ELSEVIER

Geomorphology 30 (1999) 165–174

GEOMORPHOLOGY

Dendrogeomorphological analysis of a slope near Lago, Calabria (Italy)

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Received 23 June 1997; received in revised form 20 December 1997; accepted 17 June 1998

Abstract

The dendrogeomorphological analysis has been used to investigate the periods of disturbance on a slope affected by deep-seated gravitational movements. The method proved to be of great help in determining the temporal sequence of diffused slope movement in the study area, and, though to a lesser extent, to find out the possible causes of triggering the mass-movement. In general, leaning trees indicate that the movement is active. The visual growth analysis indicates that anomalies consisted of sudden decreases of the growth (suppression of tree-rings) induced by stress consequent on ground disturbance, followed in some cases by sudden increases of tree-ring width induced by the higher moisture content in the landslide body. By anomaly analysis, an increase of the anomaly index (It) occurred between 1840 and 1860; subsequently, a period of strongly oscillating values of It occurred that levelled off around 1950. It also appears that mass-movements began to affect this zone soon after 1850s, thus, we can tentatively assume that they have been the cause of the growth anomalies, with a maximum influence in the period between 1860 and 1895.

As regards the causes for mass-movement, we inquired about timing of extreme meteorological events and earthquakes. The meteorological data obtained from raingauging stations are not so well related to mass-movement reactivation as the seismic data are. However, only a minority of extreme meteorological events may produce such a disturbance that can be recorded in the tree-ring record. Indeed, only 30% of anomalies can be explained in terms of extreme events. On the other hand, the continuous creeping of the sackung might irregularly trigger the movement of shallower landslides in non extreme-events years. We obtained, instead, a higher degree of coincidence between disturbing causes and anomalous tree growth using archive reports on extreme rainfall periods.

Keywords: dendrochronology; mass-movement; historical records; Calabria

1. Introduction

Dendrogeomorphology, firstly introduced by Alestalo (1971) has been applied successfully in the spatial and temporal analysis of mass-movement by many authors: Shroder (1978) investigated landslides in the Table Cliffs Plateau of Utah finding peak periods of mass-movement reactivation. Many authors (Terasme, 1975; Shroder, 1978; Hupp, 1984; Strunk, 1992; Denneler and Schweingruber, 1993) found that trees subject to stress due to mass-movement have manifested strong and sudden decreases in ring growth. This effect on tree growth was also

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0169-555X/99/$ - see front matter
PII: S0169-555X(99)00052-5

found by Orombelli and Gnaccolini (1972) in dating the Vajont landslide in Italy through the study of tilted conifers. Another important kind of information on the causes of landslide-movement was pointed out in the papers of Jibson and Keefer (1988) and Filion et al. (1991). Those authors discovered coincidence between the dating of tree disturbances and past strong earthquakes in the Mississippi Valley and Rivière du Gouffre, respectively. Dendrochronology was used by Hupp (1984), Van Asch and Van Steijn (1991), and Strunk (1992) to evaluate the frequency of landslides activity. Kashiwaya et al. (1989) have instead investigated the relationship between tree-ring width and heavy rainfall in the landslide-prone area of Kobe District in Japan.

The aim of this study was to investigate the phases of past activity of a large-scale deep-seated gravitational slope deformation involving the part included between the Vallone Pizzoto canyon and Greci Village, of the right-side slope of the torrent Elicetto, near the city of Lago, in northern Calabria (Figs. 1 and 2). The deformation is of the sackung type (Zischinsky, 1969) and is ca. 1300 ha in extent. It is active, as is clearly indicated by the current activity of the landslide at its upstream and downstream boundaries, and by inclinometric and topographic data (Sorriso-Valvo et al., 1996). The slope comprises essentially allochtonous terranes emplaced during the Alpine Orogeny. They consist of low- to medium-grade metamorphics represented essentially by ophiolite-bearing phyllites with metacalcarenite and quartzite bands, and by porphyroids. High-grade metamorphics (white schist and gneiss) lie over the lower-grade metamorphics, forming the top of the slope. Carbonate rocks outcrop just north of the deformed slope; they represent the basement onto which the metamorphic units are thrust. This basement outcrops extensively in a tectonic window that is geometrically protruding through the allochtonous nappes. All the rocks are very intensely jointed and faulted. Thrust faults pervasively affect the parent rocks at every dimensional scale. Only the major tectonic structures are mapped in the geo-structural scheme of Fig. 2.

