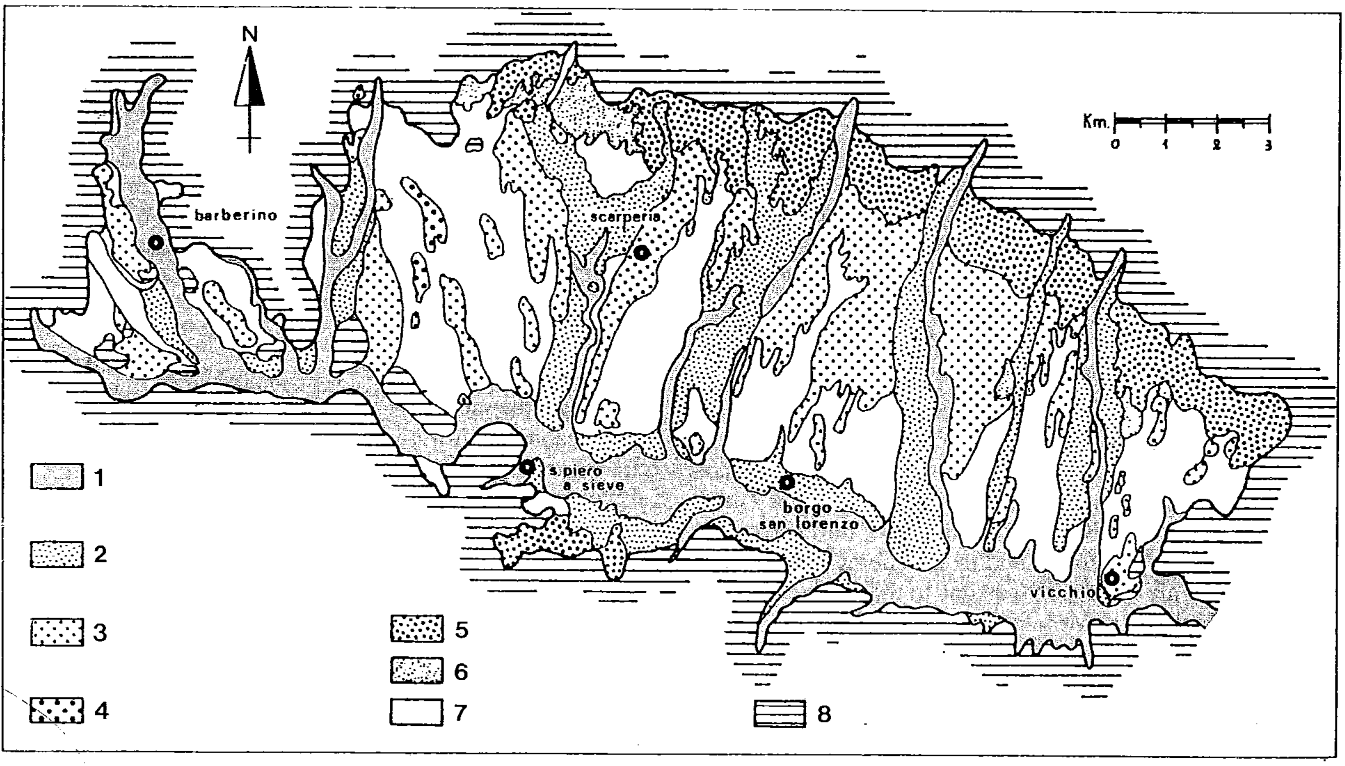

FIG. 5 - Geological sketch-map of the Mugello basin.
1) present and Olocene alluvial deposits; 2) last glaciation alluvial deposits; 3) penultimate glaciation alluvial deposits; 4) pre-penultimate glaciation alluvial deposits; 5) coastal fluvio-lacustrine deposits; 6) lacustrine sands; 7) lacustrine silts and clays; 8) pre-lacustrine bedrock.

as well, uplift of the northern ridge continued, as is revealed by the anomalous bedding of the coastal lacustrine deposits. The lake was infilled up and the River Sieve, the main drainage element, set its course at the foot of the southern ridge (fig. 5).

The lacustrine series is visible in limited tracts along the principal water-courses. The outcrops are essentially made up of clays, lignitic sandy clays and silts in the central part of the basin, and by sand and fluvio-lacustrine deposits in the border areas. Deep drilling (GEMINA, 1963) permitted the identification of a basal conglomerate and the evaluation of the thickness of that sequence as over 500 m.

At least four alternating phases of erosion and fluvial deposition must have occurred in succession during the later part of the Pleistocene (SANESI, 1965, 1977; RODOLFI & *alii,* 1978).

The terraced remnants of these deposits overlie lacustrine sediments in unconformity at various elevations, with respect to the recent alluvial plain of the River Sieve.

After the lake was filled and before the subsequent phases of terracing, there must have been erosion, whose extent, in terms of its intensity and duration, is difficult to determine. However, it was sufficient to destroy the greater part of the shoreline deposits from the former lake.

With the exception of scant remnants of an older surface, at higher elevations, the upper terrace is now broken up into tracts that extend perpendicularly to the basin's axis and show a slightly undulating surface that is evidence of the older drainage network. The numerous convergences of this surface towards the mouths of the Apennine valleys are also quite evident. They appear in the form of alluvial fans which are still quite distinct, even if terraced by the subsequent fluvial phases. The modalities of the sedimentation of this surface should be considered in relation to a fluvial environment with braided streams.

On their entry into the Mugello Basin the Apennine streams built extensive forms similar to alluvial fans. One of these, which is still well preserved, was noted in the basin of the Pesciola Torrent. Its preservation is probably due to a local attenuation of the fluvial dynamics in the erosive phase subsequent to the formation of this surface. In fact the larger streams re-worked the materials which were initially deposited, thereby annulling practically everywhere the forms which they had made, up to the point where they reduce them to isolated limbs which are then difficult to correlate with each other. On the other hand, the Pesciola torrent limited itself to continually deepening its bed, and always remained on the eastern margin of its ancient alluvial fan.

A study of the paleocurrents (fig. 6) was carried out in order to highlight the form described above. Besides confirming that the main Mugello paleosurface was almost entirely constructed by the Apennine streams, the study also highlights the fact that this surface is the result of the coalescence of different alluvial fans which extended their distal parts almost as far as the River Sieve.

As a period of biostasy drew near, pedogenesis leading to the formation of a soil of considerable thickness began (SANESI, 1965). That soil is found not in a complete series at present, but truncated at several levels.

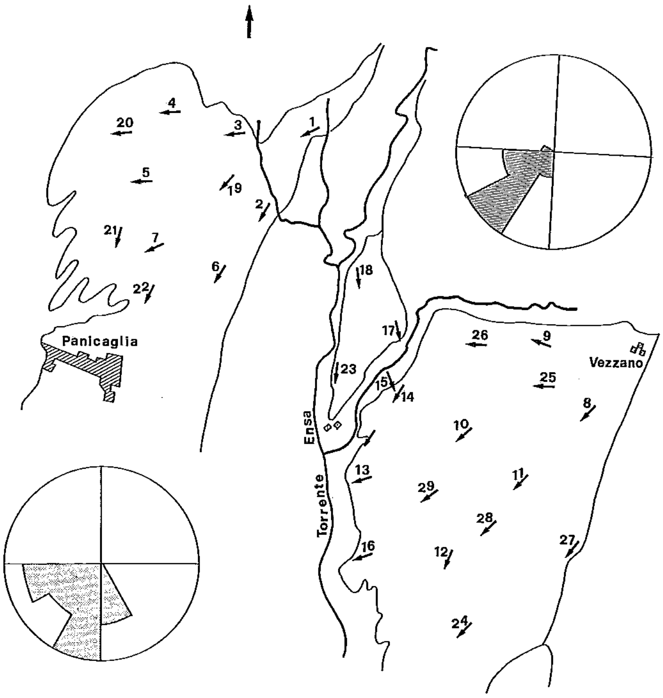

FIG. 6 - Palaeocurrent analysis on the pre-penultimate glaciation alluvial deposits.

The third surface or middle terrace, the pedogenesis of which dates back to the last glacial period, represents a subsequent cycle of fluvial deposition. Such surfaces are mostly found inside valleys, the interfluves of which consist of deposits of the upper terrace. A sequence of material with extremely varied particle sizes can be observed. In addition, there are lenses of heterogeneous material, which indicate deposition by braided streams. These deposits make up extensive plain surfaces that run parallel to the main tributaries on the left side of the River Sieve. At the confluence with the main valley, the deposits are arranged in the form of very flat fans (RODOLFI & *alii,* 1978), cut in their distal parts by subsequent erosive phases of the River Sieve.

The most recent terrace is of Holocene age. It developed along both sides of the River Sieve and is characterized by a marked counterslope and decreasing particle size of the deposits at increasing distances from the river bed. This situation testifies to the frequent overflowing of the Mugello Valley's main river, which continues to occur today.

4. HAZARDS

The progressive abandonment of the countryside mentioned in the introduction, which mainly affected the areas of the hills and mountains which were in the most disadvantageous positions, caused the degradation of the improvement works built in the past. Negative effects were also felt in the more fertile plain areas. This situation led to an acceleration of the erosive phenomena which in turn made many agricultural areas of the hills and mountains unproductive and damaged infrastructures and settlements even in the plains. This has led, in the last few years, not only to a growing awareness of the problems but also to the urgent need to combat these erosive phenomena. An adeguate zoning system, in keeping with the acceptable ways of utilizing the area, from a conservation point of view, is therefore necessary.

Such planning should have been and must be based on quantitative evaluation, at least in the erosive sector. This is the reason why a series of research projects were set up at the end of the 1960s, the aim being to quantify the erosion, taking into account the main factors acting in this process, and to determine what conservation measures were needed.

4.1. EROSION HAZARD

Erosion measurement was carried out at several sites in the Mugello with different morphological situations and agricultural conditions. The evaluation of erosion risk in the Mugello Basin has followed various lines of investigation. Given the vast extent of the area under examination (about 850 km^2, the entire basin of the river Sieve) it is clear that it is not possible to carry out extensive quantitative measurements within reasonable cost and time limits. Therefore it is necessary to find representative areas which are then studied in detail in order to extrapolate the data obtained to wider areas, choosing of course the most homogeneous areas possible.

We therefore proceeded by picking out the areas where the processes which have acted and which are still active at present have made it possible to identify categories of erosion risk.

