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Application of shrubs for dendrogeomorphological analysis to reconstruct spatial and temporal landslide movement patterns. A preliminary study

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with 2 photos, 7 figures and 2 tables

Summary. A detailed dendrogeomorphological landslide investigation has been carried out at the Tertiary escarpment in northwest Rheinhessen, Germany. The basic idea is that a spatial and temporal landslide movement is reflected in annual growth rings of the vegetation on a landslide body. This study uses growth variations of shrubs as indicators of movement. For the first time, analysis of shrub growth curves using optical and statistical techniques has demonstrated the potential of this type of vegetation for dendrogeomorphological analysis. Indications of known dates of landslide occurrence (1981/82) have been found in growth rings and showed the potential of shrubs for this type of analysis. In addition to the known event, further temporal and spatial activity of the investigated landslides has been identified. Despite these promising results, further detailed analysis of growth patterns in shrubs (*Crataegus oxyacantha*) and their application as indicators for landslide movement has to be undertaken.

Zusammenfassung. *Pilotstudie zur Anwendung von Sträuchern für dendrogeomorphologische Untersuchungen zur Erfassung räumlicher und zeitlicher Hangrutschungsbewegungen.* Am nordwestlichen Rand der Rheinhessischen Schichtstufe wurde eine detaillierte dendrogeomorphologische Untersuchung durchgeführt. Grundgedanke dieser Untersuchung war, daß sich die räumlich verteilte Hangbewegung der rutschgefährdeten Gebiete in den Jahrringen der dort vorkommenden Sträucher widerspiegelt. Erstmalig wurde diese Methode an Sträuchern getestet. Methodisch wurde mit Jahrringbreitenkurven gearbeitet, die optisch und durch eine statistische Analyse ausgewertet wurden. Auf dem untersuchten Hangrutschungskörper konnten die aus den Jahren 1981/82 stammenden bekannten Bewegungen in dem Wachstumsverhalten der Sträucher rekonstruiert werden. Neben dem bekannten Ereignis konnte eine weitere räumliche und zeitliche Aktivität der Hangrutschung nachgewiesen werden. Trotz der vielversprechenden Ergebnisse müssen noch weitere methodische Untersuchungen des Wachstumsverhaltens der Sträucher (Weißdorn) und der Anwendungsmöglichkeit dieses Vegetationstypes für den Nachweis von Hangrutschungsbewegungen durchgeführt werden.

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1 *Introduction*

This paper presents results of a pilot study contributing to research on temporal and spatial activity of landslides within the project "Landslides in Rheinhessen and their Significance for Landslide Hazard Modelling and Slope Evolution", which is part of the "Landslides in South and West Germany" project funded by the German Research Foundation (DFG). Different geomorphological techniques have been applied to investigate the temporal and spatial movement pattern of three different landslides. Besides aerial photography, ground surveys, geomorphological mapping, and geophysical techniques such as seismic and geoelectric methods, dendrogeomorphology has been used within this study to obtain further details of landslide history.

Dendrochronology is defined as an ecological science (dendroecology), analysing the relation of environmental factors to each annual ring (SCHWEINGRUBER 1996). Dendrogeomorphology is concerned with the relation between geomorphic influences and annual growth of a specific type of vegetation. The term dendrogeomorphology was first used by ALESTALO (1971) and is recognised as a tool for analysing geomorphic processes. General aspects have been summarised by SHRODER (1980), HEIKKINEN (1994), SCHWEINGRUBER (1996), and STRUNK (1997).

Effects of mass movements on trees are described by SHRODER (1978), who introduced the term "Process-Event-Response-Chain" for the different responses in trees, and by HUPP (1983), VAN ASCH & VAN STEIJN (1991), and DENNELER & SCHWEINGRUBER (1993). Furthermore, there are numerous publications on specific types of geomorphological processes e.g. debris flows (HUPP 1984, HUPP et al. 1987, STRUNK 1992, 1995, 1997,) and, pertinent to this paper, landslides (BEGIN & FILION 1988, FILION et al. 1991, JACOBY et al. 1992, FANTUCCI & MCCORD 1995, SCHMID & SCHWEINGRUBER 1995, LATELTIN et al. 1997, FANTUCCI 1999). The analysis of landslides through eccentricity of annual rings is described by BRAAM et al. (1987a, b) and WEISS (1991).

