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Tree rings and Geomorphological Processes in a Mountainous Region (French Alps)

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Introduction

Mass movements on slopes are regularly observed in mountainous regions. Assessment of mass movement hazard risks requires, besides the spatial mapping of endangered zones, insight in the temporal character of related processes. In many regions information about these temporal aspects is not available. However, information about frequency, magnitude and duration of mass movement processes is needed to reliably forecast possible future changes.

Our research concentrated on tree ring- and tree stem characteristics in relation to the periodicity of recent and formerly active landforms: landslides, hill slope debris flows and a sub-recent active rockglacier.

Survey Area

The survey area lies in the Southern French Alps, about 100 km northwest of Nice (Fig.1.). Fieldwork was done by students of the Department of Physical Geography in the central and eastern parts of the Ubaye valley and surroundings. Altitudes vary from 1100 m to peaks exceeding 3000 m. The tree line is found between 2000 m to 2400 m and is strongly affected by man in many locations. In many cases the tree line is situated about 200 m below the natural tree line. Lithology varies from very unstable thick series of black marls to hard sandstones, limestones, dolomites and quartzite’s. Climate has a mountainous character with Mediterranean influence. Precipitation peaks are found in spring and autumn, but also heavy rainy summer storms can occur. The trees are relative young, mostly 100-150 years old. On isolated places trees of more than 700 yrs can be found. At the highest elevation of the tree line, Swiss stone pine and European Larch grow. Towards lower levels Mountain pine and Scotch pine are found. Most study areas are positioned near the tree line at about 2000 m.

In the Rioux de Bourdoux drainage basin, northwest of Barcelonnette (Fig. 1), a complex of active landslides in highly erodable marls overlain by moraine deposits was investigated on periodic movement patterns. The drainage basin was strongly deforested by man at the end of the 19th century, but reforested up to 2200 m in the 20th century. Common species are Scotch pine in the lower parts and European Larch and Mountain pine on the higher parts. At three landslide locations (A, B and C, Fig 3), between 1200 and 2000 m, tree ring eccentricity was measured. For comparison location D was chosen on a relative stable slope without moving parts (Braam et al. 1987a; Weiss, 1988).

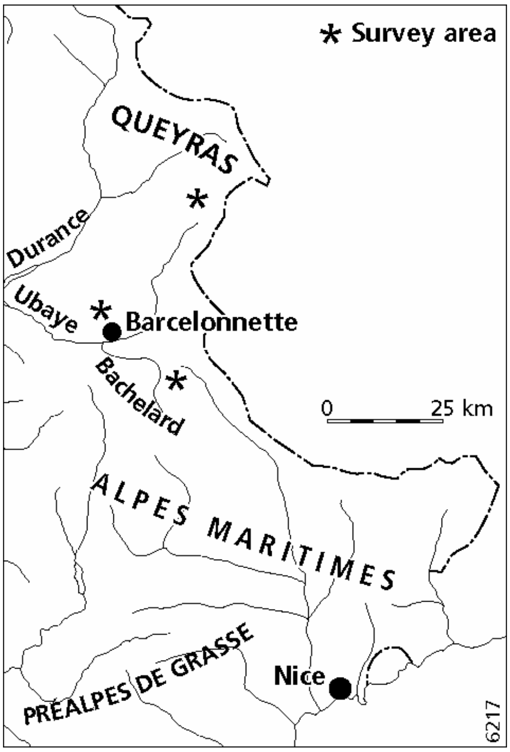

Figure 1: Location of study areas

Hill slope debris flows coming from above the tree line were studied on their frequency patterns in the drainage basin of the river Bachelard (Fig. 1). Larch trees growing in the deposition zone are in many cases affected by strong mechanical forces. The result can be tilting, bark damage, burial and nudation. Undisturbed trees can give a minimum date for the age of flow deposits.

Detailed investigations on the dynamics of debris flows took place south of the small village Bayasse (Blijenberg 1996; Overbeek & Wiersma 1996). Five deposition zones with 117 debris flows were selected for geomorphological investigations and dating.

In the Tronchet valley of the Parc Naturel Regional du Queyras (Fig. 1) a nowadays-inactive rockglacier was studied (Meijer & Wils 2001). Recent living trees were used to date the moment the rockglacier became inactive.

