Geogr. Fis. Dinam. Quat.
27 (2004), 159-166, 12 figg.

MARIA CLEOFE STEFANINI (*)

SEASONAL DETERMINATION OF MASS MOVEMENT OCCURRENCE BY MEANS OF DENDROCHRONOLOGY AND WOOD ANATOMY: EXAMPLES FROM ITALIAN CASE STUDIES

ABSTRACT: STEFANINI M.C., *Seasonal determination of mass movement occurrence by means of dendrochronology and wood anatomy: examples from Italian case studies*. (IT ISSN 1724-4757, 2004).

Dendrochronology has often been used to determine the spatio-temporal evolution of mass movements, allowing the annual dating of events. In this study we present the possibility of defining the seasonal occurrence of events by using dendroanatomical techniques. For these techniques we need to determine the trees radial growth period. This was done by cutting and analysing thin sections from selected tree ring sequences. The anatomical structure of normally growing tree-rings was compared with the structure of tree-rings showing growth anomalies. This allowed a setting of the occurrence of growth anomalies within the growing season. The mass movements analysed are located both in the Alps and in the Apennines. Reactivations characterized the Apenninic landslides mostly during the dormant season, rarely during spring or summer. On the contrary, debris flows, analysed in the Italian Maritime Alps, occurred mostly in the late spring-early summer period. The determination of mass movement occurrence with a seasonal definition enabled us to restrict the time span in order to analyse correlation between the events and their triggering causes.

KEY WORDS: Dendrogeomorphology, Wood anatomy, Seasonal dating, Mass movements, Italy.

RIASSUNTO: STEFANINI M.C., *Determinazione stagionale dell'occorrenza di movimenti di massa attraverso l'uso della dendrocronologia e dell'anatomia del legno: esempi tratti da casi di studio italiani*. (IT ISSN 1724-4757, 2004).

La dendrocronologia è stata spesso usata per determinare l'evoluzione spazio-temporale dei movimenti di massa, permettendo la datazione a scansione annuale degli eventi. In questo studio viene presentata la possibilità di definire a scansione stagionale l'occorrenza degli eventi, attraverso l'uso di tecniche dendroanatomiche. Per applicare queste tecniche è necessario determinare il periodo di crescita radiale degli alberi nella zona di campionamento, cosa che è stata fatta realizzando microsezioni da sequenze di anelli di accrescimento opportunamente selezionate. La struttura anatomica degli anelli che mostrano una normale tendenza di accrescimento è stata comparata con la struttura di quelli provenienti da alberi che hanno subito anomalie di crescita. Ciò ha permesso di definire l'occorrenza delle anomalie di crescita all'interno del periodo di accrescimento dell'albero, ovvero il periodo vegetativo. I movimenti di massa analizzati sono localizzati sia nelle Alpi che negli Appennini. Le frane appenniniche sono state caratterizzate da riattivazioni soprattutto durante la stagione di dormienza degli alberi, raramente durante la primavera o l'estate. Al contrario i fenomeni di debris flow analizzati nelle Alpi Marittime Italiane sono avvenuti soprattutto nel periodo a cavallo tra la tarda primavera e l'inizio dell'estate. La determinazione dell'occorrenza dei movimenti di massa è particolarmente utile nella caratterizzazione di quegli eventi che non sono stati riconosciuti o datati in precedenza e la definizione stagionale degli stessi permette di restringere il periodo di tempo nel quale eventualmente analizzare la correlazione tra gli eventi e le loro cause scatenanti.

TERMINI CHIAVE: Dendrogeomorfologia, Anatomia del legno, Datazione stagionale, Movimenti di massa, Italia.

INTRODUCTION

Dating mass movements is an important step in the assessment of their state of activity. Landslide hazard itself is defined as the probability for a landslide to occur within a given area and within a given period (Varnes, 1978). A definition of mass movements temporal occurrence is then required. This can be done by means of dendrochronology, which is the study of tree rings, where the annual growth layers are assigned to specific calendar years (Fritts, 1976). Variation in the rings pattern is due to variation in environmental conditions when they were formed. Studying this variations leads to improve understanding of past environ-

(*) *Dipartimento di Scienze della Terra - Università di Pisa, Via S. Maria 53, 56126 Pisa, Italy - phone: +39 050 2215738, fax: +39 050 2215800, e-mail: stefanini@dst.unipi.it*

Microsections were prepared during the «1st Winter school on Wood Anatomy of tree rings», Davos (CH), 8-15 December 2002, under the supervision of Prof. F.H. Schweingruber, whose help is greatly acknowledged also for the reading of this paper.

The researches were supported by the Italian M.I.U.R. Project «Glacier retreat in the Italian Alps and the climatic changes, since the deglaciation to the present phase» (Local Head P.R. Federici), the Italian CNR-GNDCI publ. n° 2561 (U.O.13-Pisa, head Prof. P.R. Federici), and the CNR Project «Case studies of earthquake, induced in the Tuscan Emilian Apennines between Mt. Libro Aperto and Mt. Antola» (Head M. Pellegrini).

mental conditions, being the basis for many research applications of dendrochronology. Dendrochronological analysis of geomorphological processes, such as mass movements, is based on the interaction between geomorphological events and the reaction of tree growth in a certain area (i.e. Alestalo, 1971; Shroder, 1980; Schweingruber, 1988, 1996; Cook and Kairiukstis, 1990; Heikkinen, 1994; Wiles & *alii*, 1996; Strunk, 1997; Solomina, 2002).