Landslides represent a change of local conditions in so far as a tilting of the trunk may occur and roots may be damaged or even torn off (BRAAM et al. 1987a, b, FANTUCCI & MCCORD 1995). This causes stress to the tree, which has to be compensated. Annual tree rings show evidence of tilting through reaction wood (here: tension wood) with resulting eccentricity (BRAAM et al. 1987a). Severe damage to the root system is recognised as an abrupt negative change in growth, known as suppressions. These responses, compared with common growth characteristics of a plant species, are indicators of the occurrence of landslides. By determining the first appearance of a modification in annual growth, it is possible to date the year of a landslide movement (BRAAM et al. 1987a).

Within dendrogeomorphology the use of shrubs as indicators of landslide movement has been discussed by dendrochronologists, though such application is not yet common. Dendrochronology of shrubs has been used to analyse the growth conditions of *Empetrum Rubrum* by ROIG (1988) from climatological and ecological perspectives. Further references to shrub dendrochronology published to date are rather concerned with anatomical (SCHWEINGRUBER 1990) or general growth characteristics (BROWN 1971). The effect of mechanical stress on shrubs is mentioned by TIMELL (1986) and WESTING (1965), but is not linked to geomorphic processes.

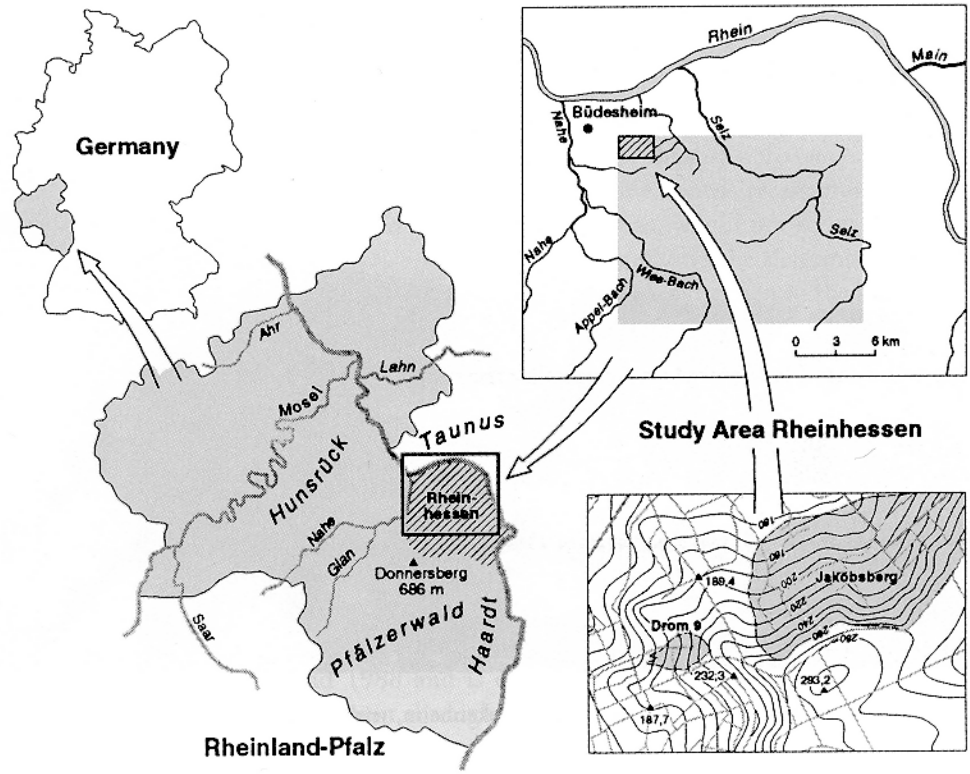

Fig. 1. Location of study area and landslides Jakobsberg and DROM9.

The prospect of interpreting annual growth in annual rings of shrubs with a single leader, analogous to the technique used on trees, represents a promising method for analysing geomorphic processes, even on successive shrubby stadium surfaces. The reconstruction of movement pattern with pioneer plants, in this case shrubs (*Crataegus oxyacantha L.*), is the main intention of this preliminary study.

2 *Research area*

Two landslides, Jakobsberg (2 km south of Ockenheim) and DROM9 (3 km west of Dromersheim), have been investigated within the present study. They are both located on a Tertiary escarpment in northwest Rheinhessen, belonging to the Rheinhessisches Tafelland in the Mainzer Becken (Fig. 1).

