Suppl. Geogr. Fis. Dinam. Quat.
II (1989), 13-17, 2 ff.

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DENDROCHRONOLOGICAL INVESTIGATIONS ON THE FREQUENCY OF DEBRIS FLOWS IN THE ITALIAN ALPS (**)

Abstract: STRUNK H., *Dendrochronological investigations on the frequency of debris flows in the Italian Alps.*

With the help of the example of the Kaserbach debris flow cone in the Dolomites of Prags/southern Alps, the analysis of debris flow frequencies by dendrochronological methods is demonstrated. Episodic burying of trees causes sprouting of secondary root systems at the top of each of those aggradations. By age determination of such layers of adventitious roots, as well as of the time of drastic decline in annual increment of the stem (suppression) due to aggradation, and by dating deaths of trees resulting from deep aggradation on the one hand, also by age determination of trees and shrubs growing upon debris flow cones on the other hand, a stratigraphic division comprising, in the study area, the last 246 years can be constructed, which permits sufficiently accurate conclusions on the frequency of episodic debris flows. The methods applied will be presented in detail, their problems and limits being discussed in conclusion.

KEY WORDS: Debris flows, Frequency analysis, Adventitious roots, Southern Alps.

Riassunto: STRUNK H., *Ricerche dendrocronologiche sulla frequenza dei debris flows nelle Alpi Italiane.*

Sulla base di studi condotti nella zona di Kaserbach nelle Dolomiti viene esposta e dimostrata la frequenza dei fenomeni di *debris flows* con metodi dendrocronologici. L'episodica caduta di alberi genera un nuovo sistema di radici avventizie alla sommità di ognuno degli accumuli. Dall'età di questi letti di radici secondarie, così come dal tempo del netto declino nell'incremento annuale del tronco dovuto al ricoprimento e dall'età della morte degli alberi ad ogni successiva aggradazione detritica, così come dall'età degli alberi ed arbusti cresciuti sopra i coni dei *debris flows*, è stata stilata per gli ultimi 246 anni una colonna stratigrafica che permette una sufficientemente accurata frequenza dei *debris flows*; il metodo e i suoi limiti nonché i problemi che ne conseguono sono esposti nelle conclusioni.

TERMINI CHIAVE: Debris flows, Analisi di frequenza, Dendrocronologia, Alpi Meridionali.

INTRODUCTION

Mountainous areas of high potential energy are permanently exposed to geomorphological hazards such as landslides, rockfalls, snow- and ice avalanches, disastrous floods, or debris flows. Due to their great intensity, these powerful episodic events may cause greater changes within a few hours than decades or centuries of continual or even periodic geomorphological activity (e.g. SCHICK & MAGID, 1978). Consequently, at a relatively early stage, geoscientists like HEIM (1932, cfr. HSÜ, 1978) and STINY (1910, 1931 cfr. MÜLLER, 1979) investigated the causes of low frequency geomorphological mass movements of high magnitude, which, from time to time, damage productive areas and infrastructural installations. Nowadays, the Alps have become Europe's playground all year round and are being made accessible for larger numbers of people by touristic installations which have penetrated into greater and greater altitudes and more and more unsuitable regions — considering their potential natural hazards. In consequence such natural geomorphological processes of high magnitude, which have always occured in these areas, are now considered disasters. This situation led to efforts to picture the natural hazards of a region in a cartographic survey intended to help those institutions concerned with spatial and architectural planning (e.g. KIENHOLZ, 1978; KIENHOLZ & *alii*, 1983). Now, as ever, the greatest problem consists in the investigation of magnitude-frequency relationships of extreme geomorphological events with low or very low frequencies over long periods of time (STRUNK, 1986). A great number of recent processes are accessible, the easier the more regulary they occur (WOLMAN & MILLER, 1960). Hitherto, the fluvial morphodynamics of small catchments has been most frequently examined (e.g. BURT & WALLING, 1984), an almost traditional field of research for English geomorphologists. The greatest problem in frequency research of episodic processes is the poor probability of their recurrence. In view of a given frequency of several years or even several dozens of years, usual geomorphological process measurements do not make sense and, considering the long periods of geomorphological stability, the expenditure for field measurement equipment can hardly be justified. If due to the poor proba-

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(**) *Presented at: Joint Meeting on Geomorphological Hazards, I.G.U., Firenze-Modena-Padova, May 28 - June 4, 1988.*

bility of their recurrence, the investigation of the frequency of such rare episodic processes, is not possible directly by measurement, the strategies of traditional historic-genetic geomorphology, which can be transferred to these problems of subrecent geomorphodynamics, can be some help (AHNERT, 1980). This approach to a solution will be treated in detail, analysing the frequency of episodic debris flows as an example.