The rockglacier is situated at about 2450 m with its lowest point at 2400 m. Active parts of rockglaciers in the vicinity are reported at 2600 m (Assier 1996). Glacier relics in the direct environment are found at 2500 m (Pics de la Font Sancte).

Dendrogeomorphological Concepts

Dendrogeomorphology studies the relation between active or inactive landforms, tree form and tree ring patterns, generally on a local scale.

Besides the general concepts of dendrochronology (Fritts 1976), the concept of process-event-response systems in relation to tree growth and geomorphological environment was formulated (Alestalo 1971; Shroder 1986).

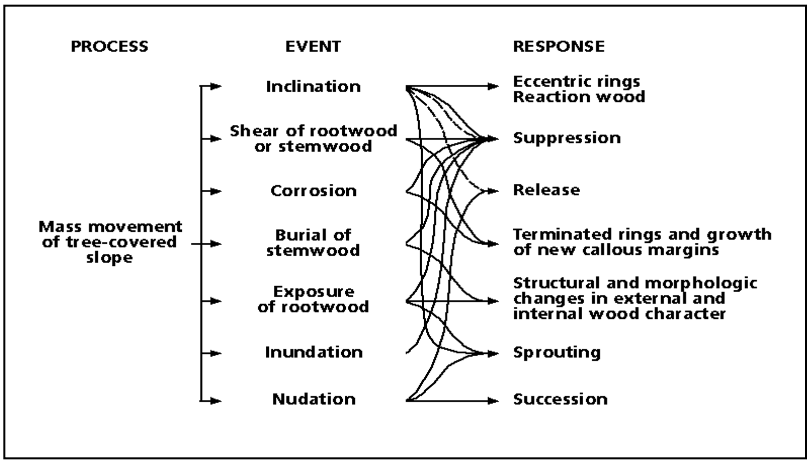

Figure 2: Process-event-response model between geomorphic processes and tree growth (after Shroder 1986)

Geomorphological processes can produce several basic events and processes on trees as shown in Figure 2.

On dynamic hill slopes, inclination, corrasion and nudation were factors that mostly act on trees. Tilting is a most frequent and obvious phenomenon in mass movement areas. Stem form and ring eccentricity combined with compression wood can help to decipher the temporal pattern of mass movements.

Methods

This study concentrates mainly on trees with stem deformation and eccentricity ring patterns to detect periodic characteristics of gravitational surface processes. Braam et al. 1987a,b describes several tree stem forms in relation to mass movements. These forms are a first indication of movement and movement history.

A more precise dating of tilting can be inferred from the patterns of eccentricity pattern and reaction wood. In conifers reaction wood is formed as compression wood on the lower side of the tilted tree. A relation between tree characteristics and landform must be clear when used as an indication for mass movements. Many other factors such as wind stress and avalanches can also result in eccentricity.

Eccentricity is best described and calculated by comparing several radii in cross sections. In most cases this is not possible or desirable. Eccentricity is then calculated from several increment cores: one in the tilting direction (*rA*) and one perpendicular to it (*rB*). More extreme degrees of eccentricity occur in opposing radii but then the problem of many missing rings can arise.

Eccentricity for year *i* is computed according to: $E_i = \frac{rA_i - rB_i}{rA_i + rB_i} * 100\%$

The beginning of a mass movement is indicated by a jump in the eccentricity level and is calculated by a simple filter technique of the running means in a split-moving window. Significant jumps are determined with a t-test at a 0.01 confidence level.

After synchronizing the trees-ring series, significant responses are expressed by an index. A high index means that many investigated trees have a response in the same year. Finally a response curve can be constructed. Periods with index peaks point to possible active mass movements. Periodicity of movement was estimated by constructing power spectra of the index series (Braam et al. 1987a).

In case of debris flow studies, eccentricity of tree rings can be used as indicator for dynamic flows after 5-10 years. Colonization time of minimum age trees appears to be only a few years. Not all debris flows have trees with movement indication or probably, some trees are not affected. In those cases, if possible, lichens are used to date the flows. Where lichens and trees exist together on debris flows, the age of the lichens can be related to characteristics of trees concerning age, ring eccentricity, growth suppression and date of bark damage. Lichens also date flows without trees, especially the higher positioned parts of debris flows above the tree line.

