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GEOMORPHOLOGICAL FEATURES AND TEMPORAL DISTRIBUTION OF THE PRESENT-DAY LANDSLIDES ACTIVITY IN THE HIGH GORDANA BASIN (ZERI, NORTHERN APENNINES): A DENDROGEOMORPHOLOGICAL ANALYSIS

ABSTRACT: CHELLI A. & STEFANINI M.C., *Geomorphological features and temporal distribution of the present-day landslides activity in the high Gordana basin (Zeri, Northern Apennines): a dendrogeomorphological analysis.* (IT ISSN 0391-9838, 1999).

Patigno Village (Zeri, Northern Apennines) is build on a slope widely involved in a large landslide. The superficial part of the slope is reactivated by an high number of landslides which damaged either villages and roads.

Looking for understand the dynamic of these sliding movements a survey have been made taking in account those that can be considered as active. Two of them are located in Ternesia site and six others on the toe of Patigno slope.

Dendrogeomorphology has been the main analysis technique. That allowed to reconstruct either the temporal and spatial evolution of landslides, looking at effects recorded by trees involved in the movements. Trees belonging to *Quercus cerris L.* species have been sampled by using an increment borer, leading to a total amount of 251 cores collected. Their analysis allowed to date trees and abrupt growth changes, which are linked with effects inducted by landslides.

Development of master plot has shown some event years for the slope. On Ternesia site, activity phases have been pointed out during the years 1957, 1961-62, 1974-76, 1981-83, 1993; along the toe of the Patigno slope the main phases can be referred to the years 1970-72, 1974-75, 1982-83, 1993. By drawing event-response maps has been possible to reconstruct the spatial evolution of sliding movements in Ternesia site. This pointed out as the increasing of the displaced mass was mainly due to a retrogressive distribution of activities.

KEY WORDS: Landslides, Dendrogeomorphology, Temporal distribution of the activity, Zeri, Northern Apennines

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RIASSUNTO: CHELLI A. & STEFANINI M.C., *Caratteri geomorfologici e distribuzione temporale di frane attive nell'alto bacino del Torrente Gordana (Zeri, Appennino settentrionale): analisi dendrogeomorfologica.* (IT ISSN 0391-9838, 1999).

Il versante su cui sorge l'abitato di Patigno (Zeri, Appennino settentrionale) è interessato da un vasto movimento franoso la cui porzione superficiale è rimobilizzata da un elevato numero di frane di scorrimento e scorrimento-colata che hanno danneggiato sia i centri abitati sia la viabilità.

Al fine di comprendere la dinamica di questi movimenti franosi è stato condotto uno studio per alcune di queste frane, considerate attive, due delle quali poste in località Ternesia e altre sei in corrispondenza dell'area di piede del versante di Patigno.

La metodologia impiegata è stata quella della dendrogeomorfologia. Essa permette di ricostruire l'evoluzione sia temporale che spaziale di fenomeni parossistici come le frane, studiando gli effetti indotti sul tronco degli alberi coinvolti nel movimento del substrato.

Sono state campionate 147 piante appartenenti alla specie *Quercus cerris L.* estraendo da ognuna di esse delle carote tramite l'impiego del succhiello di Pressler. L'analisi delle carote ha permesso la datazione degli alberi e l'individuazione delle repentine riduzioni di crescita degli anelli annuali correlabili con gli effetti indotti dai movimenti franosi. L'elaborazione di *master plot* ha evidenziato l'importanza di alcuni anni nella «storia dendrogeomorfologica» del versante. In particolare per le frane a Ternesia sono state individuate fasi di attività negli anni 1957, 1961-62, 1974-76, 1981-83, 1993, mentre per l'area di piede del versante di Patigno, le fasi mobilitative principali sono riferibili agli anni 1970-72, 1974-75, 1982-83, 1993. Per le frane poste in località Ternesia attraverso la stesura di mappe del tipo evento-risposta è stato possibile, inoltre, ricostruire l'evoluzione spaziale dei movimenti evidenziando come l'incremento della massa spostata sia avvenuto, prevalentemente, attraverso una distribuzione dell'attività di tipo retrogressivo.

TERMINI CHIAVE: Frane, Dendrogeomorfologia, Distribuzione temporale dell'attività, Zeri, Appennino settentrionale.

INTRODUCTION

The land of the settlement of Patigno (Municipality of Zeri, Province of Massa-Carrara) presents itself as a broad slope facing south, about 2.5 km long and with a maximum upper transversal width of 1 km. It is situated in the upper basin of the River Gordana, one of the main right tributaries of the River Magra (fig. 1).

The entire slope is subject to landslide movements which, during their evolution, have damaged both built-up areas and the road system. Starting in 1998 the Department of Earth Sciences of the University of Pisa initiated, in the context of an agreement stipulated with the Provincial Administration of Massa-Carrara, a programme of research regarding Patigno. The aim of the research is the identification of the factors conditioning the stability of the area and the description of the characteristic parameters of the landslide movements present, in order to suggest possible kinds of intervention for recovery of the area. An analysis of the field data obtained through the application of the study methods of applied geology and geomorphology is currently in progress.