The events can be dated in two ways: 1) dating of the germination of plants on previously cleared areas; 2) the analysis of tree-ring patterns on trees which have been directly involved in the events. When mass movements clear large forested areas, their recovery is characterised by even-aged groups of trees, or an abrupt growth increase in surviving trees. Various characteristics of mass movements, such as the rupture surface depth and landslide size, or the velocity, thickness and size of transported clasts, are reflected in the stress applied on the trees wood and bark. The modifications, due to the applied stress, can vary in intensity and duration and are recorded in the tree anatomical structure, often appearing also as variations in the external shape, such as the leaning of trees and the presence of injuries on the bark.

Intra-seasonal occurrence of events can be determined by microscopic studies: Schweingruber (1988), Fantucci and Mc Cord (1995), Stefanini and Schweingruber (2000), Gärtner & *alii* (2001), Gärtner (2003a; 2003b), Stefanini and Ribolini (2003), Stefanini (2004). Growth stresses are reflected in trees by growth variations and anomalies within their vegetation period. In temperate regions, the vegetation period starts with the formation of early wood and progresses into «late wood» formation; the growing period is followed by a period of dormancy. The duration of these phases varies with the climatic conditions and it is species-specific. By knowing the seasonal dynamics and the anatomical structure, it is possible to date the reaction to geomorphological events.

In this study we present the results of seasonal dating, by means of wood anatomical investigations, on mass movements in the Apennines and the Alps.

STUDY AREAS

Two large landslides located on the western and on the eastern side of the main northern Apenninic watershed, were studied. The first movement involves an entire slope, which includes the village of Patigno (Provincia di Massa-Carrara, Italy-740 m a.s.l. - fig. 1). The movement has a total length of about 2500 meters, a maximal width at the toe of about 1000 meters and mean depth of around 20 meters. This large landslide has been reactivated superficially by several smaller landslides of different types (Federici & *alii*, 2002). Some of these smaller movements, where a good tree cover was present, were dendrochronologically investigated. Moreover, tilted trees were found, clearly indicating ground movements. The reactivations are characterized mostly by composite rotational flow slip

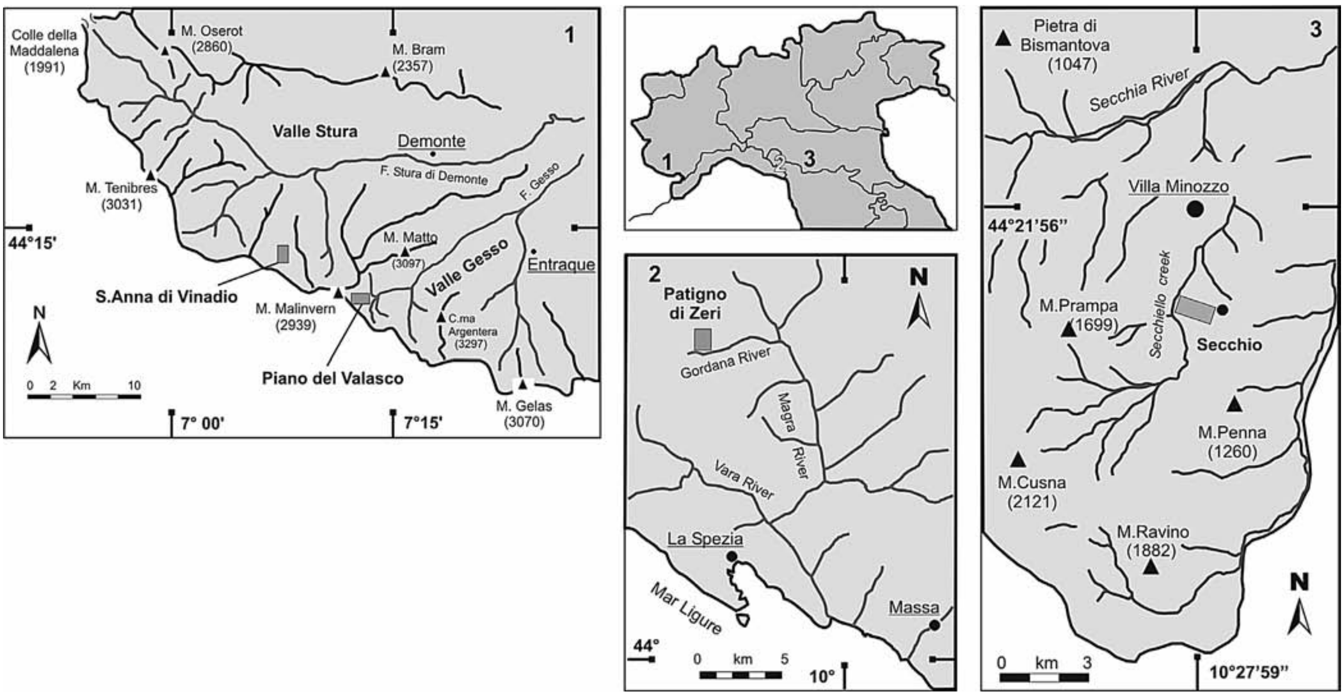

FIG. 1 - Location of the study sites. Left (1): Piano del Valasco and S. Anna di Vinadio in the Maritime Alps; center (2): Patigno di Zeri in the western sides of the Apennines; right (3): Secchio, in the eastern side of the Apennines.

and rotational retrogressive slip, often associated with the down-cutting action of rivers flowing at their bases. Between 700 and 800 m Turkey oaks (*Quercus cerris* L.) dominate the stand. At the upper sites of this level, Turkey oaks are replaced by chestnuts (*Castanea sativa* Mill.). Higher up, beeches (*Fagus sylvatica* L.) largely prevail.