THE WORKS AREA

The Kaserbach area is situated in the province of South Tyrol (Alto Adige), Italy, at the north-eastern edge of the Dolomites of Prags in the Eastern Alps, a few kilometers south-west of the water divide between the rivers Rienz and Drau. The Kaserbach stream rises at the upper end of an almost 2 km long, steep-sided valley, which ascends smoothly from a height of 1500 m to 1620 m. The valley head is surrounded by up to 560 m high, steep rock walls consisting of dolomite. The highest point of the drainage area is the Rote Wand (Croda Rossa) with an elevation of 3146 m above sea level. As the whole drainage area is karstified, a direct run-off into the valley head exists only in case of excessive precipitation and snowmelt. Usually, all water inflow, even from the Kaserbach, percolates down through the thick accumulations of the talus cones and torrential fans of the river head. The bottom of the valley, a meadow, sparsely timbered with spruce, is used as pasture in summer, but is, unfortunately, being devastated increasingly by detrital accumulation. The latest debris flow of 1981 alone destroyed 5.3 ha of pastureland.

MECHANISM OF DEBRIS FLOWS

The debris flows consist of dolomitic debris, derived from debris fall, which is not only transferred by rock fall, congelifraction and avalanches from the cliff walls surrounding the valley head onto the steep talus cones at the base of the walls, but also remains in considerable quantities in the steep grooves and ravines within the rock walls. These detrital accumulations are the delivery areas for the episodic debris flows in the works area. Furthermore, a talus cone on a rock terrace high above the valley head is being removed by retrogressive erosion of a steep ravine. This talus cone delivers considerable amounts of debris into the basin soil. Since surface run-off of rainfall and meltwater are being collected in the ravines and clefts of the rock walls, which serve as outlet channels, the debris there stored can, in case of excessive precipitation, be mobilized and thus all be moved downwards as a water-debris mixture of high density (PIERSON, 1981; COSTA, 1984; SASSA, 1985), called debris flow, to the valley head, where it is repeatedly accumulated and thereby buries timber and devastates pasture (STRUNK, 1988).

Debris flows are triggered off by excessive precipitation, mainly during thunderstorms. Excessive rain with daily amounts of precipitation above 50 mm/m^2, which may cause debris flows in the works area, occurs nearly every three years on average (STRUNK, 1988). One must, however, bear in mind that not each of these instances of excessive rainfall triggers off debris flow, since, in addition to sufficient average rainfall intensity, there must first be, unstabilized debris in the drainage area. This debris is constantly accumulating through weathering processes, but is removed only episodically by debris flows. After the steep ravines in the rock walls have been cleared out by debris flow, they are only gradually refilled with newly accumulated debris. Consequently the storage of debris appears to be, indeed, the most important factor, besides a sufficient average rainfall intensity, which controls the frequency of debris flows.

FREQUENCY ANALYSIS OF DEBRIS FLOWS

The degree of danger in an area is, in general, calculated by the frequency of the processes of high magnitude occurying there; the latter must, as a consequence, have priority for investigation. With regard to the frequency of debris flows, especially, too few facts have been established until now. In China, where observation in a drainage area in Yunnan has been going on for almost 20 years by now (LI JIAN & *alii*, 1983; LI JIAN & WANG JINGRUNG, 1984), similar investigation is far-advanced. But one must bear in mind that the frequency of mud-flows (10-30 events a year) is extraordinarily high. In the Japanese Alps, a study group cooperating with OKUDA and SUWA has been exploring the interaction of precipitation, moistening and the origin of debris flows as well as the velocity of debris flows and the changes of the cross sections in valleys over long periods of time by experimental measurement since 1973 and with the help of field measurement stations since 1977, in order to establish fundamental principles for mass balances (OKUDA & *alii*, 1980). Whereas RAPP & NYBERG (1981) found 4 debris flows only during the last 2700 years in a works area in northern Scandinavia, KRONFELLNER-KRAUS (1977) proves a mean frequency of 30 years for debris flows in the Alps.

These publications permit the conclusion that the frequency of not immediately observed and documented debris flows remains very difficult to reconstruct. A number of investigations have been carried out nevertheless. SCHLESINGER (1967) made us of radiometric, palynolytic, vegetational and dendrochronological methods for his frequency analysis. RAPP & NYBERG (1981), on the other hand, used lichenometry instead of dendrochronology as a dating method above the timberline.

Investigations carried out by the author in the meanwhile permit the conclusion that, when dendrochronological methods are used, the frequency of debris flows is reconstructable with very high accuracy even over a period of several centuries. ALESTALO (1971) designated the procedure of geomorphological survey by dendrochronological methods as dendrogeomorphology.