A study of the temporal and spatial dynamics of the landslides has been carried out on one portion of the Patigno slope by means of dendrogeomorphology, in collaboration with the Eidgenössische Forschungsanstalt für Wald, Schnee und Landschaft (WSL-FNP) of Birmensdorf (Zürich) where samples of trees from the area were analysed.

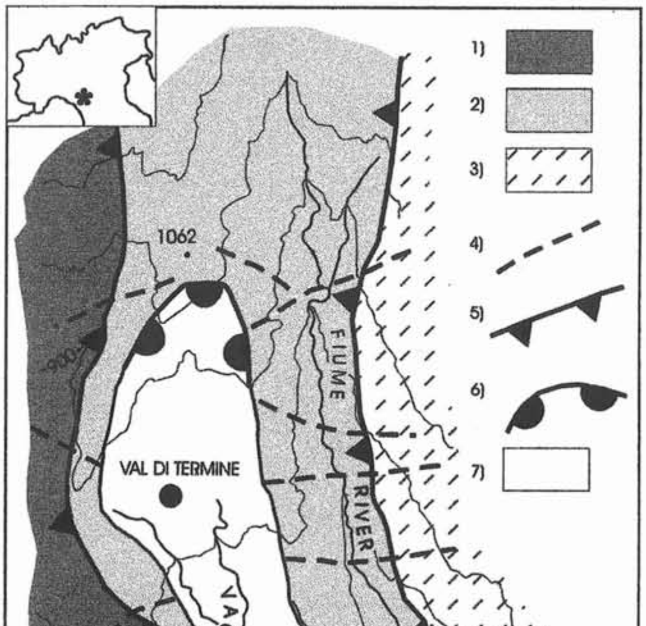


FIG. 1 - Sketch map of the area of Patigno. 1) Ottone-S. Stefano Unit; 2) Canetolo Unit; 3) Tuscan Series; 4) Fault; 5) Overthrust; 6) Landslide's crown; 7) Area of the landslide of Patigno.

Dendrogeomorphology is a method of study developed above all in the last thirty years and consists in the analysis of the dynamics of geomorphological processes by using techniques peculiar to dendrochronology. Through the study of the effects on arboreal plants of geomorphological processes it is possible to reconstruct, with seasonal resolution, their moments of activity. This type of study is particularly useful where direct, bibliographical or historical information on the activity of the processes considered is scarce or practically absent.

Dendrogeomorphology is easily adaptable to the reconstruction of the dynamics of paroxysmic phenomena, such as landslides, which induce evident changes in the morphology of plants. The main effects can be identified both in the external morphology of the trunk, e.g. cortical scars, growth of adventitious roots or new branches, tilting of the trunk, and also in its internal structure, e.g. abrupt variations in the growth of the annual rings often associated with eccentricity and formation of reaction wood (Fantucci, 1997).

With regard to landslide movements, dendrogeomorphology has been used successfully in the determination of the moments of activation and reactivation of landslides of the rotational slip (Terasmae, 1975; Begin & Filion, 1988; Jibson & Keefer, 1988) and rotational slip-flow type (Fantucci & Mc Cord, 1995).

GENERAL FEATURES OF THE AREA

The area being examined is situated in a sector of the Northern Apennines in which we can distinguish, outcropping in tectonic superimposition, proceeding from west to east, the Unit of Ottone-S. Stefano, the Unit of Canetolo and non-metamorphic Tuscan Series (Elter, 1960, 1973; Elter & Schwab, 1959; Dallan & Nardi, 1974) (fig. 1).

The Patigno slope is entirely modelled within the Unit of Canetolo. Here the main outcrop is the Formation of Argille e calcari (Lower Eocene - Middle Eocene), constituted by prominent banks of argillites interleaved with intercalations of calcareous-marly calcilutites and turbidites. Side by side with these lithotypes are those of the Formation of Calcari del Groppo del Vescovo (Lower Eocene - Middle Eocene), calcareous and calcareo-marly turbidites with intervals, occasionally laminated, of marny limestones, marls and argillites and of the Formation of the Arenarie di Ponte Bratica (Lower Oligocene - Upper Oligocene), pelitic sandstone turbidites constituted by a regular alternation of fine micaceous sandstones and of siltstone and, more rarely, argillitic levels.