The second landslide studied is located on the south-western side of the village of Secchio (Provincia di Reggio-Emilia, Italy - fig. 1), affecting an area of between 956 m and 625 m a.s.l., with a maximum length of 1250 m, and a width of the landslide body of ca. 300 m. The landslide is complex, with compound slide movement in the upper part, progressing into a flow in the lower part. A mixed mesophilus wood is present on the landslide surface, mainly represented by Turkey oak, hornbeam (*Carpinus betulus* L.) and Hop hornbeam (*Ostrya carpinifolia* Scop.). In the surrounding area, Turkey oaks are dominant.

The other study sites are located in the upper Gesso and Stura river basins, belonging to the sector of the Maritime Alps closer to the Mediterranean Sea. For each river basin one study area was selected respectively at Piano del Valasco (1760-1950 m a.s.l.) and S. Anna di Vinadio (1700-1900 m a.s.l. - fig. 1). Both valleys are characterized by intensive glacial and periglacial morphologies (Federici and Pappalardo, 1995; Federici & *alii*, 2000). The crystalline nature of the rocks forming the Argentera Massif (high grade metamorphites and granitoid rocks) coupled with the periglacial environment and the high relief energy supplies a huge amount of debris to the slope. This is mobilized by debris-flows, which are frequently triggered by the prolonged rainfall occurring in this alpine region. The sediment sources of the six debris-flows vary between glacial and periglacial deposits, rill-wash deposits, and debris on the slope and inside the channels. Soil slip and side erosion often occur during the same debris-flow events.

At both these sites, the vegetation is dominated by European Larch (*Larix decidua* Mill.), which often constitutes the only essence present on the slopes. At higher altitudes, a few stone pine (*Pinus cembra* L.) specimens are also present in the open forests.

MATERIALS AND METHODS

Turkey oaks were selected in the Patigno and in the Secchio area as representing the most widespread and mature species on the investigated surfaces. Turkey oak wood exhibits a typical ring-porous structure: on the «early wood», large vessels are surrounded by few parenchymatic cells. The late wood is characterized by progressively smaller vessels and libriform fibres, with a very thick cell wall (Schweingruber, 1993). Libriform fibres and few small vessels mostly form the late wood.

In the Maritime Alps sites we sampled the European larch (*Larix decidua* Mill.) This conifer presents very distinct tree-rings with an abrupt transition from early to late wood. In the early wood, cells are large and thin-walled (tracheids), while the late wood thick walled tracheids are smaller. Sparse resin canals, bordered by 8-12 secretory cells, are often formed.

Several samples were collected within the cones investigated. Trees were chosen for their location on the surfaces involved, taking into account their possible interactions with the movements. Tilted, S-shaped and injured trees were also sampled.

A geomorphological mapping of the study sites were done both to characterise the processes, to localize trees in relation to the movements and also to choose areas undisturbed by geomorphic processes. Within these areas we need to select dominant, undisturbed trees, whose growth is not affected by mechanical stress. These trees are used to develop a reference chronology, which allows correct dating of the other trees.

We took two cores per tree with an increment borer. After polishing all the cores, ring widths were measured, from the bark to the pith, using the measuring stage Lintab and the software Tsap (Rinn, 1996). The ring width measurements from undisturbed trees were crossdated both by visual inspection and by means of the Tsap application. During the process possible errors due to extremely narrow rings, absent rings and false rings were eliminated. This led to species-specific reference chronologies, which were used to date all the other cores.

Growth anomalies present in the dated cores were recorded by using skeleton plots (Stokes and Smiley, 1968). Each growth anomaly represents a response to an ecological or mechanical stress. The ecological stress involves the entire tree population within an area, while the mechanical stress affects only trees, which are directly involved by the geomorphological process investigated. Then, in order to select the mechanical stress reaction the curves from trees affected by mass movements are compared with the reference chronology. Different features indicate the mechanical stresses. Frequent features are: abrupt growth changes, especially reductions lasting more than three years, reaction wood, eccentricity, traumatic resin ducts, injuries, usually followed by callous tissue, and, finally, death of all the trees. Moreover, it is possible to reconstruct the spatio-temporal evolution of movements by mapping the features.

This dendrogeomorphological analysis was performed for all the mass movements here presented. In addition, wood-anatomical studies were carried out. A mechanical sliding microtome was used to cut thin sections from selected tree-ring sequences. The microsections were treated with *javel water* (NaOCl), to destroy the cell contents, and then the sections were rinsed with normal water. To increase the visibility of the anatomical structures the sections were stained with safranin and conserved with Canada Balsam (Schweingruber, 1978).