The geological substrata of the sites are comprised of Oligocene clays, sand and marl, overlain by Miocene marl and limestone, and covered with Pliocene sediments (gravel, sand, loess) (ROTHAUSEN & SONNE 1984).

Both landslides have been described in the literature (LAUBER 1941, KRAUTER & STEINGÖTTER 1983, PREUSS 1983). A review of literature published on landslides in Rhein-

Photo 1. Slope of the research area Jakobsberg/Ockenheim, with local shrub vegetation.

hessen in general and with specific reference to the Jakobsberg and DROM9 landslides is given by GLADE et al. in this volume. Landslide activity for the winter 1981/1982 has been documented by KRAUTER & STEINGÖTTER (1983). It is possible to identify the effects of these and other mass movements in the growth rings of the local vegetation (Photo 1). The predominant types of shrubs in the research area include *Juniperus* and *Crataegus. Crataegus oxyacantha L.* has been used for further analysis.

3 *Methods*

Cores of *Crataegus oxyacantha L.* were sampled, with a preference for shrubs with a single leader. If possible, cross sections of the trunk were taken to allow a more detailed interpretation through the extended view of tree rings.

Shrubs on stable sites were sampled next to the landslide body of DROM9, forming the ring-width curve of ordinary growth conditions. Dates from these cores represent the reference for both test areas, under the premise that growth conditions at neighbouring locations (distance <500 m) did not differ significantly. Samples of 26 shrubs with two opposite cores were taken perpendicular to the inclination of the slope. Eight shrubs showed significant similarity in growth, which was tested through crossdating (Gleichläufigkeit >70 %, Significance Level min. 95%, min. Overlap 10 years). Following the experience of several other authors

(FANTUCCI & MCCORD 1995, WEISS 1991: 4) these samples, although a small proportion of the actual range of samples, formed the basis for interpreting the growth signals in disturbed shrubs. Implications of sample size are discussed in a later section.

Disturbed shrubs were sampled on both landslide bodies. Two opposite cores aligned with shrub or slope inclination were taken. 56 samples (28 shrubs) were taken in each case. The cores were analysed for evidence of suppressions and/or eccentricity, assuming that a geomorphically undisturbed shrub, given equal local conditions, would not show these effects. Comparison between disturbed and undisturbed samples allows the determination of the time and duration of the landslide effects on the shrub, and consequently the dating of the process itself. The identification of suppression and eccentricity was attained by optical and mathematical–statistical analysis of the growth curves.

4 *Results*

Optical analysis

Typical curves from optical analysis are illustrated in Fig. 2. Solid and plain dotted lines represent the annual growth (mm^{-1}/year) of both shrub radii, and the solid line reproduces the mean growth of all undisturbed shrubs.

Fig. 2a shows an example of eccentric growth caused by landslide activity. Eccentricity is perceptible in 1982, 1985 and 1988 and is characterised by anomalous curve begaviour. Identification of landslide movement through growth suppression is shown in Fig. 2b. It is manifested in a sudden decrease of growth and is visible in 1982 and 1985. In both figures the reference curve corresponds in growth of stable years and differs widely in years of movement to the ring-width curves of the examined shrubs.

Statistical analysis

The eccentricity of shrubs induced by landslide movement was essential for the following method. Here eccentricity was analysed using a slight modification of a statistical method described by BRAAM et al. (1987a). The annual ring widths and the relative eccentricity level of the opposing radii were tested with a "Split Moving Window" (SMW) filtering technique using a 5 years sampling interval, and combined with a two-tailed Student's t-test (FG $n-1$, α 0,01) of differences between window (=sample) means, where the levels of eccentricity of disturbed and undisturbed shrubs were compared. Through comparison with the reference values, also tested by SMW, the natural eccentricity becomes obvious. Where significant deviation of the change of eccentricity level occurs, the signal is interpreted as a reaction to landslide movement and consequently the time and duration of the landslide can be determined (Figs. 3–5). In contrast to this approach, BRAAM et al. (1987a) examined the relative eccentricity level by moving the SMW in the eccentricity radii, where the critical value at a chosen significance level was registered.

Fig. 3 shows an ordinary growth curve of a shrub located on the Jakobsberg landslide. Although a different growth level for the two radii is evident, eccentricity is not apparent, especially considering that a natural eccentricity was found in undisturbed shrubs.