FREQUENCY OF DEBRIS FLOWS IN THE WORKS AREA

The spruce (*Picea abies*), a flat-rooting tree, reacts very sensitively to being buried. Whereas a cover of more than 1.5-1.8 m causes the death of the tree within a few years, it reacts to thin aggradation by sprouting adventitious roots on the buried portion of the stem, a fact confirmed by SCHIECHTL'S similar observations (SCHIECHTL, 1985). Several phases of aggradation cause, accordingly, successive generations of adventitious roots, as described by ALESTALO (1971) in other species of trees. For this reason, two stems of spruce were selected on the Kaserbach debris flow cone and their stems and root collars analysed. Cores of the stems were obtained with the help of an increment borer. Sawn cross sections of the thickest root of each generation of adventitious roots were counted under a binocular microscope. Tree 1 had grown at the edge of the older, upper part of the debris flow cone, another spruce (tree 2) in the middle of the recent accumulation area a few hundred metres below. The excavations showed the following results:

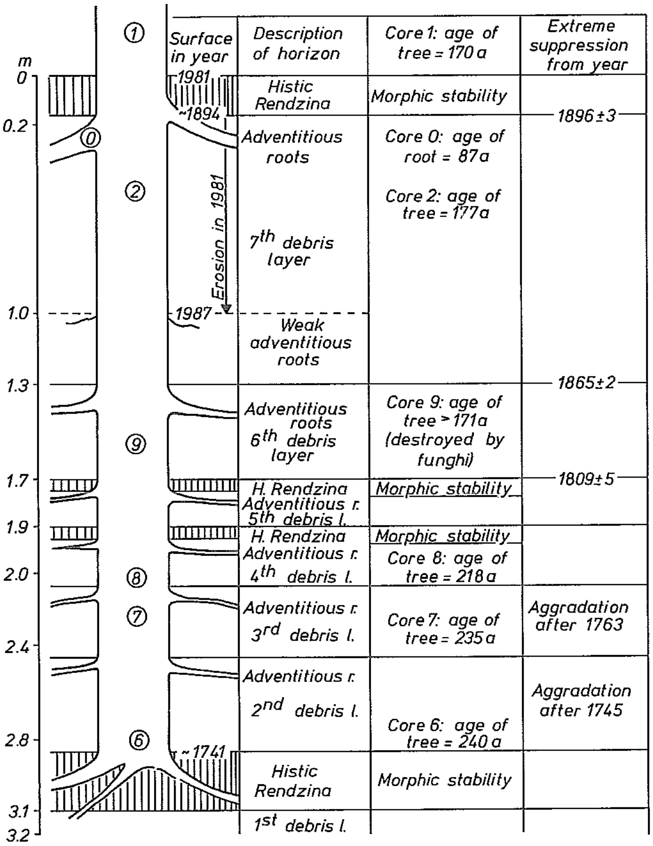

FIG. 1 - Kaserbach debris flow cone, profile of tree 1.

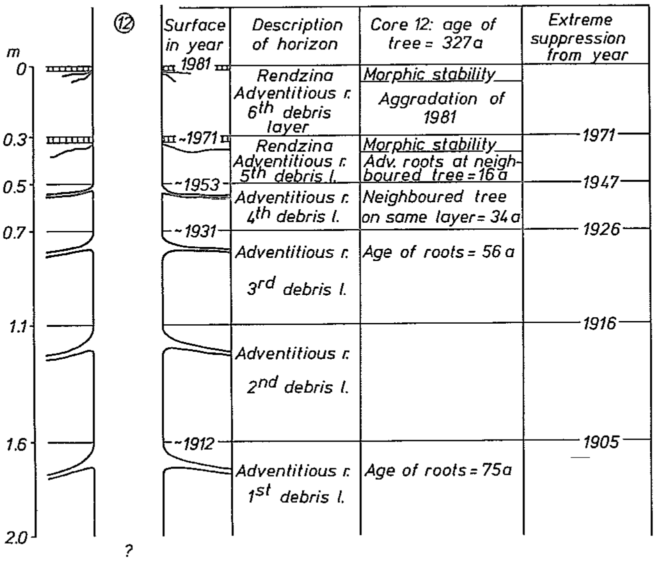

FIG. 2 - Kaserbach debris flow cone, profile of tree 2.