Once prepared, microsections can be used, at different optical magnifications, to clearly identify the anatomical characteristics of the selected tree-rings. The microsections allowed the seasonal reconstruction of events. However, it has to be kept in mind that the vegetation and dormancy periods vary in relation to local climatic conditions and species characteristics. Therefore, we must core several times per year in order to recognize the relations between growth and time. These studies allow the identification of the dynamics of the growing period.

RESULTS AND DISCUSSION

The spatio-temporal results of the present studies have already been published by Chelli and Stefanini (1999) Stefanini and Schweingruber (2000) Stefanini and Ribolini (2003) and Stefanini (2004). Here only the results of the micro-anatomical investigations are shown.

The reactivations of the Patigno landslide were recorded from Turkey oaks with abrupt growth reductions. Tree-ring sequences of the most representative events were selected to investigate the intra-annual dating. Results show a similar pattern for all the events, here represented by the event in 1957 (fig. 2). In 1956 the ring shows normal growth conditions, but the 1957 ring shows only well-shaped early wood pores and no late wood. A few rows of latewood cells were formed in 1958. «Late wood» formation gradually improved in the following years. I conclude that the event took place in the dormant season of 1956/57. The dormancy for Turkey oaks in this region lasts from October to March.

Coring in early October at Secchio proved that the growing season ends at this time (fig. 3). The analysis of microsections from the selected tree-ring sequences revealed a more widespread distribution of movements within the trees' growing periods. The most representative period of movement occurrence is the late spring. This is testified by the well-shaped «early wood» pores found at the beginning of the «stressed ring», which progresses with a few small vessels and parenchymatic cells (fig. 4). Only one event

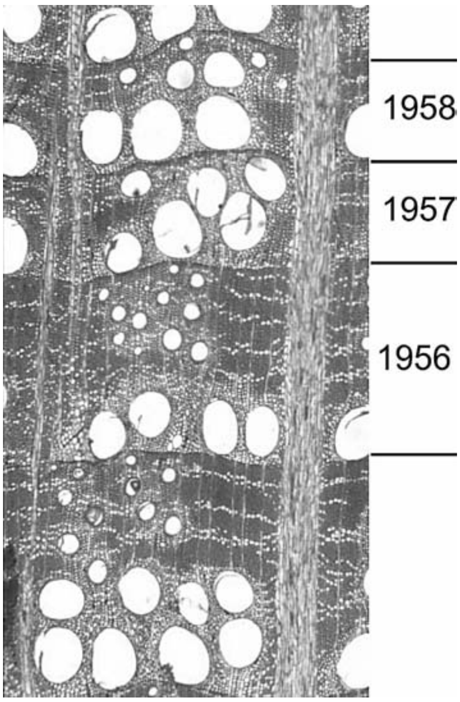

FIG. 2 - The tree ring sequence of the event occurred in 1957. In 1956 a complete ring was formed. The following year the ring formation was early truncated, producing only big pores in the «early wood». Few rows of «late wood» cells started to be newly formed since the 1958 ring.

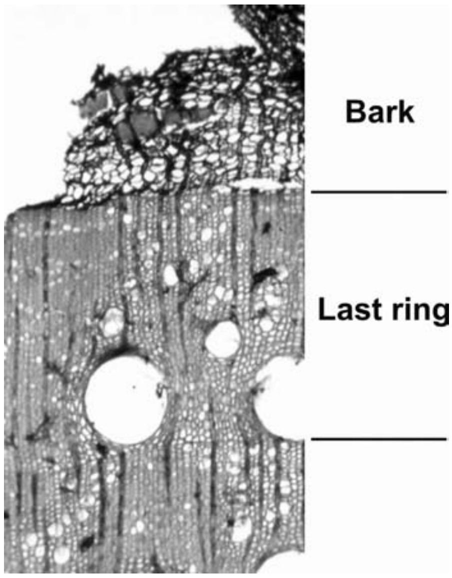

FIG. 3 - Microsections obtained from a tree sampled at Secchio in early October 2002. The last ring before the bark is completely formed and the late wood length is comparable to that of the previous years. Thus, the dendrological year is finished.

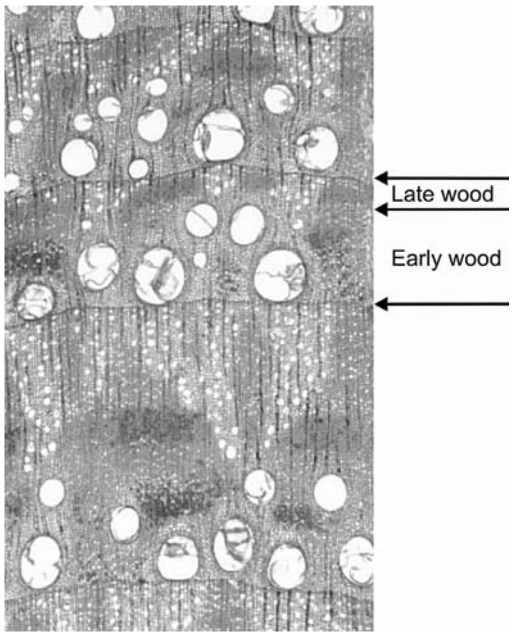

FIG. 4 - Tree ring sequences showing an event occurred in spring. Well-shaped «early wood» pores found at the beginning of the «stressed ring», are followed by few small vessels and parenchymatic cells.