In order to operate at this level it was necessary to identify all the processes and physical characteristics of the areal unit. For this first phase of the survey, various thematic maps were drawn up (land use, slope, pedology, geomorphology, lithology, quantitative analysis of the landforms) which enabled us to obtain a physiographic characterization of the area. Once this step was completed, it was then necessary to obtain quantitative data relating to soil loss from experimental plots. The third step consisted in evaluating the parameters relating to some of the soil properties, such as sealing and erodibility. During the work, soil charac-

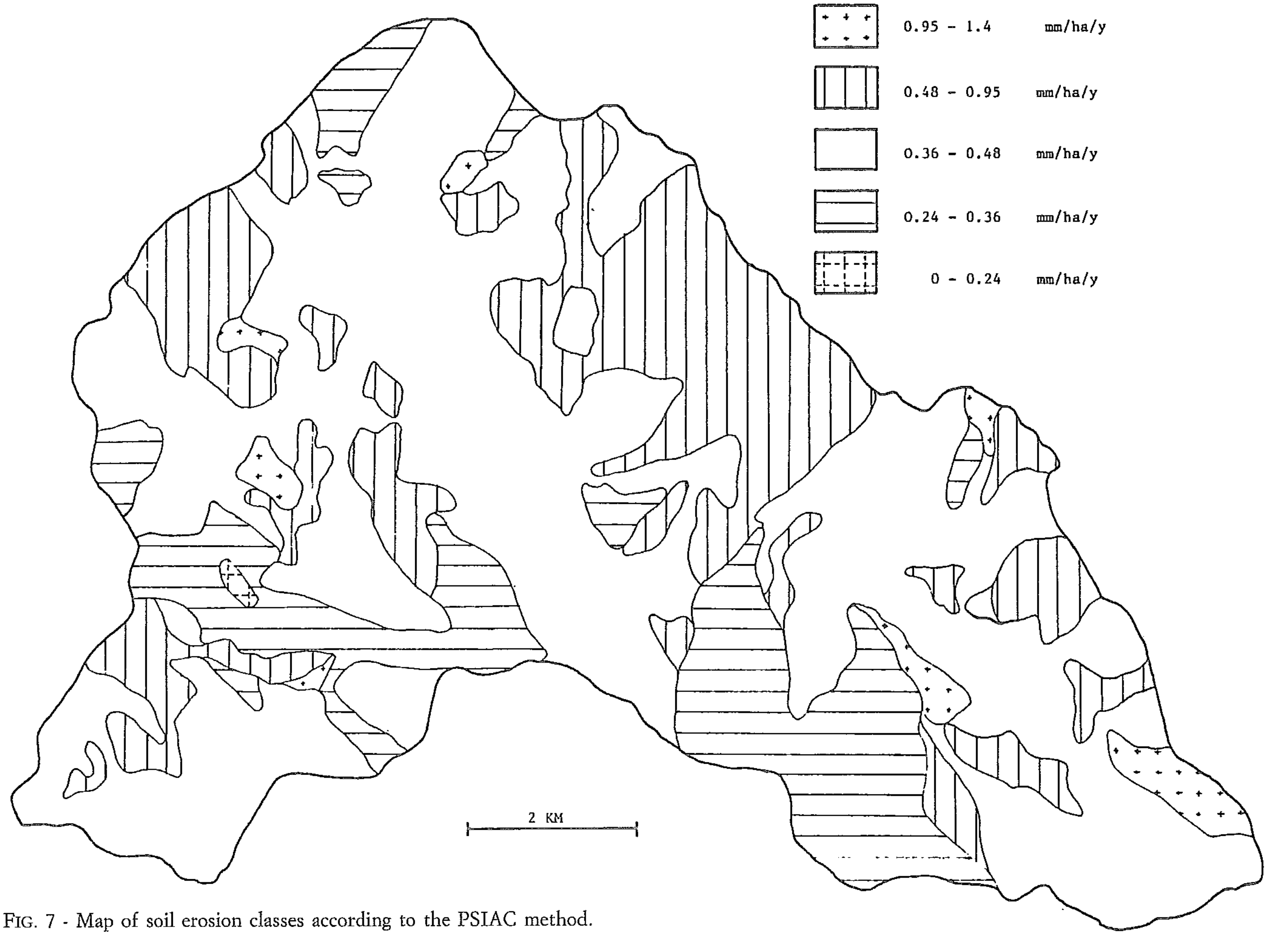

FIG. 7 - Map of soil erosion classes according to the PSIAC method.

teristics were analysed both in laboratory and field tests.

Evaluation of soil erosion is an integral part of the requirements of regional planning when carried out on the scale of drainage basin and of the analysis of land conservation techniques and hazard evaluation. Both practical and experimental scales are necessary especially if the final product is directed at the land managers.

On the regional scale, subdivision into hydrographic units comes from the fact that such units constitute the basic areal element for measuring soil loss to which we may relate the data obtained from indirect calculations by means of models such as P.S.I.A.C. (1968), U.S.L.E. U.S.D.H.A.L. (1974), or C.R.E.A.M.S. (1980). In the models the hydrographic units are described in terms of physical features such as lithology, soils, climate and morphology as well as the various land uses (in particular farming uses), in so far as these

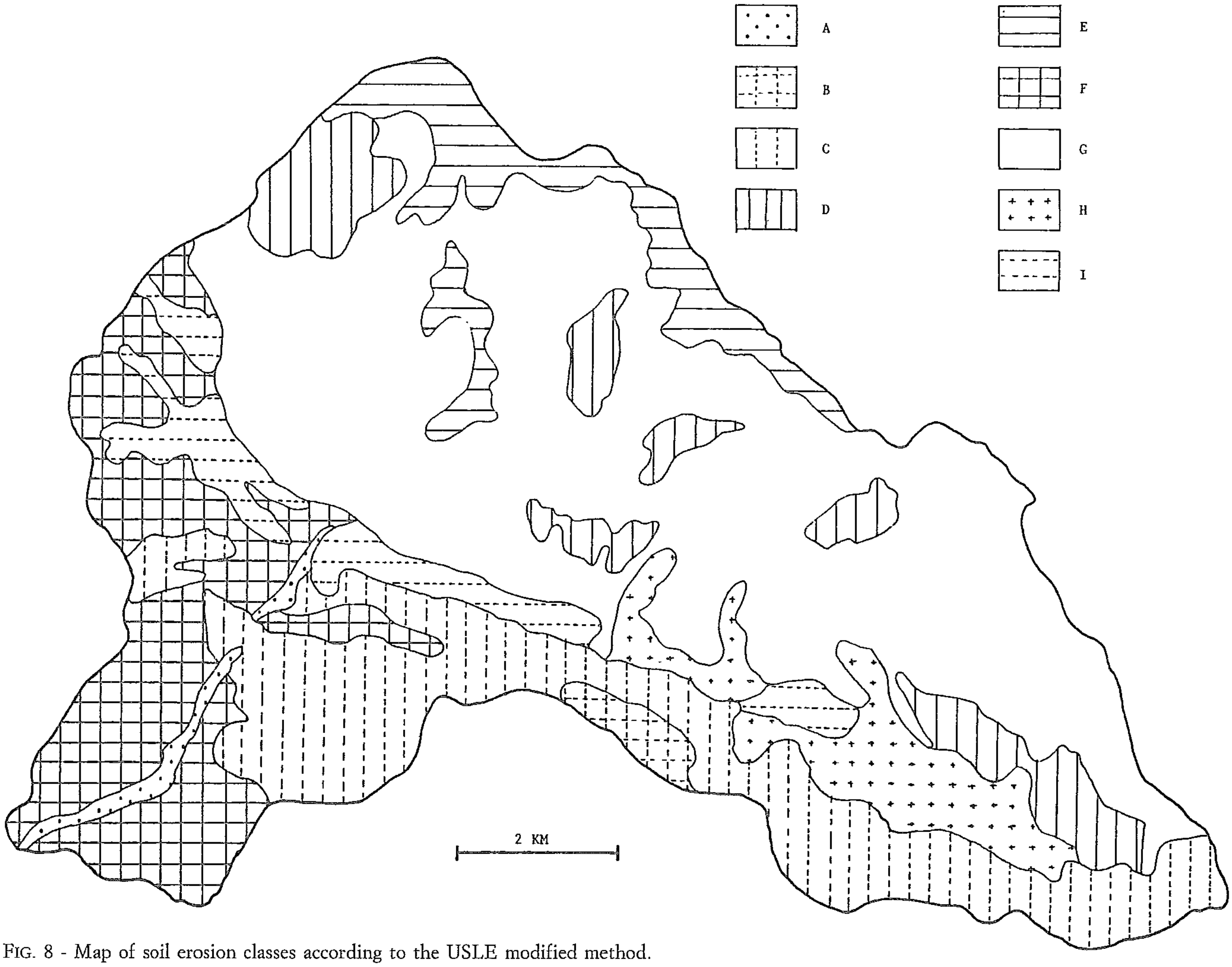

FIG. 8 - Map of soil erosion classes according to the USLE modified method.

MAP OF CLASSES OF SOIL EROSION OBTAINED USING THE USLE MODIFIED METHOD

Mapping units	Level of soil erosion	Classes of soil erosion mm/ha/y
A	Low	0.24 - 0
B	Medium Low	0.36 - 0.24
C	Medium	0.36 - 0.24
D	Moderate	0.48 - 0.36
E	High moderate	0.48 - 0.36
F	Medium high	0.95 - 0.48
G	High	0.95 - 0.48
H	Very high	1.4 - 0.95
I	Very high	1.4 - 0.95

are the main components in the process of accelerated erosion.

In the Mugello area, two main methodologies were employed: the PSIAC (Pacific South-West Inter-Agency Committes) and the USLE (Universal Soil Loss Equation). The PSIAC methodology was intended to give a broad evaluation of sediment yield in forested watersheds such as some subcatchments in the Mugello area. An example is that of the S. Godenzo torrent (Dicomano, Florence) an influent of the R. Sieve. The results indicate the need to maintain a broad vegetation cover in such a sub-basin in order to avoid an acceleration of erosion. In fact it should be made clear that in this basin the contribution of the topographic factor is of prime importance but the total sediment yield remains at rather low values because of the presence of a broad forest cover. The S. Godenzo Basin gives a result of 4.5-6.0 t/ha/year of soil loss, corresponding to an average yearly lowering of about 0.33-0.36 mm.

Further analyses have led to the implementation of both models in soil loss research. The work is based on the comparison of two different methods. This matching is done to integrate two different soil erosion evaluations which should give, in theory, the same soil loss estimate. The difference between the two methods will be clear after a short explanation of both. The PSIAC method was tested on an intermontane forested catchment of about 0.5 km^2 in which each single land element was evaluated and then weighted with relation to the others. For this reason the method requires cartographic data for establishing classes of soil erosion and sediment yield, for which purpose it is necessary to establish the range of variation of these factors.

The basin is subdivided into sub-catchment areas, each of which is examined individually to obtain a cartographic distribution of classes of soil loss. Fig. 7 shows how the map appears when the sub catchments which have the same values have been amalgamated.

The second method is based on the computation of the USLE parameters proposed by Wischmeier and Smith. The individual USLE parameters are computed using different procedures. The rain fall erosivity value (R), comes from experimental data derived from rain gauging stations and is elaborated by equations such as Fourier's, or by mean of the EI30 factor.

The other parameters come from field observations and analyses such as soil erodibility tests, the application of the Wishmeier and Smith nomograph (for K factor), morphometric analyses (SL topographic factor), and the study of agricultural practices and land use (P and C factors). In this study the original model is modified with respect to the technique used, to enable point data such as the K factor to be mapped. This method uses the land system and mapping units to identify areas, using a physiographic analysis in order to get a uniform areal distribution and to identify the factors affecting soil loss estimation. The mapping units and their distribution are shown in the map of fig. 8, and the legend is explained in fig. 9.

It is worth noting that both of these methods deal with all the land elements influencing soil loss so as to create the basis for evaluating, in a more objective way, data which are obtained from different works and areas. In the matching phase the two sets of cartographic data are compared and combined, especially in areas affected by different classes of soil loss. The final map (fig. 10) showing the integration of the two different methods is then made.

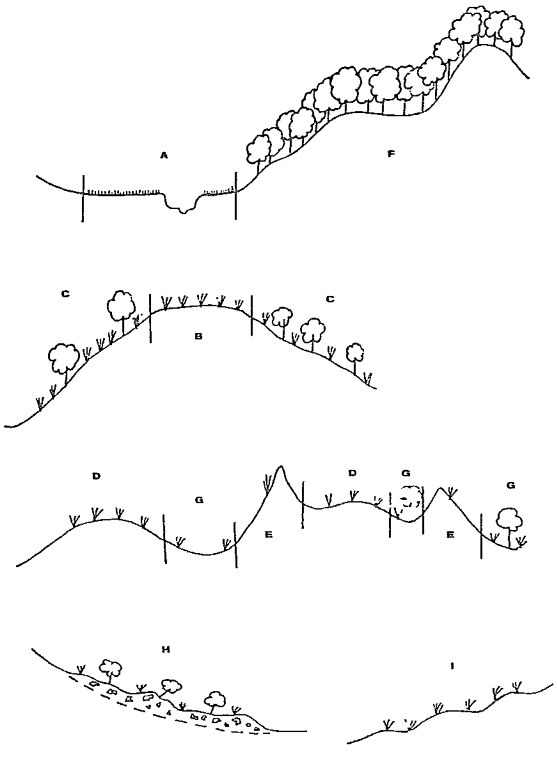

FIG. 9 - Schematic draw of the mapping units.