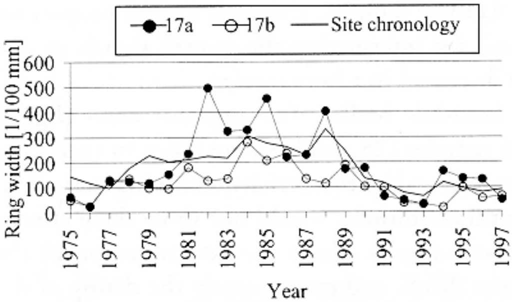

Fig. 2a. Reaction wood in the growth curves of shrub No. 17, located on DROM9 landslide compared to the site chronology.

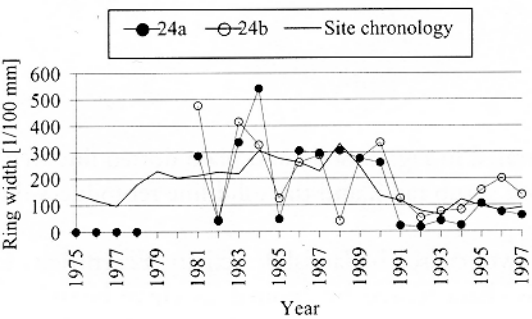

Fig. 2b. Suppression in the growth curves of shrub No. 24, located on DROM9 landslide compared to the site chronology.

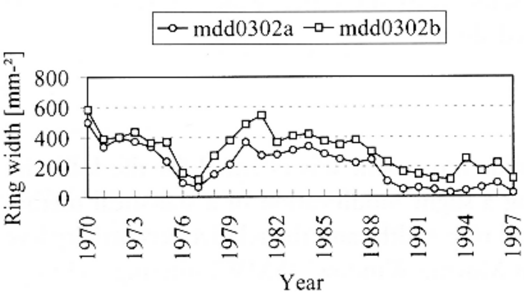

Fig. 3. Growth curves of both radii (a and b) of shrub No. 2 (mdd0302) on Jakobsberg landslide.

After calculating eccentricity and using the SMW technique on disturbed and undisturbed shrubs (Fig. 4), a difference of eccentricity is more obvious, although not yet destinctive. Undisturbed shrubs (plain dotted line) exhibit a certain eccentricity, but no sudden changes in eccentricity level, as is the case for the disturbed shrub (solid dotted line), and which is taken as an indicator for inclination occurrence (BRAAM et al. 1987a: 577) through mass movement.

To validate the difference in eccentricity between disturbed and reference shrubs, each position of window mean is tested at the above mentioned significance level. An exemplar result of this procedure is illustrated in Fig. 5. Where a calculated t-value is equal to or

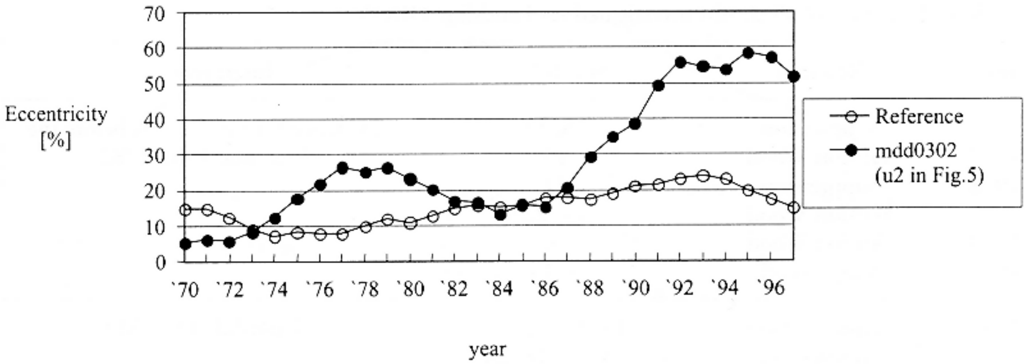

Fig. 4. Eccentricity level of shrub No. 2 on Jakobsberg landslide compared to the site chronology through a 5-year filter. (For location see Fig. 5, u2)

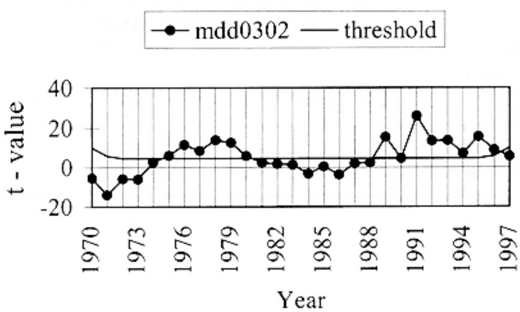

Fig. 5. Calculated and critical t-values (threshold) of shrub No. 2 on Jakobsberg landslide.

exceeds the critical t-value (threshold value), a significant change of eccentricity level is inferred, indicating tilting of the shrub and thus mass movement activity (BRAAM et al. 1987a).