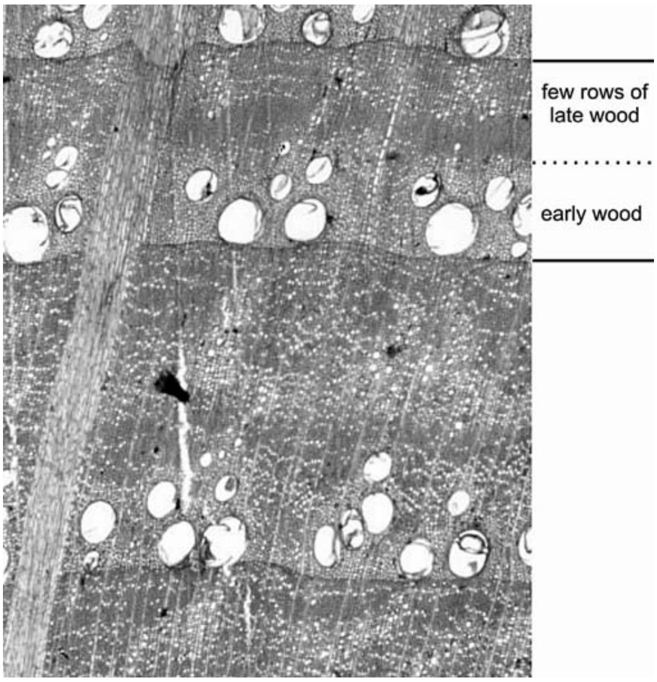

FIG. 5 - An event that took place during summer. The «early wood» is completely formed, while the «late wood» appear to be early truncated, comparing is length with the previous rings ones.

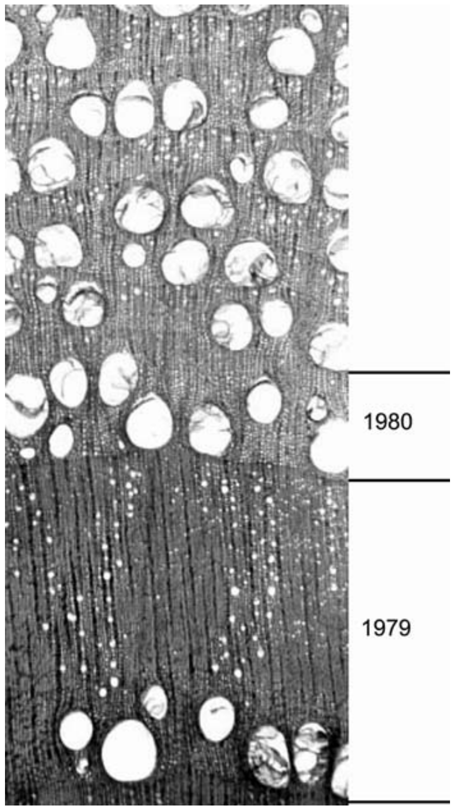

FIG. 6 - Tree ring sequences showing an event occurred during the dormant season. After a complete ring formation (i.e. 1979) only few big vessels were formed in the following stressed ring (i.e. 1980), which is early truncated.

took place during the summer. In this case the tree completely formed the early wood, but only a few rows of late wood cells followed (fig. 5). Other reactivations occurred in the dormant season (October and March). The event took place after the complete ring formation (i.e. 1979); only few big vessels were formed in the following stressed ring (i.e. 1980), which is early truncated (fig. 6).

The analysis of microsections from trees in the Maritime Alps has shown a variety of interesting features. In order to investigate the duration of the vegetation period, one of the samplings was taken at the middle of May, when snow is often still covering the ground. Microsections from samples taken in the middle of May show that the growing season had not yet started in the Maritime Alps (fig. 7). The last tree-ring below the bark is completely formed; the cambium did not form any large early wood tracheids. Samples taken during August show that the trees are in the phase between the early wood and the late wood formation, while samples collected at the beginning of September demonstrate that the growing season had already finished. Therefore, it can be assumed that the vegetative period starts in late June and ends in late August.

Samples taken from trees interacting with debris-flow events show different anatomical stress features. Abrupt growth reductions are the most frequent strong signs. Since the anatomical structure of the small rings is equal to the previous ones I conclude that the event occurred in

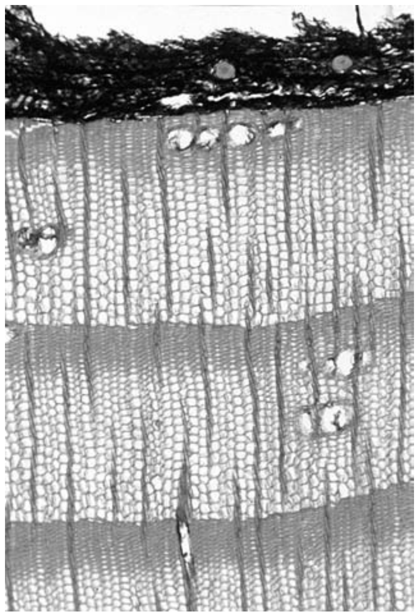

FIG. 7 - Microsections obtained from a tree sampled in middle May in the Maritime Alps. At this time the vegetative season is still not begun: the last ring before the bark is completely formed, the cambium has still not differentiated new woody cells rows.

the dormant season (fig. 8). As for the previous information on the length of the vegetative period, these events took place between September and June.