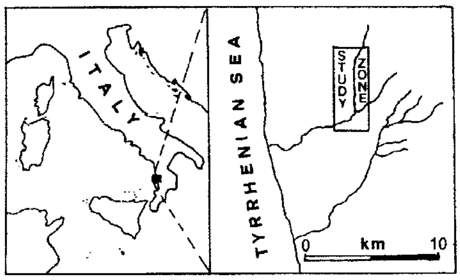


Fig. 1. Location of the study zone.

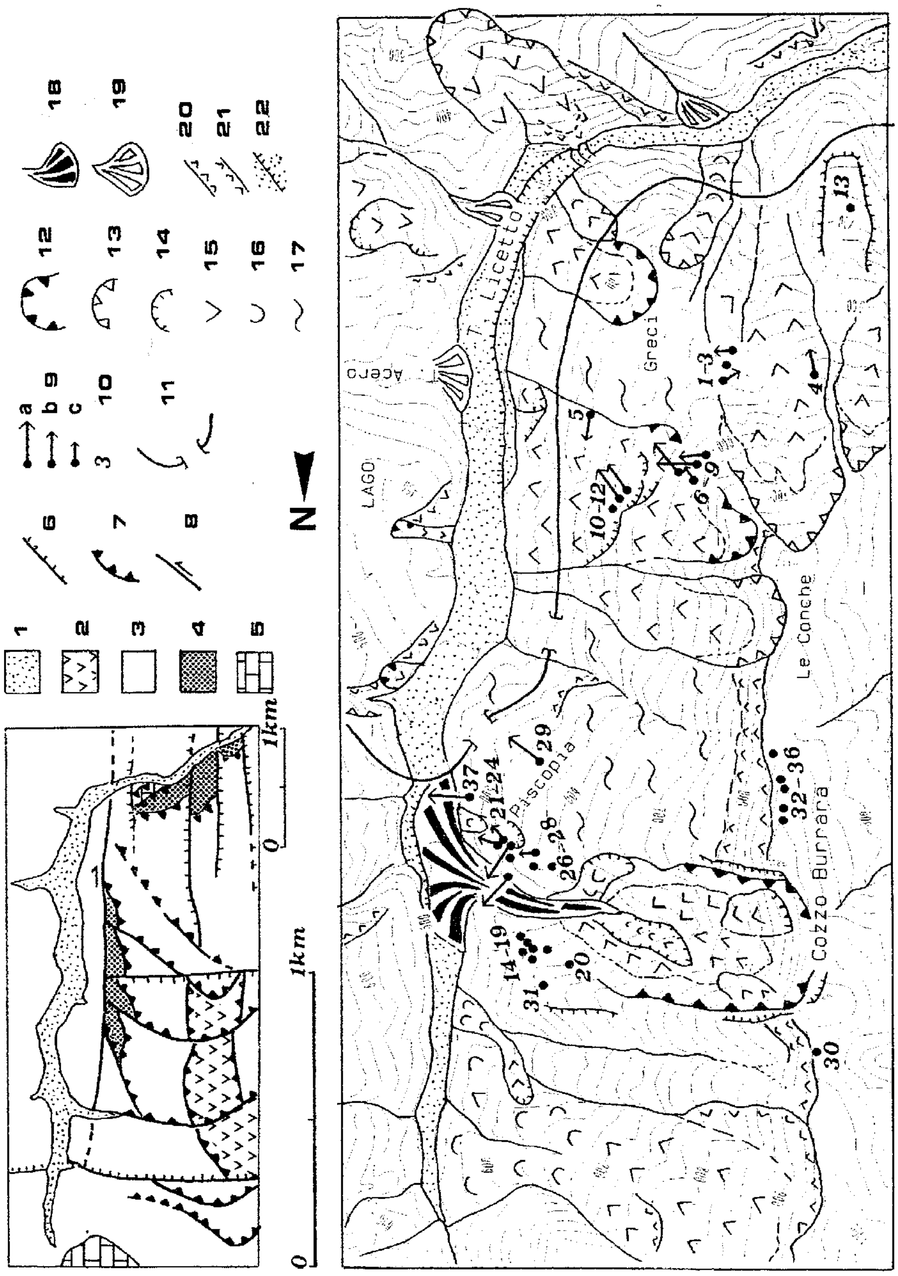
As the sackung activity is reflected in the activity of the overlying shallow slides, we decided to trace back the activity stages of the shallow slides by means of dendrogeomorphological analysis. We performed this analysis essentially on the oldest oaks (*Quercus pubescens* Willd.) scattered on the landslide area, and on *Pinus nigra* (L.) outside it. We tried to find also the causes that could have triggered the events of reactivation of mass-movement.