Recognition of the DROM9 landslide in 1981/1982

Movement of the DROM9 landslide in 1981/82 was first documented based on field surveys and aerial photograph mapping by KRAUTER & STEINGÖTTER (1983). This event is also evident in eight of 28 examined shrubs, analysed with dendrogeomorphological techniques. In each case, four shrubs show reaction wood and abrupt growth reduction in the vegetation period following 1982. The result confirms the hypothesis that shrubs react similarly to trees in response to geomorphic activity. Ten shrubs were too juvenile for the analysis because they established after the event of 1981/1982. Another ten shrubs were removed from the analysis because the cores could not be synchronised due to false and missing rings as well as core damage.

Table 1. Reactions of all shrubs investigated on Landslide DROM9.

Year	Reaction	Shrub No.	Interpretation
1976	Suppression	15, 17	Evidence for movements before the landslide 1981/1982
1977	Tension Wood	15	
1978	Suppression	21	
	Tension Wood	14, 22	
1979	Tension Wood	14	
1981	Suppression	4, 14	
1982	Tension Wood	14, 17, 22, 27	Landslide DROM9
	Suppression	13, 15, 18, 24	
1983	Tension Wood	4, 10, 28, 29	Evidence for younger movement
	Suppression	2, 3, 8, 11, 13, 20, 27	
1984	Tension Wood	3, 6, 11, 16, 18	
1985	Tension Wood	1, 13	Youngest activity concentrated in the period 1986–1988
	Suppression	24	
1986	Tension Wood	1, 22, 23	
	Suppression	10, 15, 27, 28	
1987	Tension Wood	2, 3, 14, 25	
	Suppression	9, 13	
1988	Tension Wood	5, 11, 13, 16, 17, 29	

Additional temporal movement pattern

Through dendrogeomorphological analysis, further slope instability of DROM9 has been determined subsequent to the 1981/82 event. This was evident in five shrubs exhibiting growth suppression in 1984. Some growth curves of the shrubs show reaction wood in 1986 (3 shrubs), 1987 (4 shrubs) and 1988 (4 shrubs). Another period of landslide movement is indicated through suppressions in 1986 (4 shrubs) and 1987 (2 shrubs). Five shrubs showed reactions to movements on the DROM9 site from 1976–1981 (Table 1).

Spatial and temporal movement pattern on the Jakobsberg landslide

Spatial and temporal movement patterns were also investigated on the Jakobsberg landslide. Through statistical analysis of eccentricity it was possible to identify three stages of landslide movement, not affecting the slope as a whole, but rather separating it into three sections. The upper slope (uX) was influenced by landslide movement in the 1970s, as well as in 1991 and 1992. Shrubs in the middle part of the slope (mX) indicate landslide activity in 1985, while the lower slope (lX) has been affected in the 1990s (Fig. 6 and Table 2).