At the compression side of the trunks conifers form reaction wood (fig. 9). Compression wood consists of almost circular thick walled tracheids. Between them are little intercellular spaces (Timell, 1986). The appearance of this tissue is sometimes delayed for one or two years because of the heavy stress applied to the root system by mass movements. This stress can produce on both sides of the trunk a severe suppression in growth. Sometimes the rings with compression wood occur only on one side of the trunk because the tree has not enough reserves to produce a complete ring. In this case the tree forms a wedging ring (fig. 10).

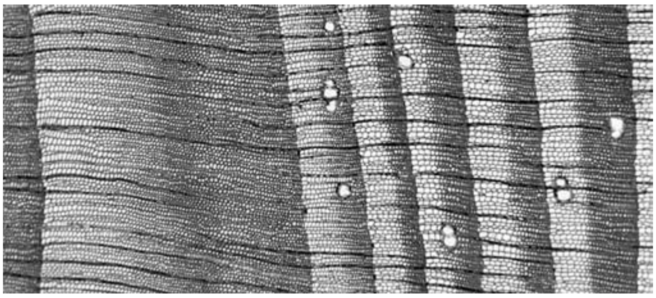

FIG. 8 - «Tree-ring» sequences from a Larch affected by debris flow events. A severe reduction in growth is clearly visible.

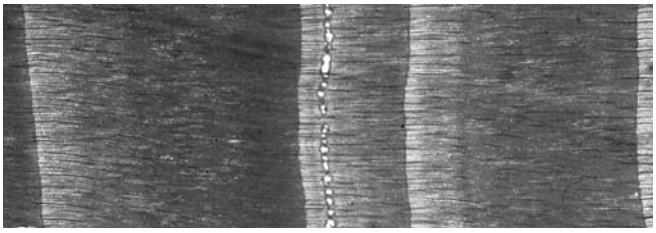

FIG. 9 - Reaction wood (compression wood in this case) is produced by the tree to react at the leaning. The thick cell walls characterizing compression wood make it clearly visible as a darker coloured zone. This «tree-rings» sequence show that the tree was affected by another stress, which is recorded with the production of traumatic resin-duct row.

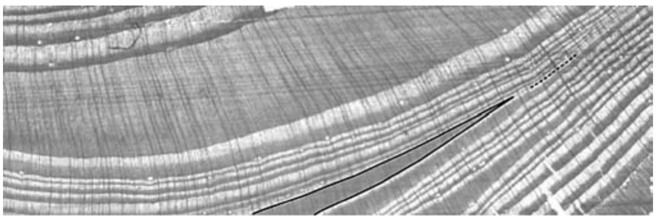

FIG. 10 - An example of wedging ring, which is highlighted by means of the black line drawn on its contour.

Deciduous trees produce tension wood on the uphill side of the trunk. Unfortunately, tension wood is not visible by visual inspections; it shows up only by means of specifically coloured microsections.

Also resin ducts are signs of debris-flows. In figure 9, the traumatic resin-duct row is set within another period of stress, as can be inferred from the presence of compression wood in the previous and successive tree-rings. This means that the tree produced compression wood in reaction to a first event and the traumatic resin duct in reaction to a second event. The position of resin ducts in the middle of the early wood indicates that the event occurred in the middle of the vegetative period, which here means during July.

In undisturbed trees frost rings were found (fig. 11). This phenomenon occurs in conifers that are injured by frosts. Usually, it is caused either by a frost late in the spring or by a freezing period after a previous warm one. Frosts damage the prematurely active cambial zone (Timell, 1986). A frost ring is typically characterized by a few rows of collapsed cells (tracheids) in the early wood.

The determination of mass movement occurrence with seasonal definition restricts the time span, so enabling us to better analyse the correlation between the events and their triggering cause. The triggering of landslides is mostly due to seismic shock or precipitation, that is either high intensity or prolonged rainfall. By comparing the meteorological and seismic time series with the season of movement occurrence the prevailing causes can be investigated.