2. Dendrochronology: material and methods

2.1. Sampling strategy

The whole of the Vallone Pizzoto-Greci slope was investigated through dendrogeomorphological techniques. The sampling strategy was to collect cores, using a Swedish incremental borer, from the oldest trees living on the area, belonging to the same

Fig. 2. Dendrochronological samples, geomorphological scheme and regional geological sketch map of the study area. The Vallone Pizzotto canyon landslide and fan complex is the active one East of Cozzo Burrara. Key to the symbols: 1 = Holocene deposits; 2 = high-grade metamorphics; 3 = low-grade metamorphics; 4 = metabasite and metalimestones; 5 = dolostones; 6 = normal fault (tics on the down-thrown block); 7 = thrust fault (teeth on the upthrust side); 8 = strike–slip fault; 9 = dendrochronologic samples; arrows if stems are reclining by: a: > 30°; b: 10°/30°; c: 1°/9°; 10 = sample number; 11 = highway; 12 = principal landslide scarp, active; 13 = principal landslide scarp, non active; 14 = secondary scarp; 15 = sliding-type landslide; 16 = flow-type landslide; 17 = sackung deformation type; 18 = alluvial fan, active; 19 = alluvial fan, non active; 20 = slope convexity (teeth on the downslope side); 21 = slope concavity (teeth on the upslope side); 22 = stream erosion scarp.



T. Licetto
Greci
LAGO
Acero
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species, and displaying signs of past disturbances such as anomalies in the tree–stem morphology.

In fact, many trees showed a tilting and sometimes an S-shape of the stem, which is a sign of recovered straight stem growth after a tilting event (Alestalo, 1971; Braam et al., 1987).

From each one of the sampled trees, usually two cores were collected: one on the side opposite to the direction of tilting, and the other orthogonal to or facing the first one. For each sampled tree, we recorded: a — its position on the topographic map; b — the direction and degree of stem tilting; c — the directions of the core sampling.

In total, 38 trees were sampled; 24 trees from different parts of the landslide and 14 trees from the stable surrounding zones.

2.2. Dendrochronological analysis

All the samples were subjected to the standard procedures used in dendrochronological research such as sample surface preparation, skeleton plots, cross dating, ring width measurement with a micrometer to construct growth curves (Stokes and Smiley, 1968). The ring width measurements were then checked through the program CHOFECHA (Holmes, 1983).

A very important method was the "visual growth analysis" introduced by Schweingruber et al. (1990), to identify sudden growth decrease (suppression) or increase (release) in the cores.

Most previous research on mass-movements has used different species of conifer trees, while this research is based principally on deciduous oak species, as in the case of a recent dendrogeomorphological study developed in central Italy on a landslide by Fantucci and McCord (1995), who used trees of *Q. cerris* (L.) species.