Further tests on sample areas were carried out to examine the process relating to sealing of the soils. Soils on the different units were analysed and once their mechanical and physical characteristics were identified the laboratory data were correlated with the observations and the field tests. In these tests the consistency index (DE PLOEY & MÜCHER, 1981) test has been used, which identifies the capacity of sealing of a soil and its susceptibility to rapid deep erosion.

Samples for the sealing test were taken from the first two horizons of each soil, so as to compare the variability of this characteristic for each individual soil and to represent each unit in terms of area and horizons (at least for the first two horizons). The tests highlight some important differences regarding the soil susceptibility to sealing, as shown in fig. 11.

Other relations with the organic matter, texture and sealing susceptibility of the soils have been found. Two regression equations can represent such relations:

$$Y = 0.3464 + 0.2939 \times \text{ and } Z = -0.05447 + 3.053 \times$$

in which Y is the organic matter in % Z, the texture and X the consistency index.

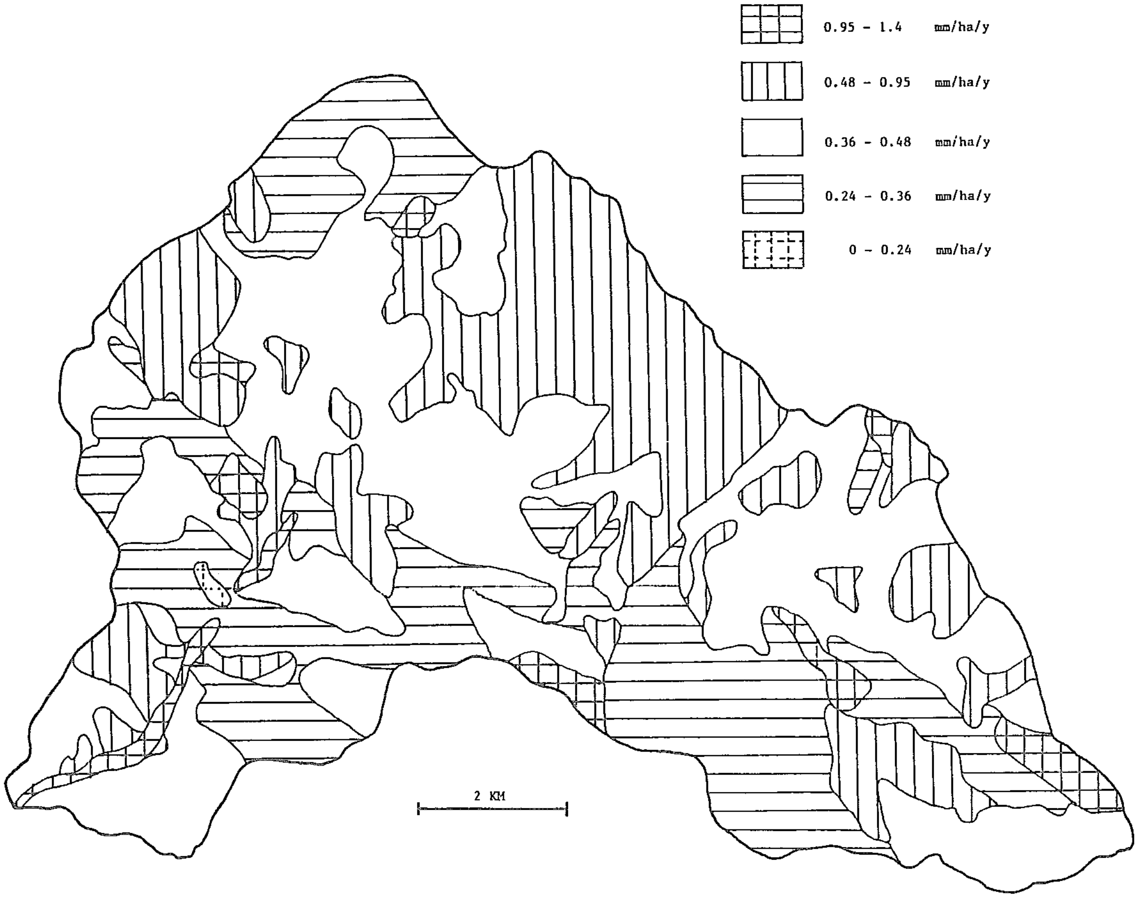

FIG. 10 - Map of soil erosion classes obtained by integration of the PSIAC and the USLE modified methods.

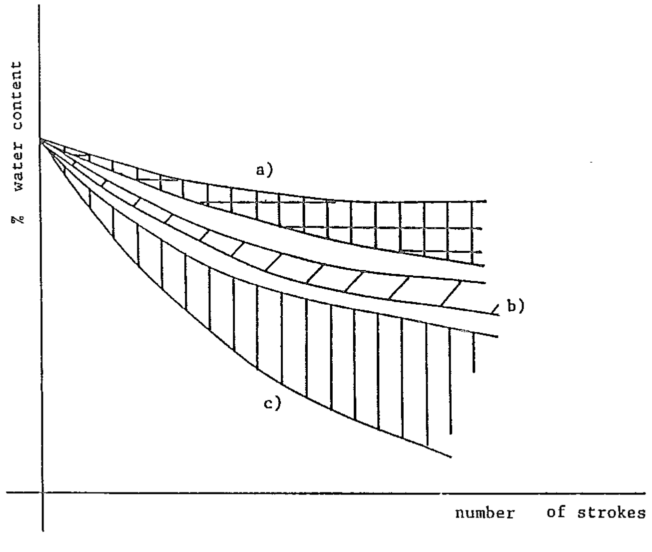

FIG. 11 - Curves of sealing tests for a) unstable soils, b) undefined soils, c) stable soils.

Some points concerning which soils to consider for particular consistency index tests emerge from the previous observations. Interesting evidence came out regarding the possible relationship between maximum organic content plus consistency index and soils with liquid limit less than 40%, which are those with a content of clay plus organic matter of less then 6%. This result has to be extended to other kind of soils, but it seems to be reasonably sure.

Further testing on a sample area was carried out in the Fagna area: in this area, the amount of erosion was calculated by measuring the sediments in plots under natural and simulated rain (CANUTI & *alii,* 1986).

The plots, which were of different sizes in the different experimental plans, were arranged with the longest axis following the steepest slope. The sides and the upper side were confined by separators in galvanized sheet-iron, which were fixed in the ground at a depth of 10 cm and which protruded 20 cm above ground. On the lower side of each plot, specially shaped troughs were arranged to ensure the collection and the conveyance of the runoff, through Geib divisors or Coshocton samplers, to the containers.

The sample area chosen in the Mugello basin is situated in Fagna, next to Scarperia. Several cultivation situations were tested in order to have data ranging across all the possible conditions of land use. The research was concentrated in the central part of the valley (Fagna Experimental Centre) where the most erodible lithotypes, which are also the most

TABLE 2

THE INFLUENCE OF RAINDROP SPLASH AND RUNOFF ON THE EROSION PROCESS. SOIL LOSS AND RUNOFF ON EXPERIMENTAL PLOTS

Years	Soil loss (kg/na)		Runoff (mm)	
	Netted Plots	Unnetted Plots	Netted Plots	Unnetted Plots
1978	529.58	6,310.51	44.76	97.59
1979	1,258.71	66,391.85	88.22	392.53
1980	1,156.21	47,959.40	66.78	302.52
1981	833.15	19,105.21	81.66	508.91
1982	16,741.84	83,271.62	292.09	614.56
1983	2,685.92	35,251.20	111.04	215.51
Total	23,205.41	258,289.79	684.55	2,131.71

subject to intense agricultural activity, are to be found. The research concentrated on the following points:
1) study of raindrop effect and runoff and their relative importance in the erosive processes;
2) evaluation of soil erodibility and its variability in the course of the year;
3) study of the influence of plot length and slope on soil physical conditions;
4) study of the amount of soil loss in relation to the length and slope of plots;

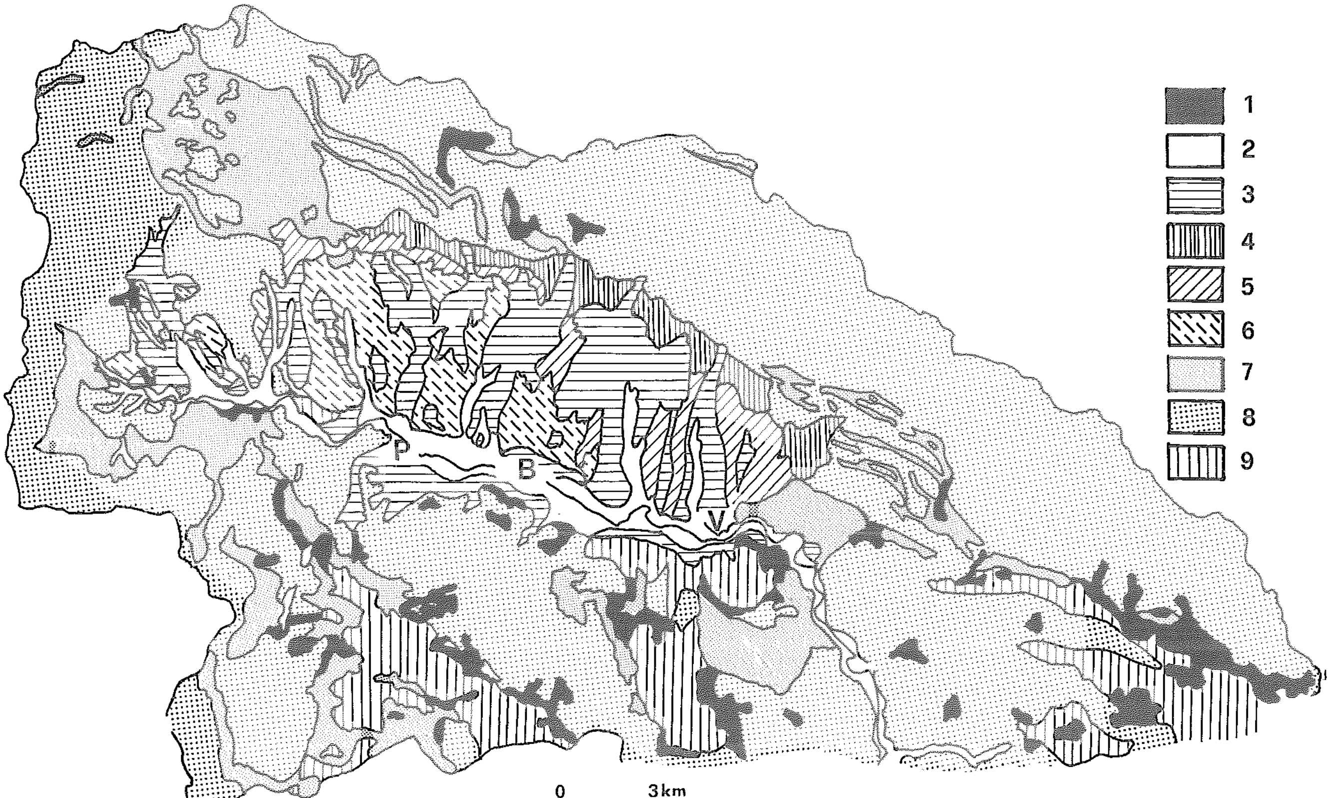

FIG. 12 - Lithological map of the Sieve River basin.
1) debris; 2) old and 3) recent alluvial deposits; 4) pebbles and sands; 5) lacustrine sands; 6) lacustrine clays; 7) argillites and marlstones with calcareous and arenaceous beds 8) sandy-marly and calcareous-marly flysch; 9) flysch with marly sandstones.
P = S. Piero a Sieve, B = Borgo S. Lorenzo, V = Vicchio

5) the effect on soil loss of different crops and different systems of utilization of turf;

6) the stabilizing effect of pipe drainage.