In the Apennines the movements occurring during the dormancy period proved to be associated with the prolonged rainfall typical of autumn (fig. 12). On the contrary, mass movements reactivated in spring and summer

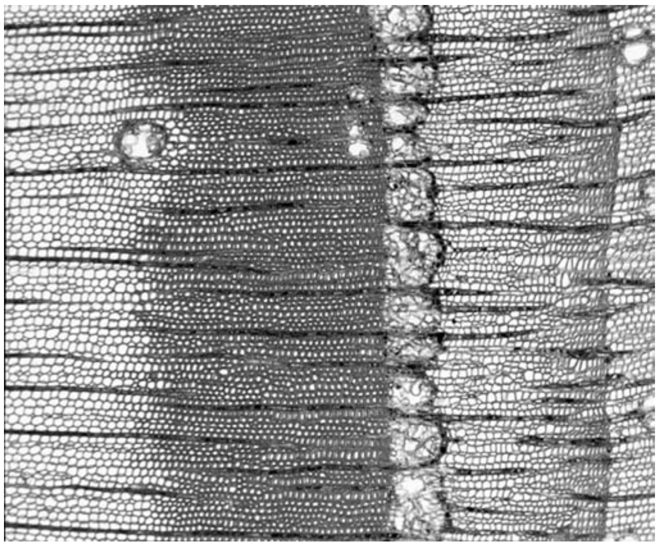

FIG. 11 - Microphotograph showing a frost ring, which compare when the tree is injured by frosts. It is typically characterized by few rows of collapsed cells in the early wood.

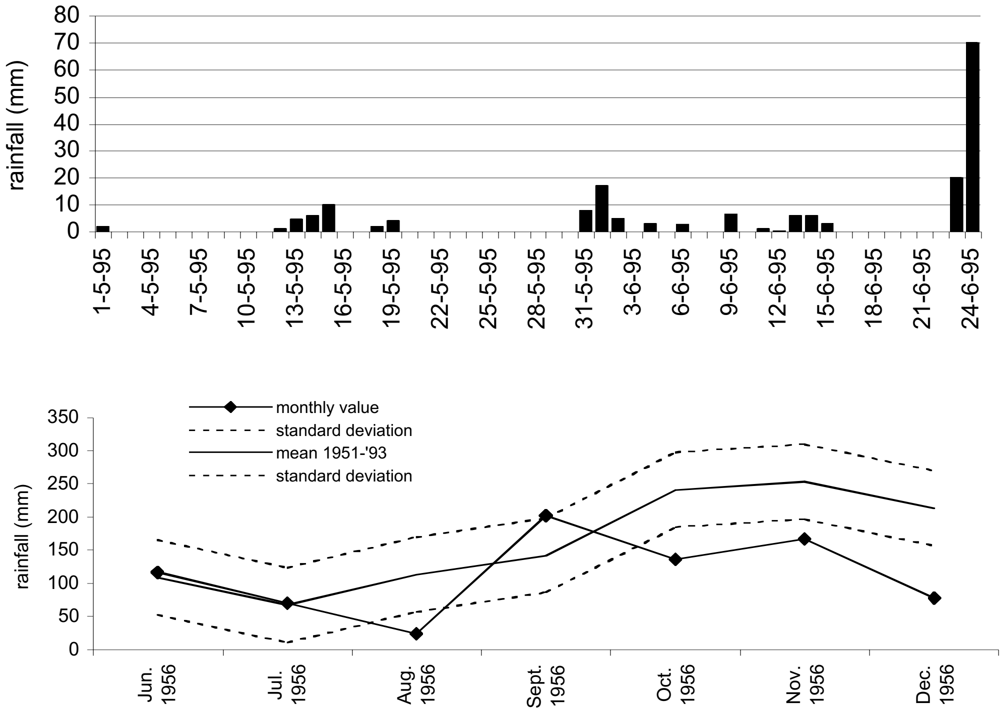

FIG. 12 - Above: a typical precipitations pattern for the Spring-Summer period, where high intensity daily rainfalls follow an almost dry time span. Below: during Autumn long lasting rainfalls exceed the monthly mean values for a thirty year period.

seem to be induced mostly by high intensity rainfall following a dry period.

The results of seasonal dating of debris-flows in the Maritime Alps correlate the occurrence of these events with the late spring-early summer period. Indeed, heavy rainfall occurring in this period, coupled with the effect of snowmelt, makes a huge amount of water available. This is capable of mobilizing the detritic deposits in the formation of the debris flow. This is well supported by the evidence of some events already recorded in these areas and relates these events to their triggering causes. However, in a few cases it is possible that debris flows have been induced by intense precipitation occurring during autumn, that is at the beginning of the dormancy period, their effects on trees being recorded only in the following year.

CONCLUSIONS

With dendrogeomorphological methods it is possible to determine the time, frequency and spatial development of events. Microsections give us the possibility of determining the intra-seasonal occurrence of events, considering the species-specific length of the vegetative period within the investigated area. Furthermore, the growth anomalies found on trees stressed by movements can be precisely placed within the vegetative season. This enables correlation of the occurrence of movements with their possible triggering causes. The dating of mass movement reactivations in the study sites here presented would have been impossible without the dendrochronological approach.

Although the microanatomical analysis of «tree-rings» is still a new application in dendrogeomorphological studies, it will inevitably become a more widely used technique due to the precision of its results.

REFERENCES

ALESTALO J. (1971) - *Dendrochronological interpretation of geomorphic processes*. Fennia, 105, 1-140.

CHELLI A. & STEFANINI M.C. (1999) - *Geomorphological features and temporal distribution of the present-day landslides activity in the high Gordana Basin (Zeri, Northern Apennines)*. Geogr. Fis. Dinam. Quat. 22, 105-114.

COOK E.R. & KAIRIUKSTIS L.A. (1990) - *Methods of dendrochronology - Applications in the environmental sciences*. Kluwer, Dordrecht, 394 pp.