From a tectonic and structural point of view the area is characterised by the presence of overthrust fronts between the Unit of the Flysch of Ottone-S.Stefano and the Unit of Canetolo and between the latter and the Tuscan Series, attributable to the compressive tectonic phase which from the Upper Cretaceous to the Upper Miocene led to the constitution of the Apennine chain (Elter, 1960, 1973; Boccaletti & *alii*, 1985). The continuity of the overthrust fronts is interrupted by the presence of normal faults with a prevalent NW-SE and W-E strike linked to the tectonic phase of a distensive character responsible for the formation of the depression of the valley of the River Magra (see the bibliography in Bernini, 1988, 1991; Bernini & *alii*, 1991), identified starting from the Upper Ruscinian-Lower Villafranchian (Federici, 1978, 1980, 1981; Bertoldi, 1988; Bertoldi & Castello, 1991). The sinking movements were followed by phenomena of differential up-lifting and of tilting of the blocks identified in the distensive phase, attributable prevalently to the Middle-Upper Pleistocene - Holocene (Federici, 1980; Bartolini & *alii*, 1983; Raggi, 1988).

At the outcrop scale the lithotypes present are therefore affected by structural elements linked to the complex tectonic history of the area. These are represented by surfaces of schistosity and of cleavage, axial planes and axes of folds, linked to ductile deformation, and by joints and to faults referable to the fragile tectonics.

The systems of normal faults present are, in part, still active, as is shown by the occurrence of earthquakes in this sector of the Northern Apennines. The seismic characteristics of the area being studied are comparable to those of many Apennine areas of average seismicity. Table 1 shows some of the most significant earthquakes that have involved the area of Zeri in this century (Postpischl, 1985). Of all of these, the one that stands out is the earthquake that struck the valley of the River Magra on September 7 1920 and was felt particularly in this zone (Patacca & *alii*, 1986; Boschi & *alii*, 1995), where it caused damage to buildings.

THE LANDSLIDES

The studies already carried out (Chelli & D'Amato Avanzi, 1998) indicate the likelihood of the presence of a large landslide involving the whole slope on which the settlement of Patigno and its districts of Val di Termine and Noce (fig. 1) have grown.

The detailed geomorphological survey has shown how the more superficial portion of the mass of this large landslide is set in motion by a large number of gravitative movements of small dimensions which determine the presence on the surface of the land of scarps, counterslopes and hummocks. In particular, they are common around the areas adjacent to the river banks, where the erosion caused by the streams themselves play a determining role in their creation.

For this study, mainly on the basis of the distribution of the tree covering in the area, a landslide movement that developed near a loop of the River Vaccareccio, in the locality of Ternesia, and the portion of the slope of Patigno adjacent to the left bank of the River Gordana (fig. 2) have been examined.

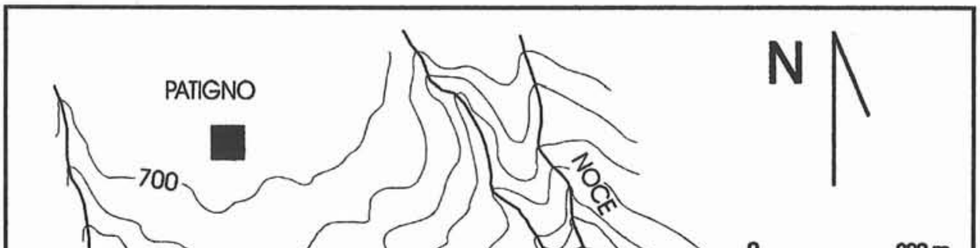


FIG. 2 - Geomorphological sketch map of the surveyed landslides.

The landslide movement located in Ternesia area (fig. 2) concerns a total area of about 2 hectares. It is a multiple phenomenon in which two quite distinct landslide bodies, which tend to be partially superimposed on each other, can be identified.

The first, here called «north landslide», involves an area of about 3000 m^2 with a length and width at the surface of 100 and 30 metres respectively, while the thickness of the mass moved is around 10 metres. It is an active landslide of the rotational slip type which is extending with a movement of a retrogressive type (Cruden & Varnes, 1996), as is confirmed by the presence of traction fractures in the land above the main scarp.

The second, called «south landslide», is about 120 metres long and no more than 30 metres wide. This is a composite phenomenon of the rotational-flow slip type (Cruden & Varnes, 1996), where the counterslope formation with respect to the head of the landslide body is clearly visible, emphasised by the presence of trees with the trunk inclined in the opposite direction to that of the movement. This phenomenon also shows clear signs of activity represented both by scarps and traction fractures and by hummocks. The latter are easily visible in the middle-lower portion where most of the trunks of the trees present are inclined according to the inclination of the slope.

For the landslide movements located near the bank of the River Gordana (fig. 2) examination of the geomorphological characteristics showed how the typology is that of the rotational slips and rotational slips-flow. They are active landslides that show a general tendency both to retrogression and advancement at the base, shown, also here, by the presence of ground fractures, scarps in succession and hummocks. Their dimensions are comparable in area and volume of the mass moved to those of the landslide movements situated in the locality of Ternesia. The only exception is represented by the landslide on the hydrographic right with respect to the River Noce. It is in fact of greater dimensions than the previous ones, presenting a length of about 450 metres and a maximum width of about 200 metres.