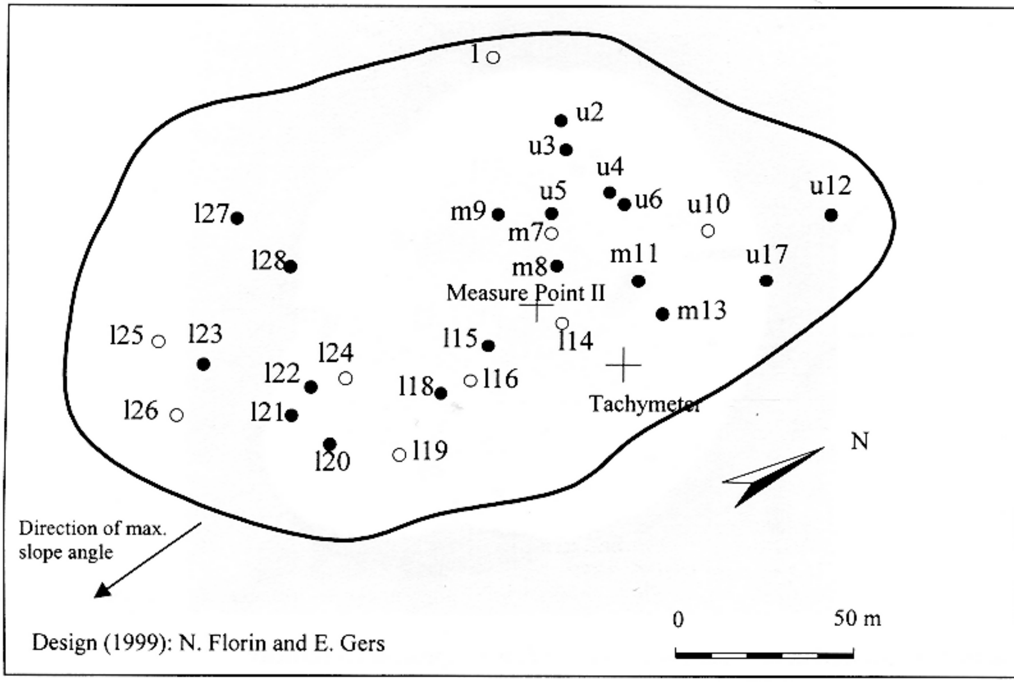

Fig. 6. Location of shrubs and related results of shrubs on Jakobsberg landslide. (○ undated shrub / ● dated shrub / → direction of slope angle). The characters u, m and l represent unique temporal and spatial movement patterns (u = upper / m = middle / l = lower part of the slope ; X = Number of shrub).

Table 2. Eccentricity in selected shrubs on Landslide Jakobsberg.

Shrub No.	Eccentricity in year	Shrub No.	Eccentricity in year
u 2	1975–1980/1989/1996	m 13	1983–1985
u 3	1994	l 15	1984–1985/1991/1993–1996
u 4	1978–1980	u 17	1990/1991
u 5	1991	l 18	1989/1991
u 6	no reaction	l 20	1986
m 8	1985	l 21	1984–1985/1992
m 9	1983/1985–1986/1989	l 22	no reaction
m 11	no reaction	l 23	1990–1991/1993/1995–1996
u 12	no reaction	l 27	1983–1985/1987/1992–1993
		l 28	1992/1994–1996

Site chronology

The site chronology is formed by eight shrubs, showing a reliability of 95 % in slope-corresponding colinearity. Its characteristics are the growth trend of decreasing ring width in relation to age, as well as negative event years (1969, 1977, 1987) and an abrupt growth change

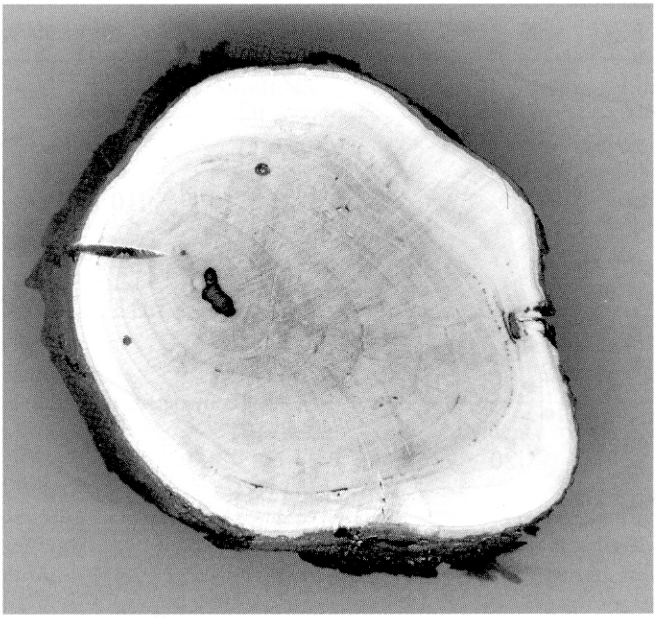

Photo 2. Cross section of *Crataegus oxyacantha L.* with apparent eccentricity.

from 1991 to 1997. These reductions of annual growth are linked to climatic impact or to disadvantageous substratum (SCHMID & SCHWEINGRUBER 1995). Within the framework of this investigation the mean curve is also divided into two parts (radii of slope and downslope sides of all trunks). The comparison of the two curves indicates that the growth of shrubs, even on stable sites, shows natural eccentricity. BRAAM et al. (1987a: 575) mention that eccentricity is also caused by uneven distribution of moisture and nutrient supply, as a result of an unequal development of crown or roots, but appears without concurrent reaction wood in these cases.