FANTUCCI R. (1999) - *Dendrogeomorphology in landslide analysis*. In: Casale R. & Margottini C. (eds.), «Floods and landslides: Integrated risk assessment». Springer-Verlag, Berlin, 69-81.

FEDERICI P.R. & PAPPALARDO M. (1995) - *L'evoluzione recente dei ghiacciai delle Alpi Marittime*. Geogr. Fis. Dinam. Quat., 18, 257-269.

FEDERICI P.R. & PAPPALARDO M. (2000) - *On the Equilibrium Line Altitude and lower discontinuous permafrost boundary in the Maritime Alps (Italian side)*. Acc. Sci. Torino, Atti Sci. Fis., 134, 3-11.

FEDERICI P.R., PUCCINELLI A., CHELLI A., D'AMATO AVANZI G., RIBOLINI A. & VERANI M. (2002) - *The large landslide of Patigno (northern Apennines, Italy): geological, geomorphological and geognostic integrated analysis*. In: Rybář J., Stemberk J. & Wagner P. (eds.), «Landslides», Swets & Zeitlinger, Lissa, 547-552

FRITTS H.C. (1976) - *Dendroclimatology and Dendroecology*. Quat. Res., 1, 419-449.

GÄRTNER H. (2003A) - *The applicability of roots in dendrogeomorphology*. In: Schleser G., Winiger M., Bräuning A., Gärtner H., Helle G., Jansma E., Neuwirth B. & Treydte K. (eds.), «Trace-Tree rings in archaeology, climatology and ecology». 1, 120-124.

GÄRTNER H. (2003b) - *Holzanatomische Analyse diagnostischer Merkmale einer Freilegungsreaktion in Jahrringen von Koniferenwurzeln zur Rekonstruktion geomorphologischer Prozesse.* Dissertationes Botanicae, Band 378, pp. 118.

GÄRTNER H., SCHWEINGRUBER F.H. & DIKAU, R. (2001) - *Determination of erosion rates by analyzing structural changes in the growth pattern of exposed roots*. Dendrochronologia, 19, 1-11.

HEIKKINEN O. (1994) - *Using dendrochronology for the dating of land surfaces*. In: Beck C. (ed.), «Dating in exposed and surface context». University of New Mexico Press, Albuquerque, pp. 213-235.

RINN F. (1996) - *Time series analysis and presentation. Reference manual.* Rinn, Heidelberg.

SCHWEINGRUBER F.H. (1978) - *Mikroskopische holzanatomie*. Eidgenossische anstalt forstliche versuchswes, Birmensdorf, 226 pp.

SCHWEINGRUBER F.H. (1988) - *Tree rings: basics and applications of dendrochronology*. Reidel, Dordrecht,, 276 pp.

SCHWEINGRUBER F.H. (1993) - *Trees and wood in dendrochronology*. Springer-Verlag, Berlin, 402 pp.

SCHWEINGRUBER F.H. (1996) - *Tree rings and environment. dendroecology*. Swiss Federal Institute for Forest, Snow and Landscape research, Birmensdorf, & Haupt, Berne, Stuttgart, Vienna, 609 pp.

SHRODER J.F. JR. (1980) - *Dendrogeomorphology: review and new techniques of tree ring dating*. Progr. Phys. Geogr., (4) 2, 161-188.

SOLOMINA O.N. (2002) - *Dendrogeomorphology: research requirements*. Dendrochronologia, 20 (1-2), 233-245.

STEFANINI M.C. & SCHWEINGRUBER F.H (2000) - *Annual and seasonal reconstruction of soil movements with Turkey oak in the Northern Apennine (Toscana, Italy).* Dendrochronologia, 18, 53-62.

STEFANINI M.C. & RIBOLINI A. (2003) - *Dendrogeomorphological investigations of debris-flow activity in the Maritime Alps (Northwestern Italy).* In: Richenmann D. & Chen Cl. (eds.), «Debris-flow hazards mitigation: mechanics, prediction and assessment», Millpress, Rotterdam, 231-242.

STEFANINI M.C. (2004) - *Spatio-temporal analysis of a complex landslide in the Northern Apennines (Italy) by means of dendrochronology*. Geomorphology, 63, 191-202.

STOKES M.A. & SMILEY T.L. (1968) - *An introduction to tree-ring dating*. University of Chicago Press, Chicago, 73 pp.

STRUNK H. (1997) - *Dating of geomorphological processes using dendrogeomorphological methods.* Catena, 31, 137-151.

TIMELL T.E. (1986) - *Compression wood in gymnosperms*. Springer, Berlin, 2150 pp.

VARNES D.J. (1978) - *Slope movements. Types and processes*. In: «Schuster R.L. & Krizker R.J. (eds.), «Landslides: analysis and control». Natural Academy of Sciences, Research Board, Washington, Special report, 176, 11-35.

WILES G.C., CALKIN P.E. & JACOBY G.C. (1996) - *Tree-ring analysis and Quaternary geology: principles and recent applications.* Geomorphology, 16, 259-272.

WIMMER R. (2002) - *Wood anatomical features in tree-rings as indicators of environmental change.* Dendrochronologia, 20 (1-2), 21-36.

(Ms. received 1 July 2004; accepted 30 October 20074)