Results

Frequency of Landslides in the Rioux Bourdoux Drainage basin

A period of about 100 years, given by the age of the trees, could be studied. The index time series of eccentricity for two larger slides (A and B) is based on about 20 synchronized trees, that for a smaller one (C) is based on 6 trees (Fig. 3).

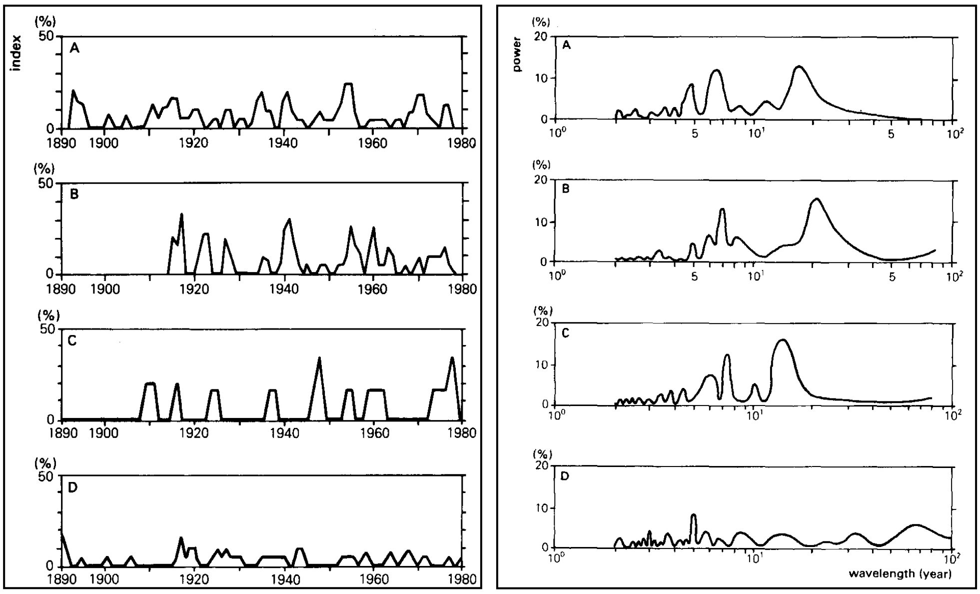

Figure 3: Index time series and power spectra at 4 locations in the Rioux Bourdoux Basin

The eccentricity series on the active landslides A, B and C show clear response peaks with rather regular periods. In contrast, trees on the stable slope show no relevant index peaks. Typical wavelengths in the power spectra are different for each landslide. It seems that periodic components are related to specific internal variables such as type of bedrock, slope, hydrology and erosion at the foot of the slope. Direct relationship between landslide activity and precipitation could not be proven, however rainfall can be a trigger factor. From the analyses, no relation was found between the maturing forest and an in- or decrease in intensity or frequency of mass movement.

Frequency of hill slope debris flows in the Bachelard drainage basin

Of 117 mapped flow deposits, south of Bayasse, 21 could be dated by tree age, suppression of ring width, ring eccentricity, or date of stem damage (Blijenberg 1998).

The maximum age of the larch trees on the investigated flows is 50 to 70 years. Individual trees on flows show mostly 1 to 2 significant responses.

As trees growing on debris flows above the tree line are sparse and absent, lichens were also used for dating. From observations it seemed that the colonization time (ecesis) of trees and lichens on debris flows is different. For (larch) trees a period of 5-10 years and for lichens 15-20 years was found (fig.4).

The temporal pattern of debris flows from the five trigger zones is demonstrated in Figure 4. In the graphs some degree of relationship in activity periods can be seen. The number of useable trees for dating is relatively low. Many debris flows are treeless or are not colonized by lichens. This means that the number of debris flows in an active period can be larger. Nevertheless clear periods of strong debris flow activity can be distinguished in the late forties to early fifties and in the late sixties to mid seventies (Fig. 4). Deposits before 1940 are most likely to be buried by more recent ones. More recent debris flows after the mid seventies could only be dated if they had influenced tree growth. Lichens could not be used as they are yet in their colonization period.