In order to identify the various periods of activation of the landslides, the trees present at Ternesia were grouped according to their position with respect to the different portions of the landslide movement itself. For the south landslide (fig. 3) the trees present in the head (zone B) were considered together, while those present on the main body were subdivided into two groups, zones A and C, corresponding respectively to the middle-upper part (rotational slip) and to the lower (flow) part. Some trees in the portion immediately outside the moving area (zone L) were also sampled, in order to monitor its tendency to expand.

For the north landslide, on the other hand, the few trees present on the main body were brought together into one group (zone E).

While at Ternesia the landslides are subject to the presence of tree covering on practically their entire surface (fig. 3), in the zone adjacent to the River Gordana the tree covering is distributed unhomogeneously and does not therefore allow the study of the dynamics of each single landslide. For this reason the trees present were divided into two groups according to their greater (zone G) or lesser (zone F) distance from the River Gordana.

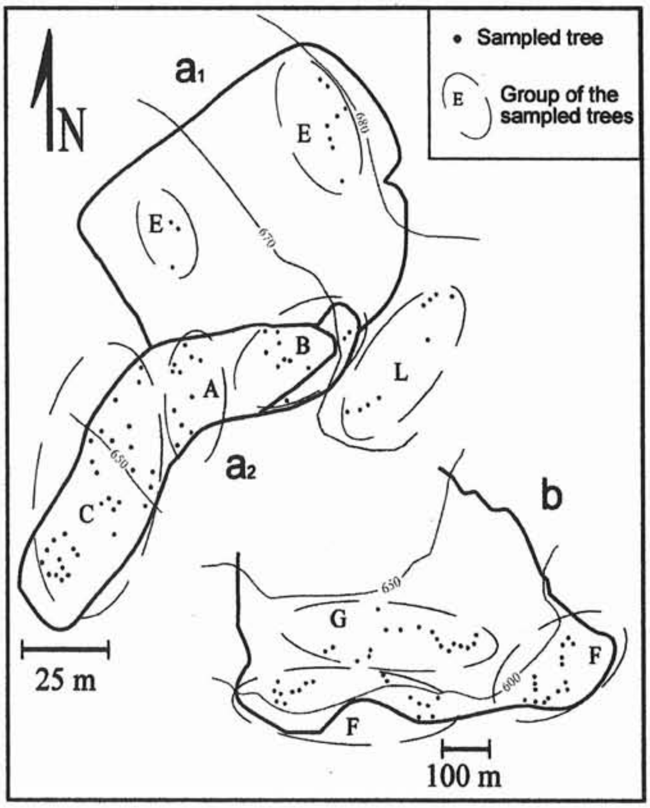


FIG. 3 - Distribution of the sampled trees. a_1) north landslide of Ternesia; a_2) south landslide of Ternesia; b) area at the toe of the slope of Patigno.

METHOD USED

The tree population present at Patigno belongs to the series of the «mesophyll mixed woods» (Ferrarini, 1981), with a definite prevalence of *Quercus cerris* L. up to 750 m a.s.l. For the study the trees of this species were used, in particular those whose external characteristics (tilting and curvature of the trunk), showed that they had been involved in landslide movements.

The sampling was carried out by taking cores from the trunks of the trees using an increment borer at about 130 cm from the base of the plant, obtaining cores with a diameter of 5 mm. Wherever possible two cores for each tree were taken, one up-slope and the other down-slope with respect to the direction of the land movement.

In the two areas analysed 131 trees were sampled for a total of 219 cores. Moreover, for the construction of the master chronology, 16 plants that had grown on the same type of geological substratum in a zone considered stable and comparable in exposure and altitude with the areas in the study were also sampled.

It was not possible to cut circular sections from the roots of the plants examined, not even in the zones where these were subject to erosive or undermining phenomena, since the root systems always proved to be considerably modified so that they did not present exposed surfaces, adhering to and penetrating deep into the ground. In addition to this, for reasons of forestry regulations, permission was not obtained to cut circular sections from the trunks of the existing trees.

All the cores sampled were prepared for analysis by placing them in special supports and polishing them with sandpaper. For each of them, the width of the single rings was measured with a precision of ± 0.01 mm, using TSAP software and the LINTAB measuring support (Rinn, 1996). This operation also made it possible to check the presence of false rings and/or missing rings by means of cross-dating of samples.