The experimental research has been carried out on trial plots measuring 20 m by 5 m, exposed to both natural and simulated rainfall. In the case of simulated rainfall, two specially-designed rainfall simulators were used. These studies wer completed with laboratory tests on soil samples that were disturbed, but suitably treated, and which were exposed to simulated rainfall (BAZZOFFI & *alii*, 1986), as well as with tests on trial plots and in basins situated in other localities (i.e., Vicarello, Valle dell'Era, various localities in the Mugello valley).

The study of the relative influence of splash and runoff upon the erosion process was carried out on four plots which were kept in bare fallow. Two of these plots were covered with a 1 mm-mesh net (approximately) to dissipate the impact of the raindrops. The net was placed approximately 20 cm above the soil surface. The other two plots were unnetted. The results for the six-year period from 1978 to 1983 are summarized in table 2 (ZANCHI, 1983, 1984).

The variation of soil erodibility in different months of the year was observed and was found to be similar, even if the absolute values were logically different, in the two soils studied. This observed monthly variation was modelled by means of a cosine function (ZANCHI, 1984). In addition, the antierosive effectiveness of a Fe-Al polyhydroxide sulfate soil conditioner was verified in 9 plots (20 m. by 5 m.) treated with 3 different soil conditioners and replicated 3 times (0, 10, 20 t/ha) (ZANCHI, 1977).

This experiment began in 1976 and continued until 1987 with the aim of verifying the effectiveness of the soil conditioner with time. The results are unpublished at present. The study on the effect of plot length (4.5 m; 9 m; 13.5 m; 18 m) and slope (10% to 15%) on the amount of soil loss was carried out using a field rainfall simulator. The results of these experiments have shown that the exponent value in the power regression which gives the unitary erosion as a function of the length of the plot, was 0.49, practically the same as the one suggested by WISCHMEIER & SMITH (1978). The relative influence of crop cultivation on the amount of soil loss was evaluated on experimental plots (20 m by 5 m) cultivated with corn, pasture and wheat crops (ZANCHI, 1983).

In addition, the amount of soil loss in relation to different cattle grazing intensity was measured on three entire hill slopes (from divide to the bottom). Each slope has a surface of approximately 1.2 ha. Three levels of grazing intensity were studied:

a) the numer of cattle limited to the productivity of the pasture;

b) twice the number of cattle with respect to pasture productivity (overgrazing);
c) grazed but cut regularly.

4.2. LANDSLIDE SUSCEPTIBILITY AND MASS MOVEMENT HAZARDS IN THE MUGELLO VALLEY

The area under examination takes in the greater part of the mountainous basin of the River Sieve, with the exception of the area situated downstream from Dicomano, and covers a total area of 720 km^2.

The built-up areas, with a population of over 200,000, are situated in the undulating or flat area of the valley bottom. There are also business and industrial centres and important infrastructures. Among these we can mention, besides the Autostrada del Sole (Milan-Rome) motorway, various state roads which connect the Florence area with Emilia and Romagna; the railway which connects the Mugello with towns in the Apennines, Tuscany and Romagna and with Florence; the Mugello Racing track and finally, in the S. Godenzo basin, there is the national methane pipeline.

4.2.1. *Lithological characteristics*

To highlight the different mechanical characteristics of the terrain in order to arrive at an evaluation of slope stability, the area has been subdivided into the following lithological units (fig. 12). These have been established by amalgamating both different geological formations and separate members within these formations:
- 1) talus: heterogeneous incoherent debris; mostly arenaceous and calcareous blocks and fragments with a medium-fine matrix;
- 2) recent alluvial deposits: gravel and sand, and in second place of sandy silts. They are present in the valley bottom;
- 3) former alluvial deposits: gravel and sand, generally with an abundant silty-clayey matrix. This unit includes alluvial terraces distributed at various altitudes;
- 4) conglomerates and sands: mostly pebbles with layers of sand sometimes loosely cemented. They crop out along the northern border of the lacustrine basin;
- 5) lacustrine clays: medium-fine sands, silty at times, with rare intercanalations of gravel. They constitute the upper part of the lacustrine deposits;
- 6) lacustrine clays: silty clays, with organic beds and with thin intercanalations of sand;
- 7) claystones and marlstones with calcareous and arenaceous beds.

This unit includes:

a) mostly argillites and marly limestones, and to a lesser extent fine quartzose sandstones, siliceous limestones, calcarenites, cherts (Undifferentiated Complex);

b) blocks and chunks of different lithology (limestones, sandstones, marls) upset and enveloped in a prevalent clayey mass (Chaotic complex);

c) prevalent argillites and mars, minute calcarenites, marly limestones and calcareous sandstones (Scaglia toscana Formation, Pievepelago and Vicchio Marls).
- 8) sandy-marly and calcareous-marly flysch. This unit comprises:

a) turbiditic quartz feldspathic sandstones, sometimes in thick banks alternating with marls (Marnoso-Arenacea

TABLE 3

LANDSLIDES DISTRIBUTION IN THE LITHOLOGICAL UNITS

Litho-logical Unit	Outcropping Area S_i (Km²)	S_i / ΣS_i (%)		Mass movements								Σn	Σ_x / S_i (%)
				Fall		Slide		Flow		Complex			
				n	S_x(Km²)	n	S_x(Km²)	n	S_x(Km²)	n	S_x(Km²)		
1	25.27	3.5	r	—	—	—	—	2	0.03	1	0.09	3	0.47
			o	—	—	1	0.09	2	0.03	2	4.58	5	18.60
2	26.65	3.7	r	—	—	—	—	—	—	—	—	—	—
			o	—	—	—	—	—	—	—	—	—	—
3	72.05	10.0	r	1	0.01	—	—	1	0.01	1	0.01	3	0.04
			o	—	—	—	—	—	—	—	—	—	—
4	13.02	1.8	r	3	0.04	1	0.03	4	0.12	2	0.11	10	2.3
			o	—	—	—	—	—	—	—	—	—	—
5	14.41	2.0	r	—	—	2	0.02	2	0.08	2	0.11	6	1.45
			o	—	—	—	—	—	—	—	—	—	—
6	36.03	5.0	r	—	—	6	0.18	29	1.63	6	0.57	41	6.60
			o	—	—	—	—	—	—	—	—	—	—
7	104.75	14.5	r	2	0.04	7	0.19	20	0.88	11	0.85	40	1.87
			o	—	—	3	0.24	9	0.63	13	2.96	25	3.66
8	396.05	55.0	r	15	0.30	11	0.92	45	2.15	5	0.66	76	1.01
			o	12	0.75	14	1.13	10	1.43	21	0.45	57	2.97
9	32.42	4.5	r	9	0.06	4	0.08	5	0.33	2	0.36	20	2.56
			o	9	0.05	6	0.63	8	0.24	13	10.52	29	37.10
Total	720.65	100.0	r	30	0.45	31	1.42	108	5.23	30	2.76	199	
			o	15	0.80	24	2.09	29	2.93	49	26.51	117	

Formation, Castelguerrino and Cervarola Sandstones);

b) turbiditic quartz calcareous sandstones with argillites more or less silty (Pietraforte Formation);

c) marly limestones and limestones with argillites and marls, calcarenites and limestone rubbles, polygenic rubbles and calcarenites with cherts (M. Morello Formation, M. Senario Rubbles).

- 9) flysch with prevalent sandstones. This unit contains:

a) stratified and cemented quartz feldspathic sandstones of turbiditic origin alternating with silty argillites (M. Falterona Sandstones);

b) coarse quartz feldspathic sandstones containing quartz clasts, phyllites and limestones (M. Senario Formation).

As is shown in tab. 3 the lithological unit which outcrops most widely is unit 8 (arenaceous-calcareous flysch) and it underlies 55% of the area, amounting to about 396 km². It forms the main reliefs. Unit 7, i.e. the shales, covers the second largest surface area with 104 km² representing 14.5% of the area, and is much lower in altitude than unit 8.

The other unit which is most important, from the point of view of the area it covers, is unit 3, i.e. the Quaternary terraced deposits of fluvial-lacustrine origin, which cover 10% of the surface area of the Mugello (about 720 km²).

4.2.2. *Analysis of landslide activity*

Geomorphological survey has enabled us to identify the most important landslide phenomena and these were then the subject of a census and detailed mapping (BECHINI et al. 1986). A census was taken of 199 recent landslides (active and dormant) and 117 ancient landslides, involving an overall area of 42 km², which represents 5.8% of the region. The largest landslides are to be found in units 7,8 and 9. The greatest of these, both in terms of its dimensions and effects, is situated in the Comune of San Godenzo. This landslide is described later.

Tab. 3 shows the distribution of the areas of the old and

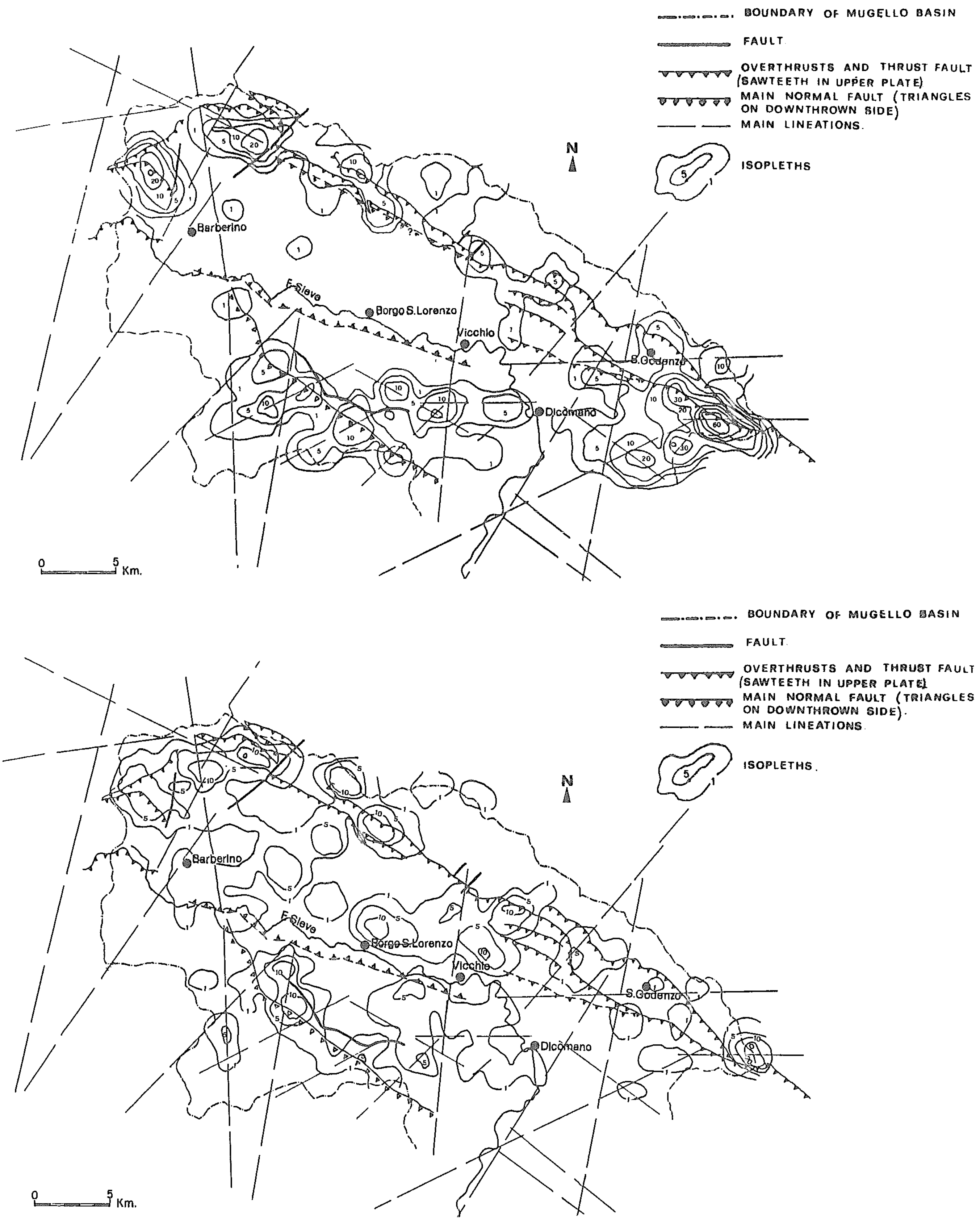

FIG. 13 - Isoplethes distribution maps of the old (a) and recent (b) landslides, and main structural features.