Here, we used a classification of growth anomaly (Fig. 3) adapting that developed by Schweingruber et al. (1990) adding a fourth class of reduction to indicate the situations in which the growth reduction was so strong that some rings were missing. Indeed, in some cases the suppression was so strong that it was impossible to read each single ring, so the average value of growth computed for the whole period of suppression, was assigned to each single ring of the strongest suppression period. This was done to have a complete growth curve for all the

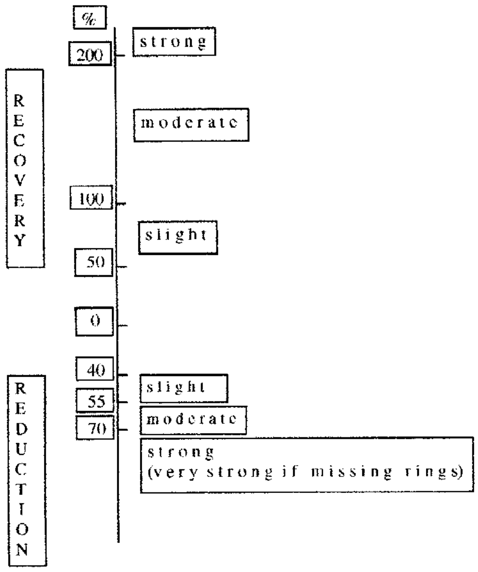

Fig. 3. Classes of growth anomaly used in the visual growth analysis.(Adapted from Schweingruber et al., 1990).

cores examined, even if the ring growth was estimated in the periods of strongest suppression.

3. Results

3.1. Trees stem tilting

The map of direction and degree of inclination of the sampled trees (Fig. 2) indicates a first important difference between the morphological characteristics of sampled trees living on the slope and those on the surrounding stable areas or on the ridge top. In fact, the latter all had straight stems without any evidence of disturbance, while the former were mostly affected by a tilting of the stem. As a whole (Fig. 4), 51.3% of sampled trees are affected by stem bending and tilting. On the landslide body, 78% of sampled trees have tilted stems while the remaining 22% have straight stems. The main tilting direction is within the sector NE to S, with a maximum in the ESE direction.

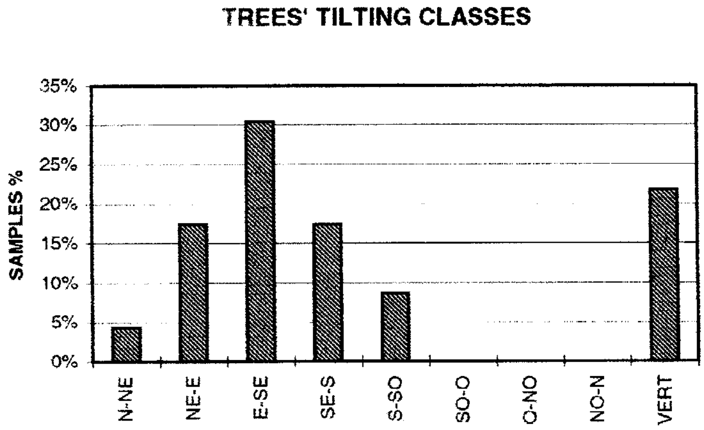

Fig. 4. Histogram of trees tilting direction in landslide area.

As regards the relationship between tilting direction and slope direction, 78% of tilted trees lean downslope or nearly downslope (this reflects the ESE peak in tilt direction); 17% lean orthogonal to the downslope direction; 5% dip counter to the downslope.

3.2. Suppression and tree-growth curves

The effects of growth anomaly can be seen in Fig. 5 comparing the ring growth curves for the undisturbed trees with some of the most representative ring growth curves for the disturbed trees. In the cores for the disturbed trees, a sudden growth decrease is clearly evident, compared to the normal growth of the non-disturbed trees.

Sometimes, the effect of the growth decrease was so strong that the trees never recovered their regular growth, as in the cases of samples C9b and C29b (respectively due to events in 1871, 1844 and 1890). The strong suppression often caused a ring growth close to zero; in some cases the cores showed a very intense suppression after the stressing event, so that many rings were missing, or the existing ones were so narrow that they became indistinguishable. In other cases, the trees recovered their regular growth tens of years later, as was the case for sample C10a.

The undisturbed ring growth curve in Fig. 5 was obtained using the mean ring width of eight trees not affected by growth anomalies.