Tree 1: Situated near the upper border of the debris flow cone. The youngest generation of adventitious roots had been exposed by lateral erosion after the debris flow in 1981, causing the death of the tree in the same year. The age of the oldest adventitious root (core 0) of this generation is 87 years before 1981 (see fig. 1). This root had started sprouting due to an aggradation with debris in 1894. As this aggradation had injured the function of the buried roots, the tree had to survive some years of famine, before a new generation of roots had developed to a sufficient extent. Thus, the date of an aggradation may also be established at the starting point of diametre decrease of the tree rings of the stem (suppression). This suppression started in about 1896 % 3 years, a date well in accordance with the age of the oldest adventitious root. Further excavation of the stem down to the germinal root collar at more than 3 m depth revealed a total of 6 generations of adventitious roots. Originally the tree had already sprouted on an old debris layer. Thus 7 debris layers are divided by 7 generations of roots. The age of the tree at its foot (core 6) adds up to 240 years. Consequently it started growing in 1741 and the first debris layer must have been deposited before 1741, accordingly. The maximum age of the second debris layer is deduced from the age of the tree at core 7. In order to survive, the tree must have been higher than the second debris layer at the time of sedimentation. It had reached this minimal sufficient height at core 7, about 235 years before 1981, i.e. in 1745. The maximum age of the third debris layer can be determined in the same way by the then minimal height of the tree at core 8, as 218 years before 1981. Consequently, the third debris layer can not have been accumulated earlier than 1763.

The maximum ages of the fourth and fifth debris layers cannot be determined by this method, nor the age of the tree, as its heartwood was destroyed by funghi near core 9. But two further extreme suppressions are of significance, starting in 1865 % 2 years and 1809 % 5 years. They must have been caused by the aggradation of the fifth and sixth debris layers. Thus, the accumulation of the fourth debris layer occurred in the interval between 1763 and 1809, but cannot, unfortunately, be determined more exactly. Four soils in the profile, however, suggest several periods of morphological stability. Whether the thickness of those Histic Rendzinas permits conclusions about the age of these soils and thereby about the length of the periods of stability, still requires further specific investigation.

Tree 2: As the frequency of debris flows could only be established until the year 1894 with the help of tree 1, a second tree in the middle of the debris flow cone was investigated in order to obtain data about the last century as well (see fig. 2). Owing to technical problems, this tree was only excavated to a depth of 2 m. Its minimal age (core 12) is 327 years. Extreme suppression of the width of growth rings started in the years 1971, 1947, 1926, 1916, 1905, 1863, 1842 and 1793. As the tree had not recovered from being buried in 1971 and had been producing very narrow annual rings only from then on, the more recent burying of 1981 caused no further suppression. On the other hand, the debris flows of the years 1905-1981 are uncontrovertibly recognizable as 6 debris layers separated by 6 generations of adventitious roots. The ages of the oldest adventitious roots of the first and the third debris layers confirm this cronology. Since the age of the roots in the fourth and the fifth debris layers was not calculable, the ages of equivalent root generations of neighbouring trees have been calculated instead and, as expected, confirmed the suppressions of tree 2.

CONCLUSIONS

The suitability of dendrogeomorphological research methods for the analysis of natural hazards has been demonstrated by a great number of recent publications. By means of dendrochronology, the frequency of floods (e.g. SIGAFOOS, 1964; HELLEY & LAMARCHE, 1973; GNACCOLONI & OROMBELLI, 1974; COSTA, 1978), of earthquakes (e.g. MEISLING & SIEH, 1980) and volcanic eruptions (e.g. FINCH, 1937; DRUCE, 1966; YAMAGUCHI, 1983), of landslides (e.g. OROMBELLI & GNACCOLINI, 1972; TERASME, 1975; BRAAM & *alii*, 1987) and avalanches (e.g. HEATH, 1960; POTTER, 1969; IVES & *alii*, 1976; OAKS & DEXTER, 1987) has been determined. Many further publications were cited by SHRODER (1980).

Though ALESTALO (1971) has described the feasibility of dating accumulations with the aid of generations of adventitious roots, this method has not previously been used to determine the frequency of mud- and debris flows. The present study shows, that the frequency of debris flows in the works area during the last 240 years could be determined by the dendrochronological analyses of only two carefully selected trees. In this period 12 debris flows occurred which reached the valley bottom and destroyed timber and pasture. Such disastrous debris flows are likely to take place every 20 years on average. It should be remembered, that the real variability in time of these events of 9 to 56 years corresponds only inadequately to this rough average. Rather the frequency seems to be superimposed by long-term trends whose causes are not yet known. Consequently, investigations in neighbouring areas will be essential. Nevertheless, the feasibility of employing dendrogeomorphological methods, which are relatively inexpensive, for research into frequencies of episodic debris flows has been clearly demonstrated.

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