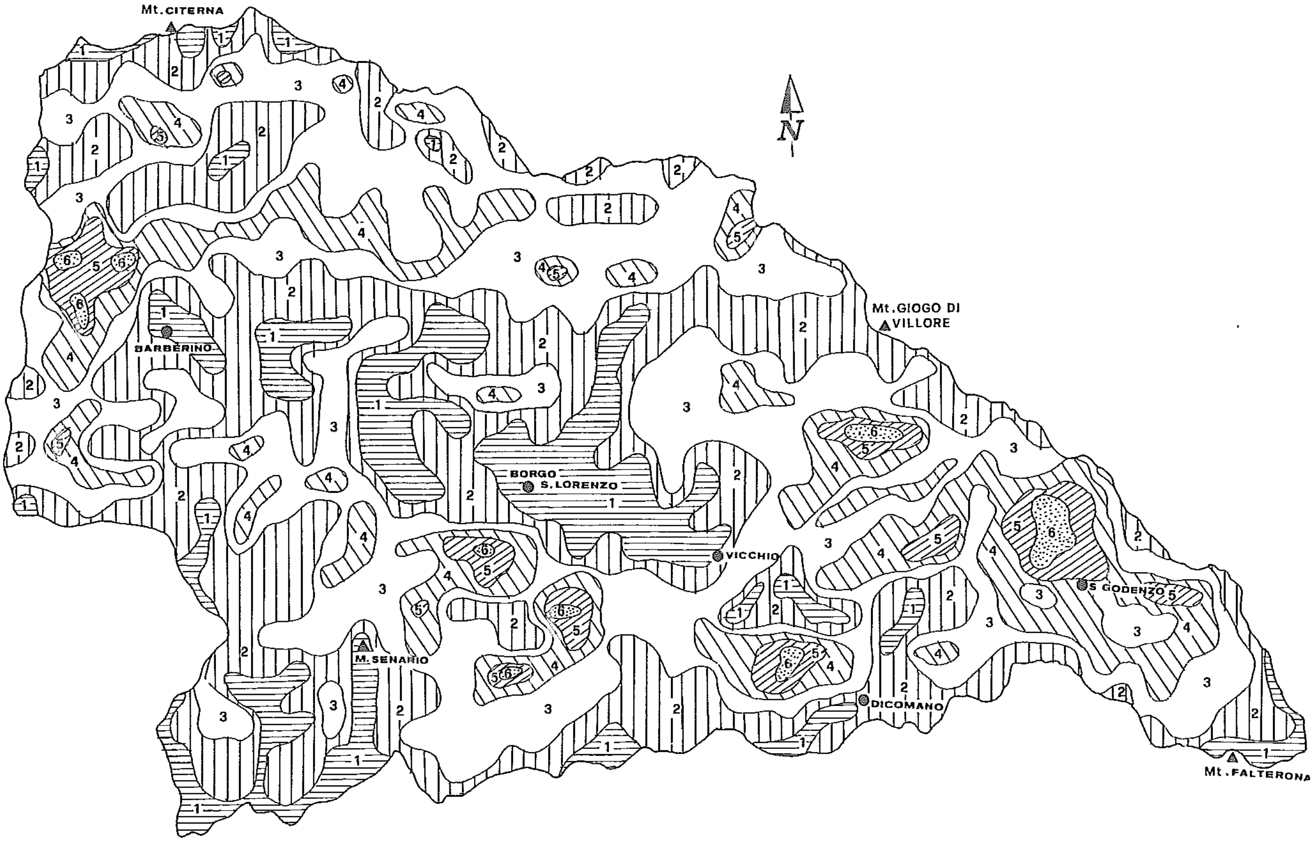

FIG. 14 - Isoplethes map of the main lineations taken from aerial phots. (class 1: lower density).

recent phenomena in the lithological units which are most susceptible to landslides. Unit 8 in particular (sandy-marly flysch) is the unit which is most subject to landslide phenomena, with 76 recent landslides and some 57 ancient landslides.

Nevertheless, if we compare, according to DE GRAFF (1978) methodology, the outcrop percentages with those of the landslide areas within each group, we can note that unit 9 shows highest ratios. This situation can be linked mainly to the tectonic structures in this unit (overthrusts, important dislocations, jointing). Other significant values for landslide areas occur in units 7 and 4, and to a lesser extent in unit 6. Comparison with the areas of old landslides, which are generally eroded, is not possible because the slopes are evolving more rapidly, with recurring surface landslides and intense human intervention. Here we find mainly surface flow and solifluction phenomena, with slow deformation, which evolve into translational flow-slide. The Fagna landslide is later described as an example which represents these phenomena. We would like to mention, however, the well known instability phenomenon in the built-up area of Scarperia (Palazzo Pretorio), the site of which corresponds with the edge of the terraced surface composed of coarse ancient fluvial deposits overlying the overconsolidated lacustrine clays. These failures, due mainly to slow movements of the flow type, derive from hydrogeological causes as well as from surface overloading.

Many of these phenomena, which at times induce hazard situations, can therefore be linked to human factors such as excavation, terracing, overloading, and leaks in the drainage network.

4.2.3. *Analysis of the distribution of landslide phenomena*

In order to depict the landslide pattern in the studied area better, the method of isopleths proposed by CAMPBELL (1975) has been used adopting, for the construction of the isopleths, a grid of 1 km by 1 km on a base map with scale 1:50.000. The isopleths given in fig. 13 a-b represent lines of equal density of landslides, expressed as percentage values in relation to the total landslide area.

The recent landslides have been distinguished from the older ones, and the main structural features have also been indicated.

In order to highlight the relation between the recent and older phenomena more clearly, a map which shows isopleths of the temporary variations of the landslide areas, dealing only with the active ones which persist or are connected to the ancient phenomena, has been drawn up.

Whereas landsliding at present is widespread throughout the entire area, the older landslides tend to be concentrated on the basin's edges, the highest density being in the areas where the most important tectonic dislocations are to be found, both to the north and to the south of the River

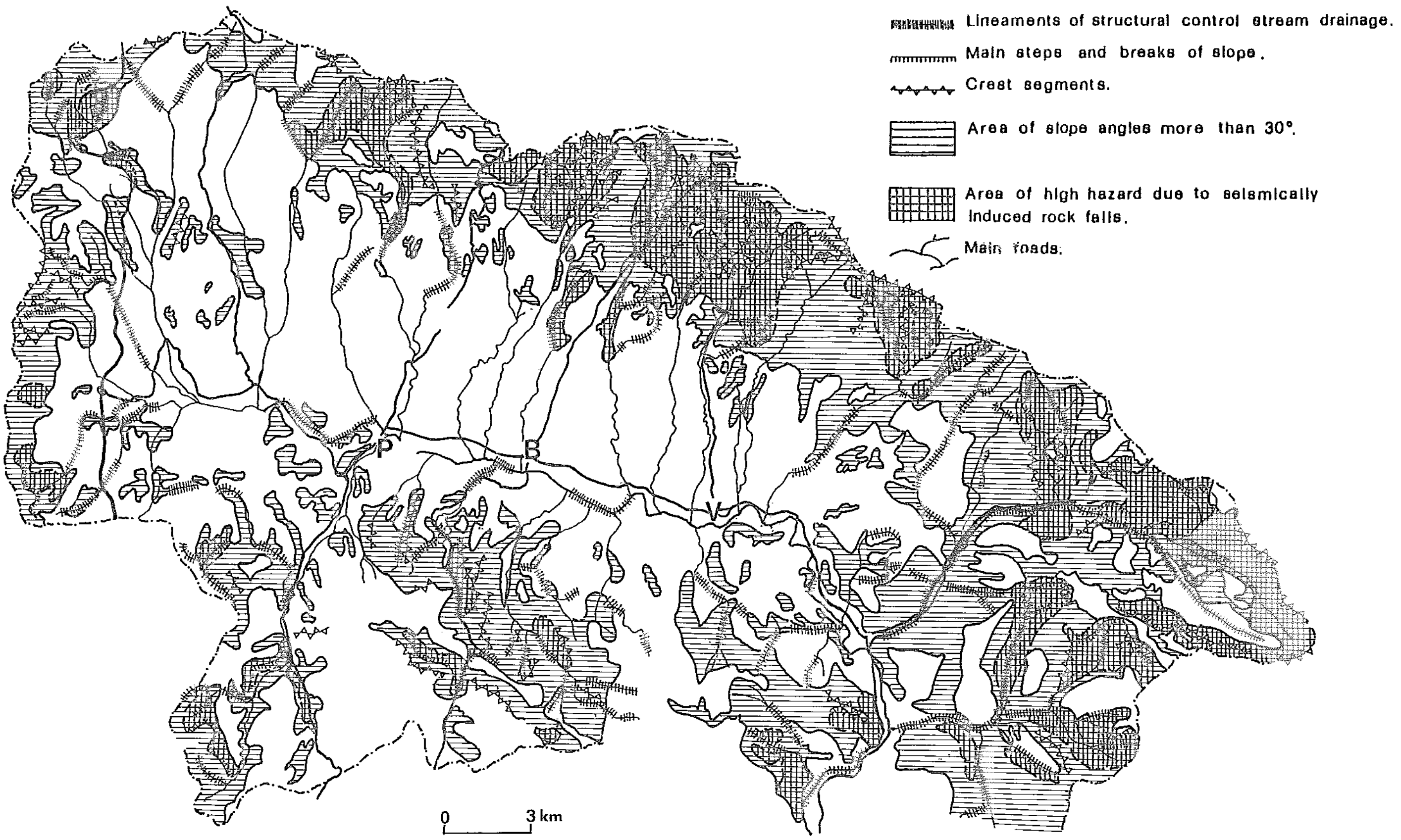

FIG. 15 - Map of seismic hazard areas. P = S. Piero a Sieve, B = Borgo S. Lorenzo, V = Vicchio.

Sieve. The reasons for this concentration of the phenomena in the areas which have undergone tectonic dislocation may be explained in various ways: the presence of steeper morphology in these areas, the contact between units with different lithologies, and weakening of the mechanical properties of the materials caused by tectonics. It is clear that these causes are not sufficient to generate mass movements and at this stage we do not fully understand the role of tectonic activity in causing states of tension capable of producing gravitational phenomena in the rock masses. However, with this aim in mind, it would appear useful to survey the particular intensity of the phenomena (old landslide-deep-seated gravitational phenomena) in the tectonically critical area to the southeast of San Godenzo, in order to see how this is expressed by present phenomena.

Fig. 14, by means of isopleths, shows the density of the main lineaments taken from aerial photos. These segments can, on the whole, be related to morphological elements controlled directly, to a greater or lesser extent, by jointing and faults (river beds, slopes, valleys, ridges, extensive escarpments etc.). The highest densities are to be found in the areas where the main structural forms are present, corresponding to formations with relatively brittle behaviour. Furthermore, there is a good correlation between the pattern of the isopleths of the landslide phenomena and that of the figure 14 under examination, with the exception of the M. Falterona area, because of the presence of the extensive and thick debris layer.