Cross sections of stems

One aim of the investigation was determination of the direction of slope movement on DROM9. For that purpose cross sections of stems were examined. The advantage of analysing the full cross–section of a stem is the complete view of all annual rings, so all different directions of the bending trunk, manifested in eccentricity and reaction wood, become more obvious (Photo 2). The location of reaction wood, as a response to landslide movement, was determined by examining eight cross sections (Fig. 7). Neither a correlation between orientation of reaction wood eccentricity and slope angle or an identification of a general movement direction were possible. The dendrogeomorphological analysis indicates that the analysed shrubs are influenced by their immediate surrounding and thus reflect various small movements within the landslide body.

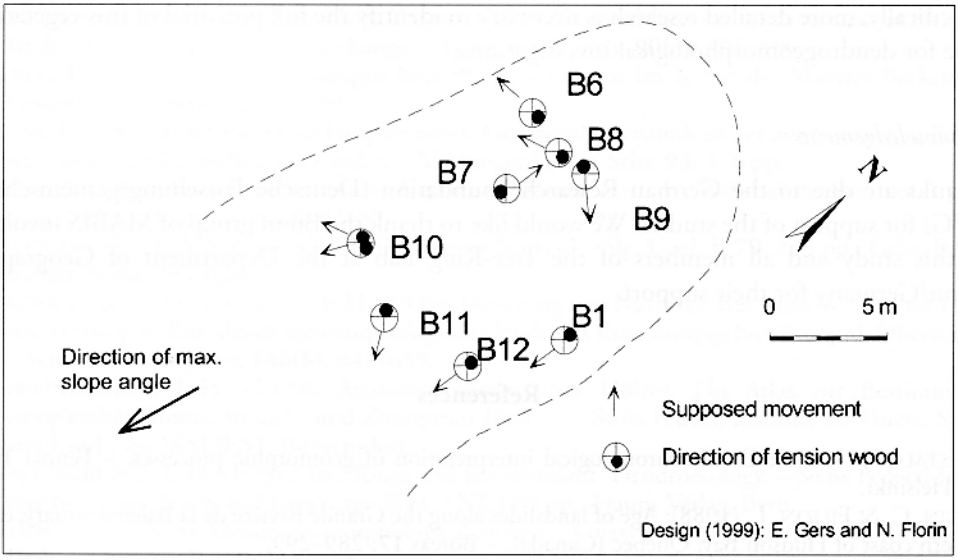

Fig. 7. Orientation of reaction wood in eight cross sections of shrubs on DROM9 landslide.

5 *Conclusion*

Although this preliminary study was based on very few undisturbed reference shrubs, it was nevertheless possible, with consideration of shrub growth and its dendrogeomorphological significance, to establish some first results regarding temporal and spatial landslide movement.

The statistical analysis technique of BRAAM et al. (1987a) is a valuable tool for detecting eccentricity. The use of this technique should be discussed further, especially the application of threshold values indicating significant deviation from a common growth pattern. Despite the application of this method, a statement of the relationship between eccentricity or suppression and intensity of an event has not been possible. The comparison between stable conditions and movement sequences within tree ring curves, and interpretation of these relationships, requires a long series of annual rings, which can not be expected in pioneer vegetation. Given the existence of natural eccentricity, it may be possible to build an average of eccentricity for shrubs and trees on stable sites.

This has been a preliminary investigation. More substantial information requires sampling from a larger amount of shrubs. Especially for building a mean chronology, it is essential to have enough cores to achieve a reliable dating. Growth on stable sites can be influenced by various impacts (COOK 1992: 98–104). Finally, possibilities for various dendrogeomorphological examinations with shrubs on landslides arise. The application of shrubs in dendrogeomorphological analysis has shown promising results with respect to temporal and spatial evidence of continuing landslide movement, which is otherwise very difficult to assess. Further efforts should be directed in part to determining the growth behaviour of shrubs.

Specifically, more detailed research is necessary to identify the full potential of this vegetation type for dendrogeomorphological investigations.

Acknowledgements

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