3.3. Visual growth anomaly analysis

The visual growth analysis was made on all the cores sampled on the landslide area. Then, all the anomalies found were used to create a graph based on a modified Shroder formula (Shroder, 1978) to calculate the anomaly index (It) for each of the event–response cases.

The modified It used was calculated considering for each year the number of observed rings affected by suppression, the intensity of suppression as expressed by a coefficient of intensity of suppression, and the total number of samples analysed in that year.

The It was calculated as follows:

$$\text{anomaly index (It)} = \frac{\sum_{t=1}^{n} (\text{Sup}(x)t \times (\text{Fx}))}{\sum_{t=1}^{n} (N_{\text{tot}})t} 100\%$$

where: $\text{Sup}(x)t$ = number of suppressions of each class (x) in year t; Fx = intensity coefficient. It is expressed by integers in a rank scale from 1 to 4, according to increasing intensity of suppression (it corresponds to slight, moderate, strong, and very strong); $(N_{\text{tot}})t$ = total number of samples analysed in year t.

In this way, it was possible to give more emphasis to those events that had induced strong growth suppressions in trees. To construct the graph, only the

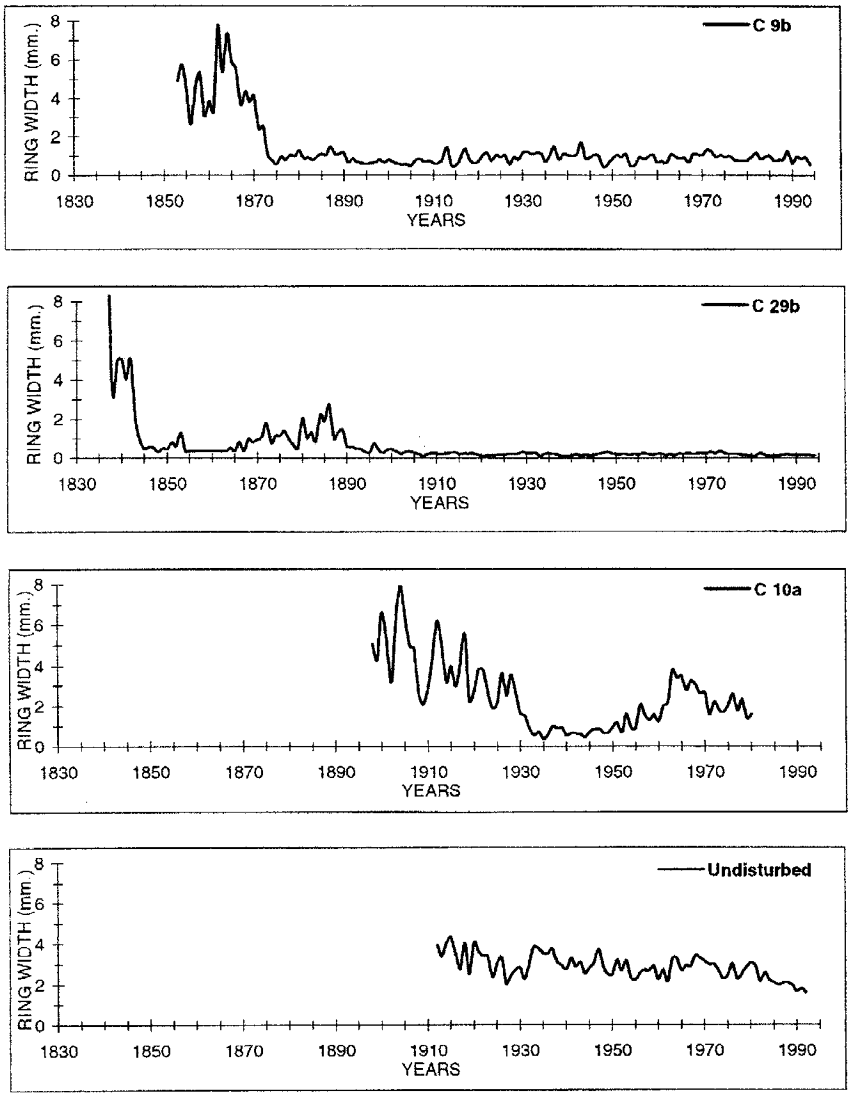

Fig. 5. Growth curves of disturbed (C9b, C29ba and C10) and undisturbed trees.

reduction growth anomaly was considered, because the recovery anomalies were very few and always subsequent to the suppression anomalies, thus they were not directly related to the events.