Lastly, morphological evidence linked to the presence of deep gravitational deformation has been noted, especially in the slopes of Mt. Senario, as is also the case with Mt. Falterona and Mt. Falco.

4.2.4. *Seismic Hazard in the Mugello*

The Mugello basin lies in an area within the Apenninic belt of high seismicity, characterized by shallow-focus earthquakes with epicentres within 15 km and magnitudes less than 6.5. Besides the earthquakes located in the basin, this area also suffers from those coming from the «Forlivese» area, situated NE, which generally develop at greater depths (about 30 km).

The highest intensity recorded is X MCS, belonging to the Scarperia earthquakes in 1542. The latest destructive shock (IX MCS) occurred in 1919; its macroscopic effects (building collapse, landslides, liquefaction) are widely supported by documentary evidence and have recently been studied.

Locating the areas which could be sites of instability, due either to existing precarious conditions, to the increased deformability and low resistance of the sub-surface materials or to obstructed drainage, is of prior importance in specifying the seismic hazard of a given area. It is a well known fact that, even in the event of not very intense earthquakes of magnitude VI (MERCALLI), natural slopes can be sites of landslides which, especially in mountainous areas, can result in damage and loss of life. The great diversity of situations which exist in reality means that it is difficult to deal with the problem in only one way. Seismic events generally aggravate the stability of the slopes in that they lead to an increase in the acting forces, a reduction in the resisting forces: permanent deformation.

In rocky areas instability phenomena caused by an earthquake can consist of rockfalls, toppling and slides with accumulation of fractured rocks extending well beyond normal limits. Therefore there are two zone which must be considered as hazardous: the areas directly affected by instability phenomena and the areas which could be affected by falling debris. The causes promoting instability are: a) increased slope angle; b) the presence of stratigraphic and tectonic discontinuities; c) dipslope strata; d) a high degree of jointing.

The mechanisms of rock slides are on the whole complex and it is not always easy to predict the behaviour of the mass during seismic disturbance. There have so far been few attempts at carrying out dynamic stability analyses on rocky slopes with complex models; therefore, evaluations of landslide hazard are generally based on the factors already mentioned and, at the most, on static or pseudo-static analysis. Experience gained from various sites has indicated that rock movements or rock detachment occur mainly where they had occurred in previous earthquakes. This fact enables us to use historical information, even relating to ancient earthquakes of which we still have some evidence.

There are various mechanisms which can occur during an earthquake to affect slopes built of non-consolidated material:

- in sandy materials below the watertable, liquefaction is generally the cause of movement; the cause which triggered off movement also in clays with alternations of sandy layers or lenses has in some cases been attributed to this same phenomenon.
- in clayey materials, seismic disturbance can lead to permanent increased deformation and consequently to failures, which in turn lead to redistribution of stress together with progressive rupture.

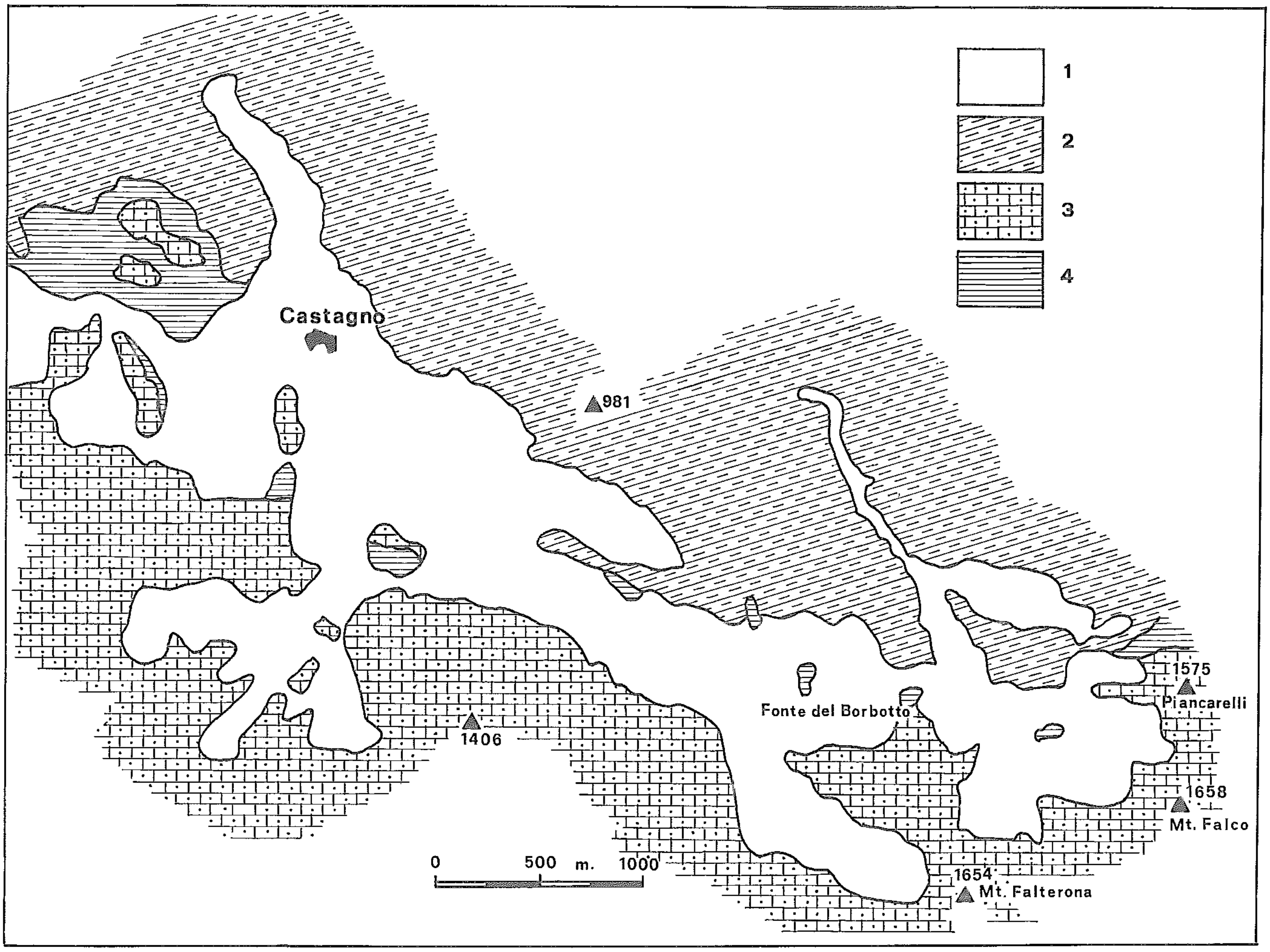

FIG. 16a

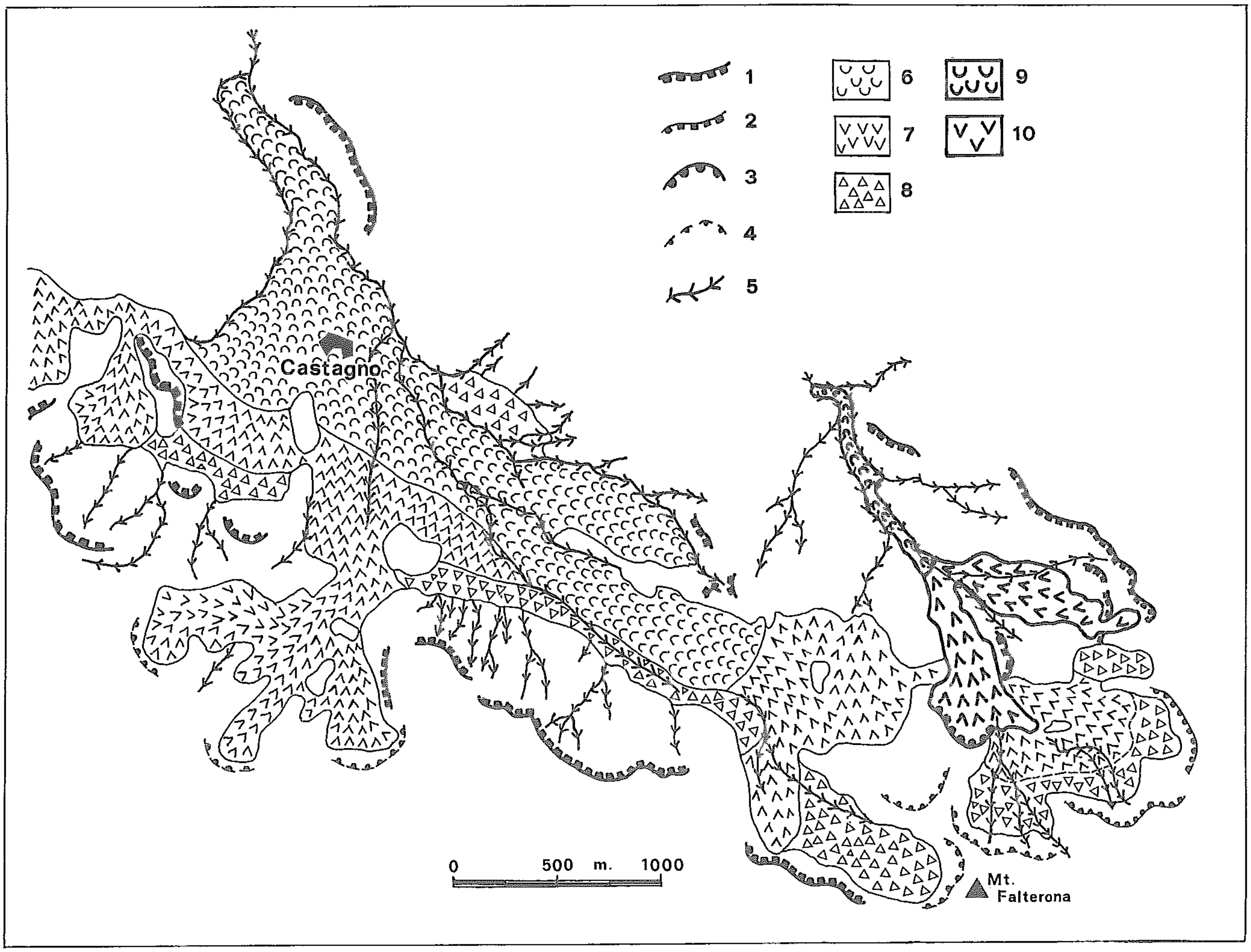

FIG. 16b - Castagno landslide area.
a) Geological map: 1) debris; 2) Marly-arenaceos Formation; 3) Sandstone of Mt. Falterona; 4) Tuscan «scaglia»;
b) Geomorphological sketch map: 1) active scarp; 2) inactive scarp; 3) active landslide crown; 4) inactive landslide crown; 5) gullies; 6) inactive debris flow; 7) inactive debris slide; 8) inactive debris fall; 9) active debris flow; 10) active debris slide.

- in clayey and debris material, precarious pre-existing conditions are almost the sole factor which determines stability under seismic disturbance. The dip of the rocks also has a considerable influence on the probability of a landslide.

The possibilities of evaluating landslide hazard with quantitative methods are still very limited even though a few quite flexible pseudo-static check programs, which utilize numerous factors, are now available. In order to evaluate the hazard in the field of seismic zonation, however, detailed geological mapping, a correct appreciation of the probable landform evolution and a thorough knowledge of the materials, both from a geotechnical and static point of view, seem more important, rather than complex quantitative analyses which do not offer sufficient guarantees. In general, the observation that situations already considered precarious from a static point of view are also dangerous from the dynamic point of view, is valid.