Once the cores were dated, skeleton plots were obtained, through visual analysis, to show for each of them the abrupt growth change of the rings. The latter were recorded and subdivided into two classes of intensity with respect to the standard width of the rings (Schweingruber & *alii*, 1990). The first class includes the values of the reduction in the width of the rings between 50% and 70% of their normal dimensions, the second class is constituted by values of reduction of over 70%. The data, grouped in this way, were summarised in the two master plots (fig. 4) which make

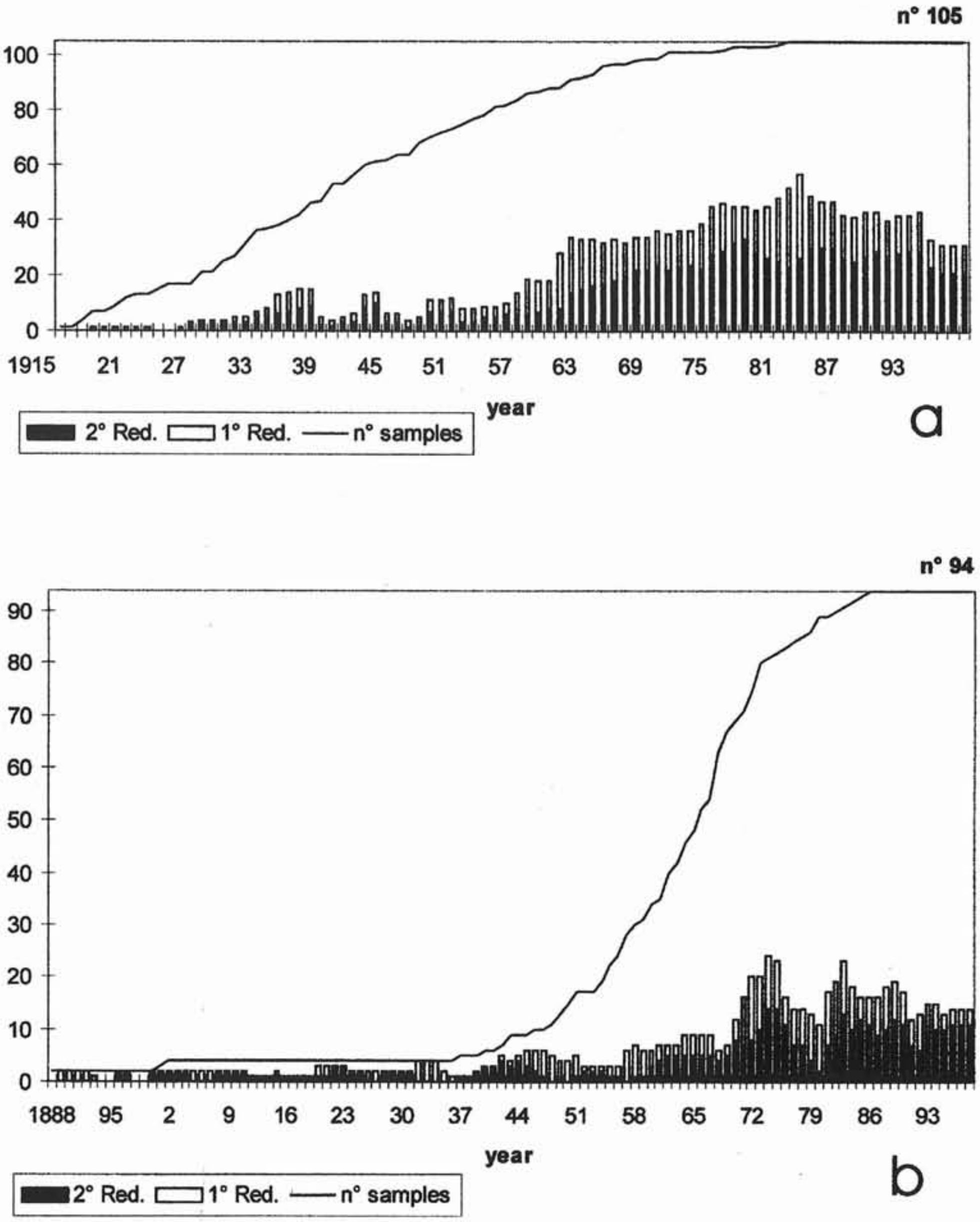


FIG. 4 - Summary of the growth reductions (Master Plot). 1° Reduction (white) 50%-70%; 2° Reduction (black) >70%. a) Ternesia locality; b) toe of the slope of Patigno.

possible the immediate identification of the years characterised by anomalies in the growth of the plants.

In order to obtain significant values for the correlation between abrupt growth change and phases of activity of landslide movements, it was decided to consider the reductions in growth shown by at least 50% of the samples analysed. Subsequently, considering the reductive events to be an index of destabilisation of the ground produced by the landslide movement, a further filtering of the growth reductions identified was carried out, taking into consideration only those involving simultaneously at least 20% of the samples (fig. 5).

Looking for determining the moments of activity of the landslides studied the growth reductions of a duration of more than 3 years were considered significant (Schweingruber & *alii*, 1990).

Micro-sections were also cutted from some cores collected. These, after being analysed under a microscope, made it possible to determine during which phase of the vegetative cycle of the plants, and consequently during which season of the year, the activations of the landslide movements occurred.