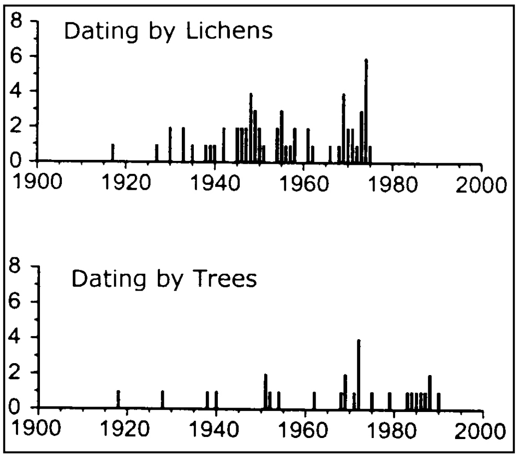

Figure 4: Temporal distribution of debris flows at 5 locations south-east of Bayasse in the Bachelard Valley (after Blijenberg 1998)

The event frequency per year for the five trigger zones indicates a relation between frequency and size of trigger area. However, no clear and significant relation was found with monthly precipitation data. Field observations showed the beginning of debris flows in this area within 5-10 minutes after the start of very high intensive rainfall of 50-100 mm/hr. Flow velocities of 3 – 10 m/s were measured.

Periodicity analysis of response curves of the above mentioned area and other areas in the Bachelard valley indicate several peaks in wavelength of years (Fig.5). Three areas showed a remarkable peak around 11 years (De Redelijkheid 1988).

However the data is too scarce to be of statistical significance for a climatological interpretation. No relation with data of the nearest climate station was found.

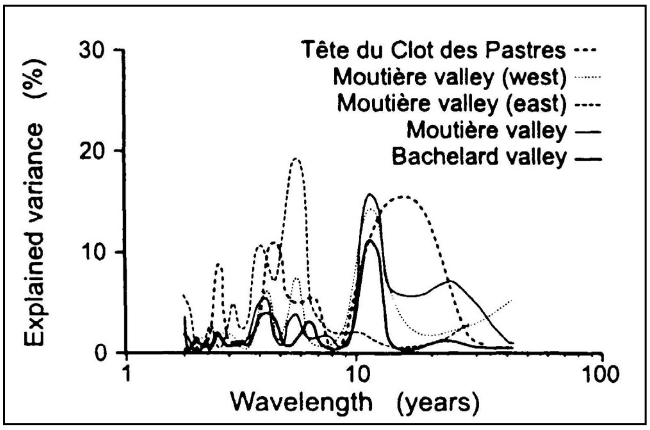

Figure 5: Periodicity of debris-flows in the Bachelard valley (after De Redelijkheid 1988)

Stabilizing phase of a rockglacier

Surface forms of the studied rockglacier show fresh sharp ridges and clear boundaries, sparsely vegetated by grasses, shrubs and a few larches. These observations of fresh forms seem to indicate that the rockglacier became inactive recently. This interpretation implies that the moment of inactivation can be dated using the oldest tree on it, corrected for missing rings, colonization delay and response time of the rockglacier.

The oldest tree counted 81 rings. Nine missing rings were identified by crossdating and by extrapolation of the ring width series to the tree's pith at ground level. Colonization delay was estimated 20-30 years (based on McCarthy & Luckman, 1993; Winchester & Harrison, 2000). Response time was also estimated 20-30 years (Barsch, 1996). Hence, inactivation of the rockglacier was dated between 1850/1870.

Inactivation of rockglaciers occurs when the mean annual air temperature (MAAT) exceeds -2° C (Barsch 1996). The MAAT is known from the neighbouring village Ceillac at 1665 m. The MAAT for the rockglacier can be calculated with the specific temperature gradient for the Alps. The difference between the inactivation temperature of -2° C and the recent MAAT yields a temperature change of +3° C since about 1850, the end of the Little Ice Age.

This reconstructed temperature increase of 3° C seems extremely high in comparison with the same kind of data (Grove, 1988). Possibly the rockglacier was only cleared of vegetation in the Little Ice Age and afterwards it was revegetated.

However, compared with the MAAT change in Ceillac over the last 40 years (1.5 to 2° C) the calculated value could be realistic over the time span in question (125 years).

Conclusions

Analysis of tree rings of trees on active landforms may enhance the understanding the dynamics of mass movement. Understanding development of landforms using tree ring eccentricity can only be successful with a good analysis of the terrain characteristics and verification with data not based on tree rings.

Weather condition is one of many trigger factors in mass movement development. However, monthly and yearly data from local climate stations are not sufficient to explain the short-term dynamics of landforms in the studied area.

Long-term climatic developments can be sustained by tree-ring dating of rockglaciers.

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