4.2.5. *Location of high-risk areas*

From bibliography (CHINI, 1875) and from newspaper reports (the 1919 earthquake) we know that liquefaction phenomena related to rockfalls and landslides occurred during various earthquakes. Unfortunately we are only in rare cases able to obtain the information from the Castagno landslide which CHINI (1875) attributes to the great earthquake which occurred on 15th May, 1335.

Given the morphological, geological, lithological and tectonic conditions of the area under study, we consider as particularly subject to landslides, especially after an earthquake, not only the areas already affected by landslides and large scars of older landslides — most which remaned dormant or were only partially reactivated — but also vast areas with steeper slopes composed of highly fractured rocks or debris. Fig. 15 indicates the areas with slopes greater than 30°, together with all the areas which for lithological and structural reasons could give rise to rockfall, using also the map of fracture density.

The ridges, the most important escarpments and structural lineaments along the valleys have been marked out on this map since they represent particular conditions in the

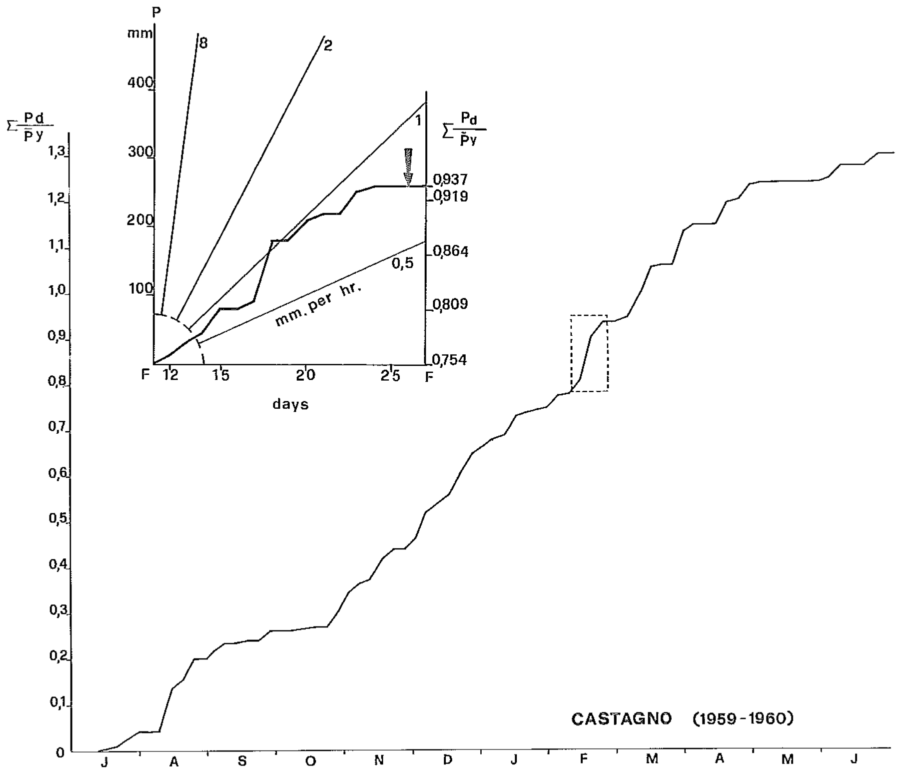

FIG. 17a - Cumulative curves of the ratio between the summation of the values of daily precipitation (Pd) and the yearly mean precipitation (Py); the arrow shows the landslide triggering.

evaluation of stability during seismic disturbance. In our opinion it is important to point out that the network of roads which connects the Mugello to the adjoining basins crosses, for stretches of varying lengths, areas where landslide and especially rockfalls could easily be triggered by seismic stress.

4.2.6. *Two examples of major landslides*

4.2.6.1. The Monte Falterona landslide

The area is situated on the northern slopes of Monte Falterona (1654 m) and on the eastern side of the principal Apennine range, with heights varying from 500 m to 1658 m (Monte Falco). It corresponds to a zone between two different stratigraphical series which are in places superimposed one (Tuscan units) on the other (Umbrian-Romagnola units) by an overthrust. Here the Tuscan unit is composed of the Tuscan Scaglia and the Sandstones of M. Falterona; the Umbrian-Romagnolo unit is, in its entirety, composed of the Marly Arenaceous formation.

The principal line of overlap (fig. 3) has a NE-SW trend and cuts diagonally across the area under observation; however the two series do not always come into contact by just one dislocation line, but by repeated inverse faults which are overthrust to varying degrees and in part auxiliary.

The Scaglia Toscana which is under the debris (fig. 16a) appears in some places; with its plastic characteristics it acted as the slip level for both series, and because of this it often appears to have a chaotic structure.

The original surface of the overthrust has only survived in a few places and has the shape of a plane with an inclination of no more than 25 degrees. The accumulations of debris occupy the band that corresponds with the overlap line and they are so widespread that they almost completely hide it and make cartography difficult. This debris is generally caused by old and new gravitational phenomena: nevertheless, some of it seems to have originated from alteration and transport phenomena, caused by ice and snow in a periglacial environment; some has a residual origin, and some is slope debris fallen from the steep northern slope of the M. Falterona chain. Most of this debris is involved in old landslides.

The northern slope of the Monte Falterona massif is characterised, for practically all of its length, by scars due to erosive phenomena; some of these are considered crowns detached from the old landslides, others are actual scars of still active erosion, and all are the source of the underlying debris (fig. 16b).

An explanatory model of the manner in which such deposits have been placed indicates, as a major cause of landslides, the fracturing of the rocks due to sudden stresses during the period of overthrust. Such rocks already susceptible to erosion, have then been worked on by weathering agents such as rain and snow, thus producing large volumes of debris at the base of the above mentioned steep scars.

Such debris was then later involved in numerous landslides whose primary causes are considered to be the following: 1) the steepness of debris slope; 2) saturation of debris following intense and prolonged rains; 3) seismic events; 4) erosion at the foot of the slope caused by channel water. All these phenomena have probably been favoured by the presence, under the debris, of plastic clayey rock of the Scaglia Toscana. The landslides began as rotational slide inside the debris body and then changed into debris flows, the biggest of which was able to transport sandstone blocks for some kilometres. Accounts of three of these landslides which happened during historic times are available. The first and foremost landslide happened in 1335 and is thus described by GIOVANNI VILLANI in the «*Istorie Fiorentine*»: «In this year on the 15th May, a layer of Falterona Mountain from the side that descends towards Dicomano in the Mugello, slid for more than four miles because of a tremor and a collapse, ending up at the village called Castagno, and destroyed that with all the houses, people, wild and domesticated animals and trees».

The phenomenon, certainly of noteworthy dimensions, originated, in the most distant part of a debris flow which started towards the Fosso di Falterona stream, forming a large accumulation. Such a flow had repercussions in the cloudiness of the water even quite far away (about 130 km) from the area of the landslide, so much so that VILLANI continues thus: «The turbid water descended to Dicomano and stained the river Sieve which coloured the waters of the Arno as far as Pisa; the water was cloudy for more than two months and to such an extent that the Arno water could not be used...».

The second slide of noteworthy dimensions, but probably much smaller then the first, happened on the 18th May, 1641, and we have an account given by BENEDETTO BUONMATTEI. The landslide happened where, because of the first slide, the «Gorga Nera» lake was formed, and the deposits are described in the «Dizionario storico-geografico della Toscana» by E. REPETTI as coming from the Poggio di Montefaino, of whose name we now have no trace.

The third landslide, of relatively modest size, happened on the 15th May, 1827, and involved the Piancancelli area. Even now the zone being studied does not appear stable; in 1960 near Piancancelli there was a landslide of notable dimensions.

A more recent landslide happened in 1969 in an area a few hundred metres east of the Borbotto spring. Descending towards the valley the situation is more stable because the slopes diminish, but some slight movements also involve the road that leads from Castagno to the Borbotto spring.

The oldest landslide that can be considered recent dates from the 26th of February 1960, and involved the high part of the Fosso di Falterona basin for an extent of about 12 ha; the separation happened mostly between 1000 and 1300 m and involved the Marnoso-Arenacea Formation (fig. 16a and b).

The area is next to the overthrust and so the rocks are particularly fractured. The movement may have been a rotational slide and may have involved a mass of deposits produced by innumerable collapses that made a steep slope (probably about 65%) which then failed. The principal causes of the slide are probably two. First of all the undermining at the base caused by the erosive force of the Fosso di Falterona stream, that has removed the toe of the slope. This fact was known and diversions were constructed, but not in time to be effective. The second cause was the abundant rain that had fallen in that period. Several days before the slide, the 18th February, there was intense precipitation, mostly between Castagno and Monte Falterona and in the space of 24 hours 86 mm fell at Castagno. This amount of rain, even if noteworthy, is not exceptional: during preceding years amounts much higher than 100 mm in 24 hours had been recorded even though no landslide had occurred. Fig. 17 shows the results of the analysis of the intense rainfall and of the rainfall pattern from July 1959 to June 1960, and in the days prior to the landslide.

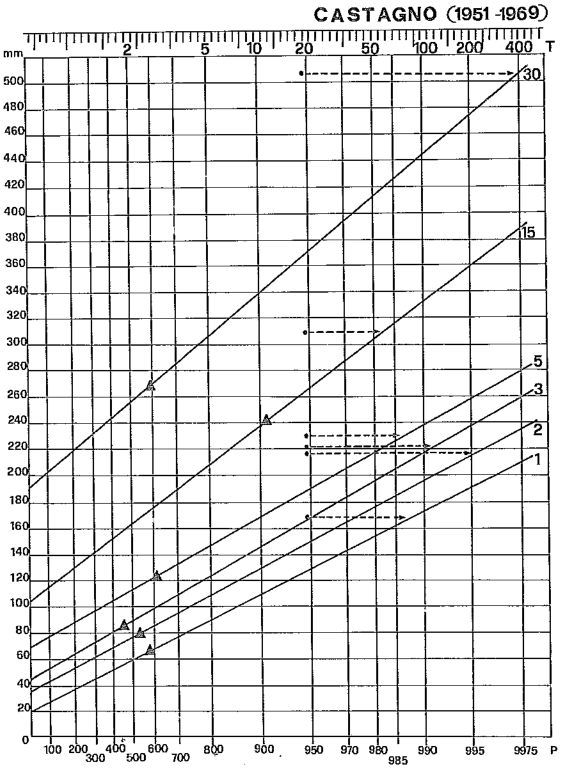

FIG. 17b - Probabilistic diagrams of the maximum heights distribution of the annual precipitation for the duration of 1, 2, 3, 5 15 and 30 days of the Castagno station. The triangles represent the precipitation events connected with the landslide, and the points the precipitation of 4th November 1966.

This shows that the role played by rain is so important that it constitutes the primary cause, but that it worked on slopes already weak because of bank erosion.

The landslide reached the Fosso di Falterona stream,

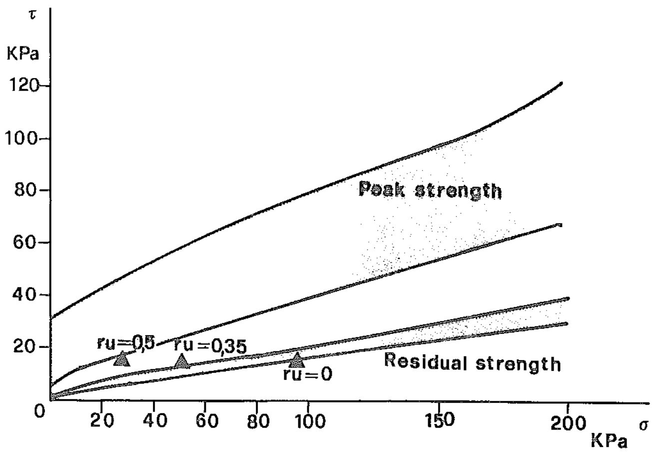

FIG. 18 - Back analysis using the Casagrande method.

forming an accumulation over 1000 m long that has contributed to supporting the slope. The last big landslide happened in April 1969 (the exact date is not known): it involved an area of about 10 ha not far from the 1960 landslide. In this case all three formations were affected; the separation happened in the intensely fractured area that is astride the overthrust.