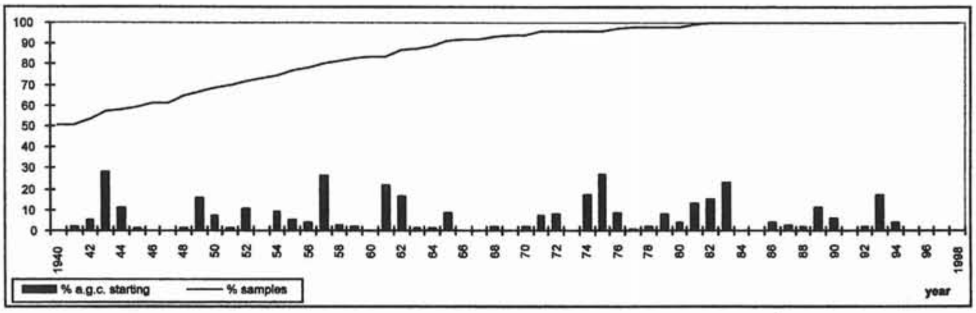
RESULTS AND DISCUSSION

The tree population, although not uniformly distributed, registered the changes in stability of the substratum, both at a macroscopic level as inclination of the trunks, and at a microscopic level with the appearance of abrupt growth change. The analysis of the data obtained by the method of study applied showed the importance of some years in the «geomorphological history» of the Patigno slope.

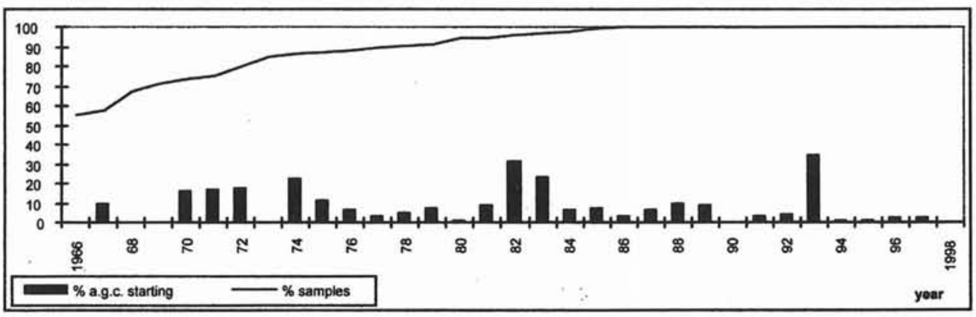
On the basis of the evidence of the temporal analysis event-response maps were drawn up (fig. 6), taking into consideration, year by year from 1940, each tree sampled (Shroder, 1980). This made possible a reconstruction of the phases and distribution of activity for the landslides studied.

The abrupt growth change indicative of the movements that have destabilised the root systems of the plants present in the locality of Ternesia (fig. 5a) highlight the main events in the years: 1957, 1961-62, 1974-76, 1981-1983, 1993.

The first significant event in the locality of Ternesia occurred in 1957 involving uniformly the trees present at the toe of the south landslide (zone C); this is particularly true for the trees situated closer to River Vaccareccio (fig. 6). The main phase of activity seems however the one that occurred some years later which involved the whole body of the south landslide, although at slightly different times in the various portions, for which reason it was dated 1961-62. In particular for zone A the signs of activity are already present in 1961, while in 1962 the movement extended to zone C. The analysis of the anatomy of the wood