The results of the visual growth analysis are represented through the It graph in Fig. 6. It (shaded bars) is scaled on the lefthand axis. The horizontal axis indicates the period of analysis (1820–1994),

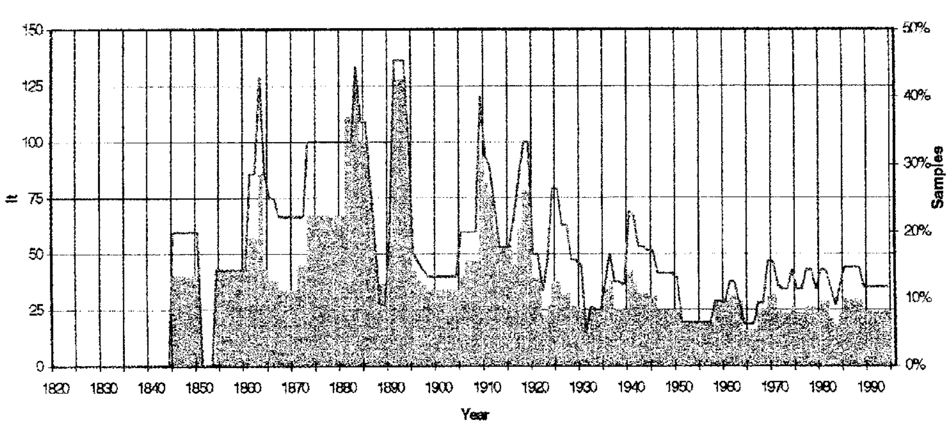

Fig. 6. Graph of visual growth anomaly index related to landslide area. It = anomaly index (solid bars); Samples = percentage of disturbed samples (line).

the percent of disturbed samples (solid line) is scaled on the righthand axis. The first registered disturbance occurred in 1845. The events that occurred during the period between 1860 and 1895 were stronger than those that occurred during the subsequent period, reaching the 45% of disturbed cases. Then, another period of disturbance followed between 1905 and 1950, with more than one low-intensity event that had involved a decrease in the percentage of cases from 40% to 23%. The last period, between 1951 and 1995, was the least disturbed with a percentage of disturbed cases never exceeding 16%.

3.4. Correlation between growth anomaly events and natural causes

In order to investigate the possible causes that could have induced the growth anomalies in the trees living on landslide body, both seismic and hydrological time-series were considered.

The seismic data are related to those earthquakes whose intensity in the study area had reached at least the 7th degree of the Mercalli–Cancani–Sieberg (MCS) seismic intensity scale. The earthquakes that affected the study area in the period 1820–1995 are listed in Table 1.

In order to correlate the meteorological data with growth anomaly, data from the rain gauge station of Aiello Calabro were considered. This station is 5.7 km from the landslide site. Unfortunately, the daily rainfall series were not complete. To overcome this problem, the missing meteorological data were estimated using the data of the rain gauge at Fiumefreddo Bruzio, 10 km from the site. The homogeneity of the data of this station was tested with those of Aiello Calabro by means of Mann–Kendall test (Holmes et al., 1986). The test resulted positive, thus, we could make the estimation required.

Table 1
Earthquakes that affected the study area. h = focal depth; I_0 = epicentral intensity in MCS scale; Mk = magnitude (Postpischl, 1985)

Date	Distance from epicenter (km)	h (km)	I_0	Mk	Epicentral area
12-10-1835	30	3	9	5.4	Castiglione (CS)
11-02-1854	20	4	9	5.6	Cosenza
04-10-1870	20	7	9	5.8	Cosenza
08-09-1905	50	11	10	6.5	Gulf of S. Eufemia
28-12-1908	130	8	11	6.8	South Calabria and Messina