4.2.6.2. The Fagna landslide

The Fagna landslide is representative of the features and dynamics of relatively superficial mass movements which frequently and seasonally move in clayey-silty deposits. The continental Plio-pleistocene clayey deposits of the Mugello are composed of alternating layers of clayey silts and silty clays (20-30 cm thick) interbedded with thin layers of sand (1-3 cm thick). The clayey material offers clear signs of alteration and a dense network of fractures in the first 5-8 m of depth. The high and irregular fracturing of the surface terrain of the slope has led to an anomalously high permeability which, is in turn, the cause of particularly serious hydraulic conditions when there is a strong recharge of the groundwater.

The high landslide activity which affects the weak clays consists of mass movements of the following types: solifluction, flow, creep of the superficial weathered layer and above all of slides (planar or rotational with shear surface of wide radius). These last phenomena, the Fagna landslide being one example, occur on slopes of a few degrees (up to 10°). Superficial morphological evidence of such movements consists of newly formed concave and convex surfaces and of open cracks that are up to 10 cm wide, with vertical displacements of approximately one metre. This irregularity of the surface constitutes a limiting factor especially for mechanized farming. The latter requires continuous levelling with the resulting acceleration of soil erosion processes.

The Fagna landslide is complex, showing multiple rotational movements and slip surfaces of wide radius. It covers an area about 2 ha on an even slope of 6°-7°, displaying a variety of morphological evidence of movement expressed by recently formed concavities and convexities. The main scar is located in the middle of the slope and reaches 1.6 m in height. At the centre of the landslide, beneath this scar, there is a narrow bench, while farther down there is a zone of gentle undulations. Minor trenches and scars of up to 50-60 cm, and undulations, are visible at several points on the slope. The slide front, stretching about 180 m, is as high as 1.2 m.

Analyses to determine the dynamics of the mass movement through surface surveys (direct measurements, land photogrammetry) have revealed maximum displacements of 2.00 m a year. Through measurements of the deformation of inclinometer pipes it has been possible to determine the position of the shear surface. The failure surface reaches a maximum depth of 5 m. Two trenches were dug using an excavator, thereby identifyng the level of least resistance along which sliding took place. The distance of 1.55 m was found between the broken pieces of an inclinometer tube. This value is slightly less than that of the movements measured on the surface.

Laboratory tests showed that the clay fraction varies from 30% to 70%. The liquid limit WL is always greater than 50% and the plasticity index IP varies from 20% to 60% the colloidal activity index ranges from 0.75 to 1.25. The consistency index of the slide material has values from 0.1 to 0.6. Samples collected below the slip surface show higher consistencies from 0.7 and 0.1. Triaxial tests provided the cohesion values of c' = 9.8-29.8 kPa; the angle of internal friction φ varied from 16° to 31°. The oedometric tests, moreover, yielded a value of 10 cm/s though this figure does not represent the actual soil permeability which is determined by the jointing of the clays. The oedometric tests and triaxial tests indicate that the material is overconsolidated with a difference of 0.196 MPa between preconsolidated pressure and lithostatic pressure.

The stratigraphic profile of the excavation located in the landslide near the main scar revealed a plastic clayey layer, 50 cm thick, markedly fractured, subdivided into elements measuring a few centimetres. Slow shearing tests, using Casagrande equipment, on consolidated specimens containing samples of the sliding surface from test 1, yielded c' = 0 and φ' = 15°. Residual shear tests using an anular instrument yielded φ' res = 9° and c' res = 1.90 kPa.

Stability checks, calculated by applying Janbu's simplified equation, and tests on the parameters of shearing resistance at the time of the break (back analysis), showed that the conditions of stability reach peak strength levels. However, residual strength levels are not required to mobilize the mass, even though the hydraulic conditions may be poor (fig. 18). One may presume that the clay reaches an intermediate stage corresponding to a critical point or to constant volume. For this reason, the fact that overconsolidated clay responds like normally consolidated material collected from the level at which the slide took place, which would seem to indicate that the deterioration of technical properties occurs on surfaces of limited thicknesses and at particular orientations. This possibility is further supported by the presence of considerable vertical and sub-horizontal fracturing of the clayey material at depths of 5-8 m. The fracturing fosters higher permeability of the terrain with softening phenomena.

The variations of the safety factors, which are tied to the depth of the piezometric level, are reported in fig. 19, calculated according to the residual parameters and shear strength parameters on iso-oriented samples taken from the slip surface.

The stabilization operation carried out on the slope consisted mainly of the installation of a drainage network, the design of which was based on the results of the studies carried out, which had brought to light the close relation between the evolution of the movements and the watertable fluctuation (fig. 20).

Drainage flow measurements together with the piezometric data brought to light the following points:
- there is a notable infiltration of water in the subsoil;
- in humid periods, there is a brief amount of time between the inflows and the outflows as measured by the drainage. For these reasons, in the absence of drainage, the level rises when there is intense rain.

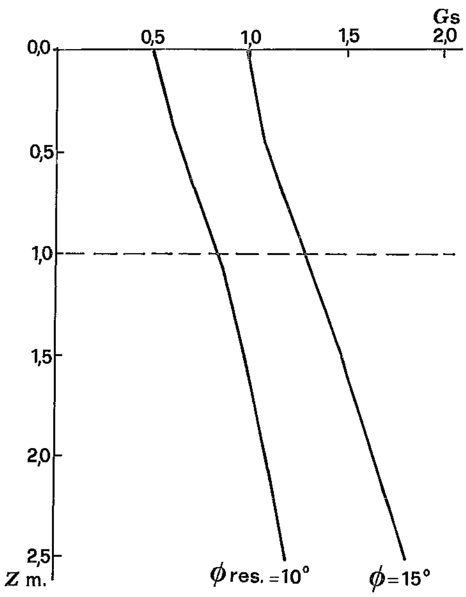

FIG. 19 - Variation of the safety coefficient in function of the water table depth.

4.3. FLOOD HAZARD

The Sieve, though known as a river, is little more than a stream, mainly considering its mean rate of flow, typical of every Appennine watercourse. In fact, the fluctuation of the rates of flow during the year is considerable: at the hydrometric station of Bilancino (180 km^2 of catchment basin) minimum rates of 0.01 m^3/s or maximum rates of 2.31 m^3/s were verified, but with an exceeding average rate 10 days a year, of 26.2 m^3/s and with an average rate of more than twice the «median» (3.66 m^3/s and 1.24 m^3/s respectively) (CANUTI & TACCONI, 1975).

The flood plain is rather wide, at least in the section between S. Piero a Sieve and Vicchio, with a maximum width of about 1.5 km as shown by the flooding events of a certain consistency, the last of which dates back to November 4th, 1966. Up to forty years ago flooding occurred nearly every year and because of this an extensive system of flood protection works was developed (transverse and longitudinal flood dams, banks, etc.). Since then, and especially after the great flood of 1966, the Sieve's bed has gradually deepned both through its natural tendency to incision, and because of excavations of the bed for the extraction of ag-

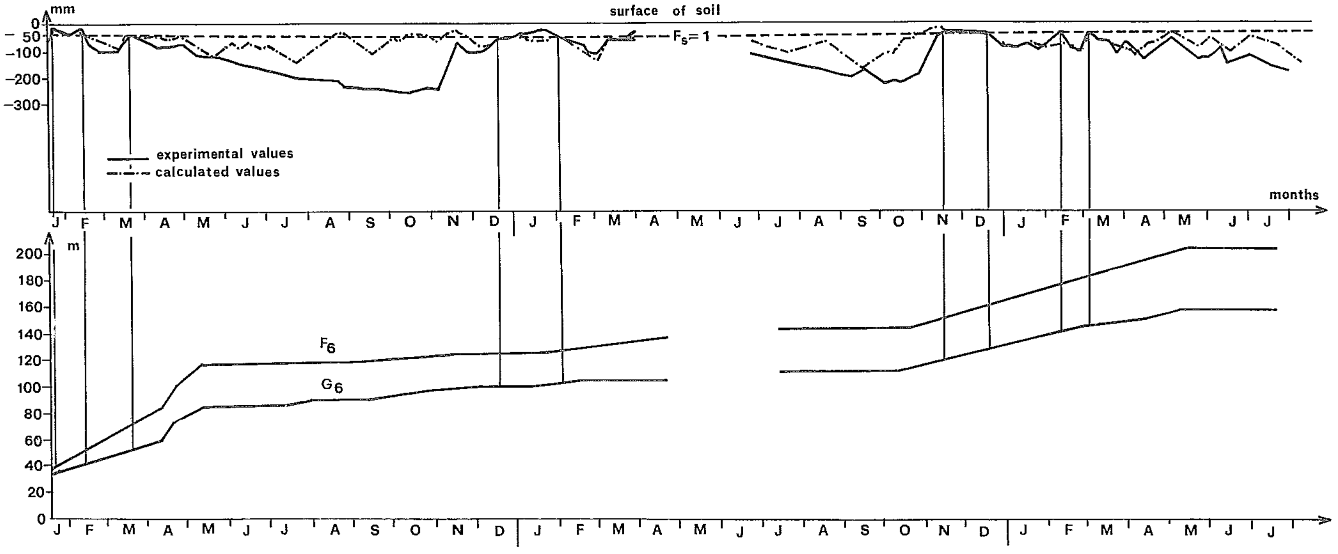

FIG. 20 - Evolution of movements and water table fluctuations.

gregates. This has caused a progressive widening of the hydraulic section of the water flow, the only positive effect of which has been the great reduction of the flooding periods. The belts of land adjacent to the watercourse which can still be flooded are situated mainly in the bottom section where the presence of rock bars has obstructed the process of vertical erosion. This danger will be totally eliminated as soon as the water storage of Bilancino, with a maximum capacity of 80 million m^3, now under construction between the upper mountain section and the middle section of the Sieve, is brought into operation.

5. CONCLUSIONS

The observations recorded so far, based both on surveys and direct measurements of morphogenetic processes, allow us to make a few general conclusions on geomorphological hazards in the Mugello Valley. As far as slope processes are concerned, these hazards comprise surface soil erosion and mass movements. In the first case the areas which are at risk are not widespread and are situated in areas with particularly erodible soils which developed on fluvial-lacustrine and lacustrine deposits affected by intense agricultural activity (arable crops). The degree of activity of the soil erosion has undergone a considerable increase in the last 20 years because of a general transformation in agricultural systems, namely their total mechanization.

This transformation, linked to the more general socio-economic progress, has also influenced the slope stability considerably especially those slopes composed of lacustrine deposits, with marked mass movements and increases in their frequency and magnitude.

Certain forms, such as those derived from the reactivation of extensive dormant landslides (Mt. Falterona, Castagno) seem to be more directly linked to tectonic activity which is still active along particular overthrusts. This can also be linked to another hazard, the seismicity of the whole valley, which induces high-risk situations depending on the infrastructures (road network) and built-up areas situated on substrata with a rigid behaviour or in particular morphological situations.

The river system seems to be characterized by a high level of dynamic activity, especially as far as its natural tendency to deepen its beds, especially on the less resistent substrata, is concerned. Rapid bank erosion of the main rivers is causing a general widening of the flood bed. In this case we have an increase in sediment transport but a reduction in the flood hazard, which was quite high in recent years. This risk will be eliminated, in particular, along the course of the River Sieve with the construction of the Bilancino reservoir.

On the whole, research carried out in the Mugello Valley has shown that the geomorphological hazards can be well located for each of the described types and it appears, at present, that risk levels are not high but are linked, above all, to human activity.

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