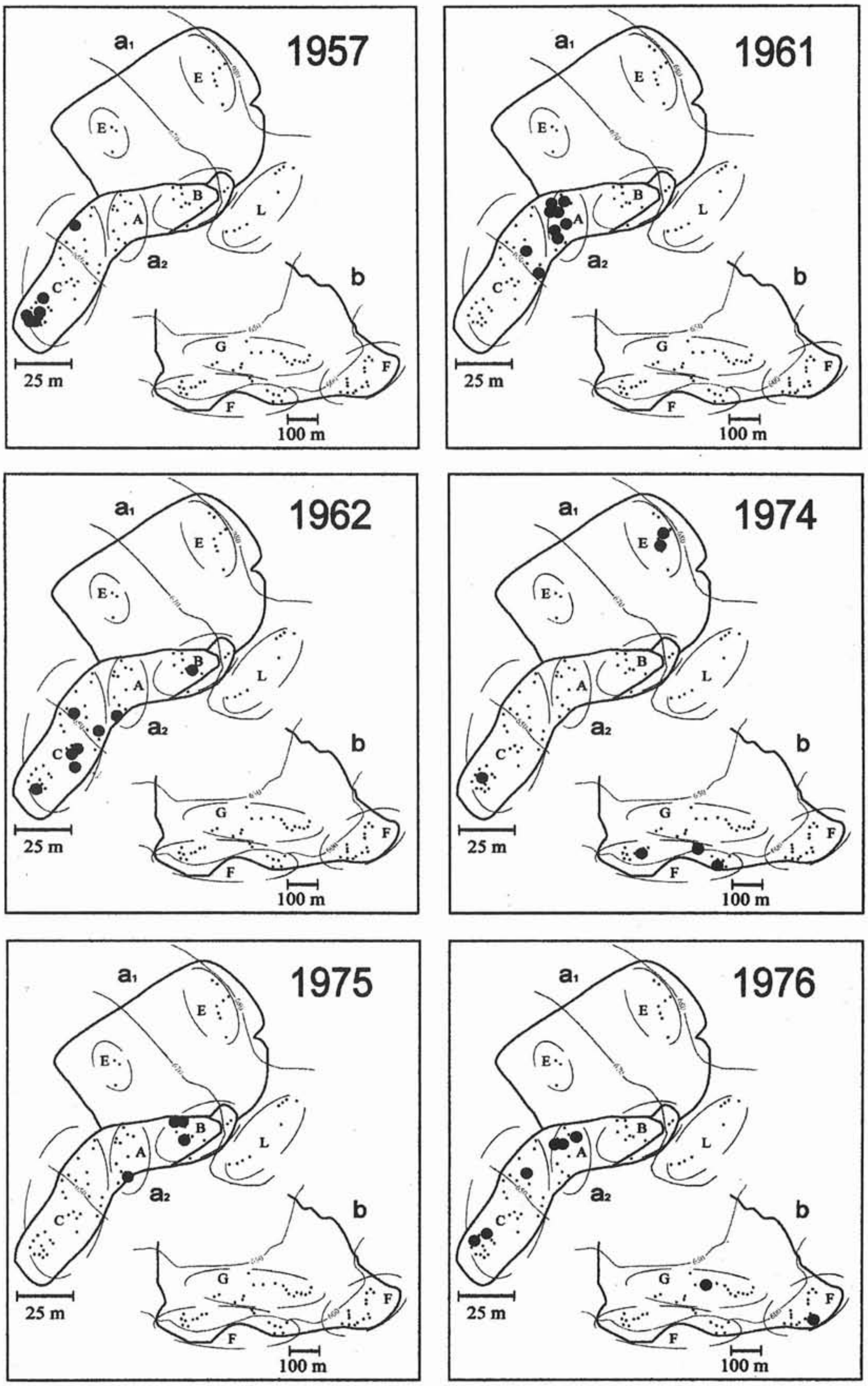


a



b

FIG. 5 - Summary of the beginning of the growth reductions. a) Ternesia locality (A, B, C, E zones); b) area at the toe of the slope of Patigno (F, G zones).



A

FIG. 6 - Event-response yearly maps at Ternesia (a_1 and a_2) and at the toe of the slope of Patigno (b). A): years: 1957, 1961, 1962, 1974, 1975, 1976. Legend: ● = sampled trees showing the growth abrupt changes; for the others symbols see fig. 3.