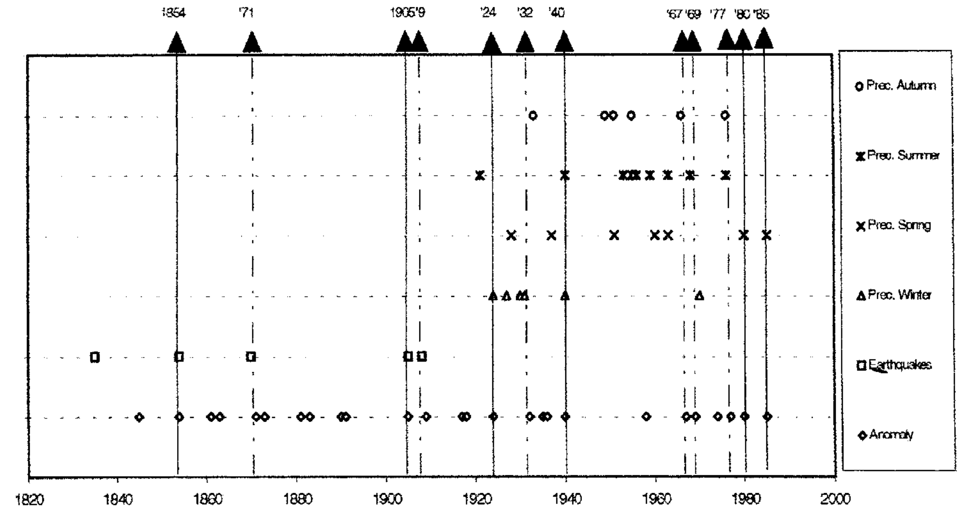

Fig. 7. Skeleton plot of the study case. Bottom figures are years; top figures with solid triangles are anomaly years corresponding with either seismic or rainfall events. The solid line means that the growth anomaly occurred in the same year of the causative event, while the dotted line means that the anomaly occurred the year following that of the causative event. Rainfall data time series began in 1913.

The monthly precipitation data were then grouped seasonally into: winter (December to February), spring (March to May), summer (June to August) and autumn (September to November). The reason for this grouping is twofold: first, the study area lies in a Mediterranean climate zone, i.e., with strong seasonality for rainfall and temperature; second, other studies conducted in study zones relatively close to the study area, demonstrated that the reactivation of deep-seated landslides is related to precipitation periods preceding the landslide, lasting 50 to 90 days (Sorriso-Valvo et al., 1993).

For each season, the average rainfall for the period of available data (1913–1987) was calculated. Then, all the seasons whose rainfall exceeded the mean value by 1.5 times the mean square residuals, were considered as extremely wet seasons. This threshold is subjective, but there are no standard values to refer to.

Climatic events able to trigger mass-movement are recorded in historical chronicles. We could obtain information over a time span that extends back to early 1800s. In the study zone, such events occurred in the winters of 1863–1864, 1882, 1894, 1896, 1910, 1919, 1927, 1936, 1937; Coincidence with growth anomaly occurs in 1863, 1882, 1910, 1927, and 1936, i.e., in 55% of the cases.

Using the dates of the main growth anomaly events, the dates of the earthquakes and those of the extreme seasonal precipitation values, we composed the skeleton plot shown in Fig. 7. In this figure, the dates in which the growth anomalies are related to the dates of seismic and meteorological events are marked by the lines with solid triangles. The discussion of this figure represents the conclusion of the present paper.

4. Discussion and conclusion

The method used to investigate the periods of disturbance, proved to be of great help in determining the temporal sequence of diffused slope movement in the study area, and, though to a lesser extent, clarify the possible causes of triggering of the mass-movement.