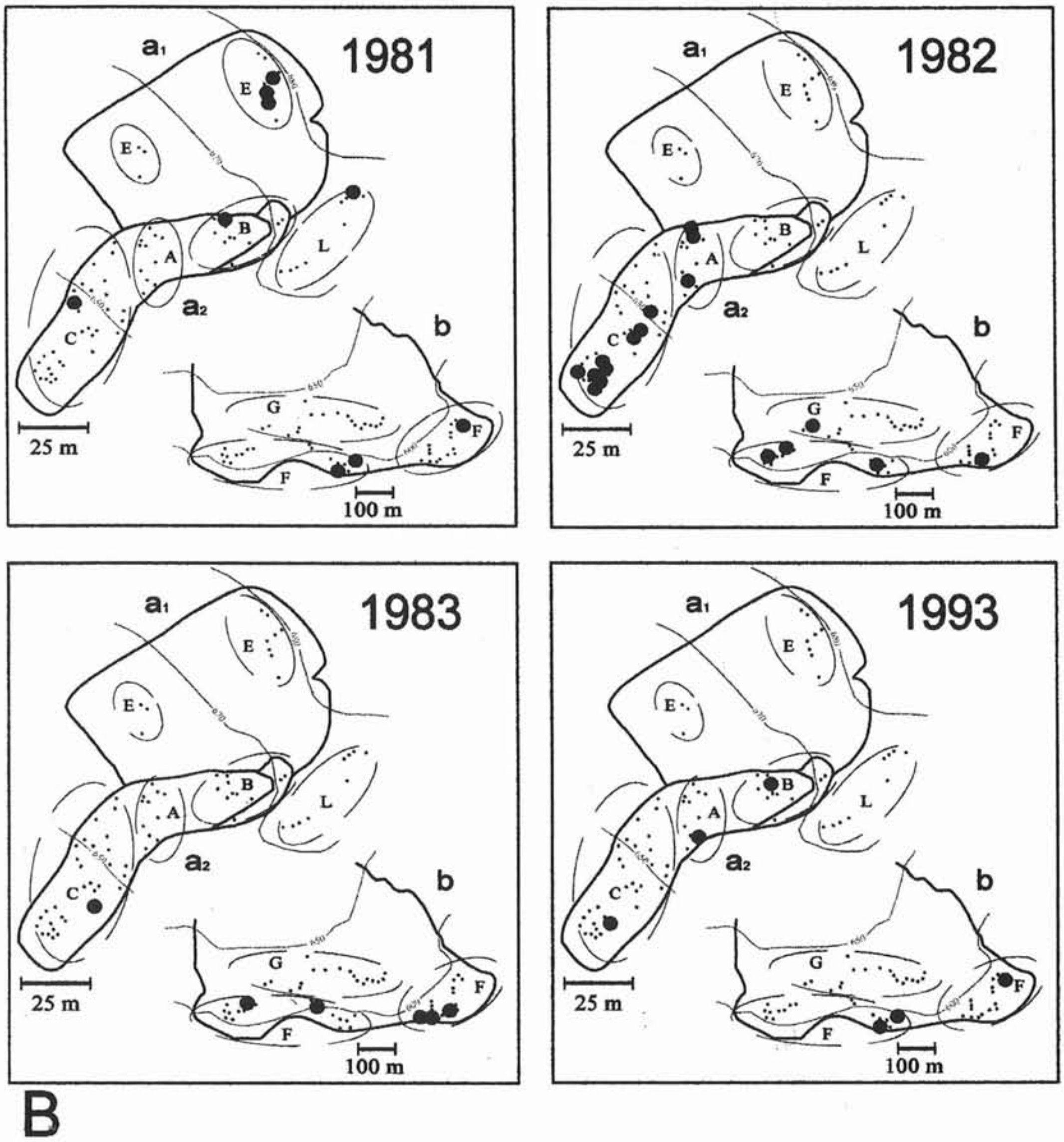


FIG. 6 - B): 1981, 1982, 1983, 1993. Legend: ● = sampled trees showing the growth abrupt changes; for the others symbols see fig. 3.

using micro-sections of the cores that registered the event of 1961, made it possible to place it in the period between the end of the spring and the beginning of the summer.

Some trees, affected by the abrupt growth change following the event of 1961, showed the tendency to maintain a reduced ring width growth for several years, therefore preventing the identification of any other variations.

Another well-defined phase of movement was highlighted for the years 1975-76 in which zone B was also involved for the first time. The movements then continued from the first half of the 1980's also completely involving the trees on the edges of the body of the landslide.

The examination of the data seems therefore to indicate that the landslide movement began in the area of the foot of the slope (zone C) probably as a result of an undermining action of the River Vaccareccio. From here it probably spread to the portions at the top of the slope involving first zone A (1961) and C (1962) and subsequently zone B, with the event of 1975. This leads to the conclusion that the south landslide of Ternesia evolved through successive increases in the volume of the mass moved, occurring during about forty years, with a general distribution of activity of a retrogressive type.

At present the crown of the landslide is extending southwards. Figure 6 shows how this phase of expansion began with the event of 1981.

For the area involved in the north landslide of Ternesia the degree of significance of the data collected proved to be fairly low because of the small number of trees present. However, in our opinion, given the proximity of this landslide movement to the one dealt with above, its evolution might have been very similar with moments of activity that were probably contemporaneous. If this hypothesis is valid, the events, registered in the trees of zone E (fig. 6), could therefore be interpreted as the response to the destabilisation of the substratum as a result of the expansion of the crown of the landslide in the sense of its retrogression, with an increase in the surface involved in the phenomenon.

In the area at the base of the slope of Patigno the distribution of the tree population is not uniform, but is concentrated in groups of plants which involve marginally the landslides identified by the geomorphological survey. In this case it was not therefore possible to reconstruct the distribution of the movements of each single landslide body.

The events registered by the trees in the area at the foot of the slope of Patigno concern above all the individuals situated adjacent to the river bank (zone F), while in the middle-upper part (zone G) the trees present limited variations. Dating by means of the abrupt growth change (fig. 5b) indicates as particularly interesting the years: 1970-1972, 1974-75, 1982-83, 1993.

The event-response maps (fig. 6) show for this area periods of activity attributable above all to 1974, 1976, 1981-83 and to the year 1993. In most cases there are above all a large number of minor responses with a very broad spatial distribution. This, in our judgement, indicates the occurrence of periods of generalised mobilisation of this portion of the slope, linked mainly to the action of destabilisation created by the River Gordana. The phases of activity of the landslide movements surveyed should also fit into these periods. Moreover, for the event of 1974 a relation can be suggested with the earthquake of 1973 (table 1), with their epicentre at Zeri, which could has played a predisposing role for the phase of activity of slope movements.

TABLE 1 - Main earthquakes of this century

Date	Intensity	Epicentral Zone	Distance
07-09-1920	IX	Lunigiana	40 km
07-05-1921	VII	Pontremoli	10 km
18-11-1926	V-VI	Bagnone	20 km
21/27-02-1928	VI	Varese Ligure	14 km
08-07-1972	V	Pontremoli	10 km
25-10-1972	VI-VII	Passo della Cisa	20 km
08-07-1973	IV	Zeri	in situ
08-02-1975	IV	Zeri	in situ

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