The trees sampled outside the slope had regular growth patterns, without evidence of tilting and distortion of stems. Available information on the geomorphology and on the deformation occurring in the study zone, indicates that the slope is deforming through deep-seated creeping and landsliding (Sorriso-Valvo et al., 1996). The movement is expanding rapidly in the northern part of the slope where deformation occurs up to the top. However, the seismic profile suggests that the entire mountain is undergoing a unilateral sagging (Hutchinson, 1988), with essentially translational displacement and no or very little rotational component. On the slope, instead, leaning trees indicate that the movement is active. This agrees with inclinometric data (Sorriso-Valvo et al., 1996). Tilted trees are 78% of the sample population (Fig. 4), 78% of which lean downslope, indicating that the velocity of mass-movement decreases with depth, but no toppling has been detected. One tree leans counter in the slope, indicating a local rotation. The remaining 17% of the stems which leanslip orthogonal to the slope are difficult to explain. By visual inspection of Fig. 2, it seems that they are located along or in the proximity to the outcropping of the shearing surfaces of the landslides, where ground deformation is controlled by the very local geometry.

Dendrochronological analysis was conducted by means of visual growth analysis, and of It.

The visual growth analysis indicates that anomalies consisted of sudden decreases of the growth (suppression) induced by stress consequent to ground disturbance, followed in some cases by sudden increase (release) induced by the high moisture content, typical of the landslide body.

From the graph in Fig. 6, it is possible infer that after a sudden increase of It between 1840 and 1860, there is a period of strongly oscillating values that however decrease to a stationary level around 1950. The reason for this pattern is difficult to explain. However, as historical records (Sorriso-Valvo et al., 1996) indicate that slope movement began to affect this zone soon after 1850s, we can tentatively assume that the cause of growth anomaly has been the landsliding, with a maximum influence in the period between 1860 and 1895.

Causes of the mass-movement may be many. By comparing (Fig. 7) the time series of possible causative events (earthquakes, extremely wet seasons), with that of ring growth anomaly, it appears that 80% of the earthquake dates correspond with growth anomalies found in sampled trees. The converse is of course not true: only 15% of anomaly dates correspond with an earthquake, confirming that the reasons for an anomaly can be other than earthquakes. However, the growth anomalies in 1871 and 1909 are delayed for 1 year with respect of the date of earthquakes because they occurred during the vegetative rest period (respectively October 1870 and December 1908), thus the effects of the stress on the trees are recorded in the following year. The two anomalies of 1854 and 1905 are instead related to seismic events which occurred during the growing season of the same year. The meteorological data are not so well related to mass-movement reactivation as the seismic data: indeed, considering the period for which rainfall data are available (1913–1987), only 55% of the anomaly cases can be connected to extreme precipitation values. On the other hand, correspondence between seasonal extreme values and anomaly is low (spring 28%, summer 33%, autumn 33%, and winter 50%; average 35%) but as expected higher than that for earthquakes.

If information from historical records of landsliding is considered, then 55% of recorded events correspond with an anomaly record, while 31% of anomaly records correspond with an historical landslide record. Correspondence is nearly equal for instrumental and historical data.

Conclusions based on instrumental rainfall data (after 1913) suggest that only a minority of extreme meteorological events may produce such a slope disturbance that can be recorded in the tree-ring record, and that only 30% of anomalies can be explained in terms of extreme events. This weak connection is probably due to the fact that the relationship between rainfall and mass-movement activity is complex. For instance, the ca. 30 m deep, slow-moving sackung-type deformation should respond to much longer periods of increased rainfall. On the other hand, the continuous creeping of the sackung might irregularly trigger the movement of shallower landslides in non extreme-events years.

Coincidence between the seismic and hydrologic–meteorologic time series can be found only for the 1908–1909 earthquake and 1910 rainfalls. An anomaly has been found in 1910. It is only one case, and it cannot be used for any kind of inference.

We can conclude that we obtained a moderate degree of success in the use of dendrochronological analysis in the identification of the temporal occurrence of causes of landslide movement. A higher degree of coincidence between disturbing causes and anomalous tree growth has been obtained using archive data for extreme rainfall periods. This might have depended on the much higher annual rainfall depth in the period from the beginning to the 1880s. On the other hand, we could successfully distinguish the dendrochronological series of trees growing in the unstable area from those of trees outside the unstable area. In addition, the period of maximum instability could be well defined between 1860 and 1895.

Acknowledgements

This paper is a part of the CEC Environment Program Project TESLEC (EV 5V-CT94-0454) "The temporal stability and activity of landslides in Europe with respect to climatic change".

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