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Reconstructing debris flow frequency in the southern Alps back to AD 1500 using dendrogeomorphological analysis

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Abstract Spruce trees which have been buried by debris flows react to even slight accumulations of debris by a pronounced decrease in growth, a so-called suppression. Nearly every active debris flow cone has been affected by several debris flow events, the timing of which can be reconstructed by dating the start of suppression in the tree-ring sequence of each buried tree. The spatial distribution of debris flows can be reconstructed by analysing the suppression periods of all living trees within a cone with the help of phase-diagrams. The cone investigated has been affected by debris flows since AD 1574, although the oldest still living tree started to grow in AD 1435. The median recurrence interval of debris flows on this cone is about nine years during the period between 1884 and 1989.

INTRODUCTION

Debris flows are a frequent form of rapid mass movement which occur in nearly all mountain areas of the world. Analysis of their recurrence interval or frequency is not only of academic interest but also important for disaster prevention. The village of Tramin in South Tyrolia, for example, was affected by a sudden debris flow during a heavy thunderstorm on 23 June 1986, which completely destroyed the new local recreation centre and seriously damaged the new cellars of the wine-growers cooperative. The damage totalled about 6 million US dollars (Strunk, 1990). Reliable information on the recurrence interval of this kind of geomorphological hazard, which occurred there for the first time in living memory, are not available, but an old document found in the archives of the local pastorate provides evidence of a similar event in the early nineteenth century, which destroyed an old chapel on the same site. Thus the recurrence interval of debris flows on this cone must be about 180 years or even more.

THE NEED FOR EXACT DATING METHODS

As such documents or chapels on debris flow cones are very rare, there is an urgent need to develop other methods for analysing debris flow frequency.

During the last three years we have re-examined and developed dendrogeomorphological methods for frequency analysis of debris flows (Strunk, 1989). This procedure of geomorphological survey by dendrochronological methods was first used by Alestalo (1971), who found that burial of living trees by drifting sand not only causes sprouting of adventitious roots in the section of the trunk which has been covered, but also changes the growth activity of the tree, which should be reflected in a change in the width of growth rings.

For this purpose we analysed about 200 buried and 260 undisturbed spruce trees (*Picea abies*) from five study areas in the Alps. Additionally, we have excavated 40 buried spruce trees down to the original root systems and we have found that these trees react even to a slight accumulation of debris by suppression, which is a pronounced decrease in growth. It is precisely this high sensitivity which makes the spruce tree an exceptionally useful indicator of growth disturbances caused by debris flows burial.

PROBLEMS OF DATING DEBRIS FLOWS ON DEBRIS FLOW CONES

The greatest problem in the reconstruction of aggradation phases is caused by the domed surface of the debris flow cone, which frequently diverts the debris flows to the margins of the cone. Thus, two aggradation events may be separated by an undisturbed interspace. Consequently, the surface of each debris flow cone is separated into active and inactive segments, represented by a series of spherical triangles, which may differ considerably in age (Fig.1). For this reason, the analysis of only a few trees upon a debris cone could give an incomplete idea of its morphodynamic activity. It should, however, be possible to reconstruct these different aggradation events with the help of dendrogeomorphological analysis of the whole cone. For this purpose we chose one of several currently active debris flow cones in the Wildsee area near Prags in the Dolomites. Its catchment area is formed by the high rock walls of Mt Seekofel (2810 m a.s.l) which are up to 1300 m high. Debris from rockfalls, slushflows and avalanches accumulates in a steep cirque, where it is stored until the next debris flow occurs. The very young age of the debris is confirmed by the items of litter that we found among the sediment in our profile trenches. Gradually, these debris flows are burying a spruce forest up to 550 years of age, which is rooted in a Histic Rendzina up to 40 cm thick. Dependent on the burial depth, the trees are harmed to a varying degree. While the mountain pine (*Pinus mugo*) only tolerates a thin accumulation and has therefore withered in most cases, the spruce (*Picea abies*) is tougher and possibly gets chlorotic, when the burial depth does not exceed 1.6-1.9 m. It only dies, when the depth of burial exceeds this value (Strunk, 1991).

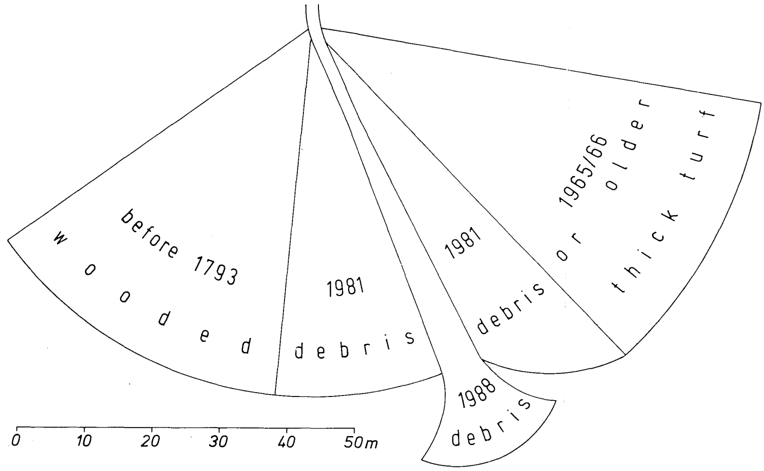

Fig. 1 Standardized sketch of a debris flow cone with several generations of debris flows.

DATING BY SUPPRESSION AND RELEASE

Due to burial by a debris layer both the growth of the trunk and the function of the original root system of a tree are severely affected. Following Alestalo (1971), the tree therefore will fall into suppression and will develop only narrow growth rings for a number of years after this event, until the new root generation has produced an adequate extension. Consequently, several burial events cause several phases of suppression lasting a number of years after each of these events. Thus, for each event the time of burial can be established by determining the first narrowing of annual rings in the trunk.

To reconstruct the frequency distribution of debris flows on the cone in this way, we bored cores from all 140 buried but still living trees which had survived the aggradation, and we constructed a special diagram for each individual core. The periods and the degree of suppression are plotted on the time axis of a phase-diagram, similar to the so-called skeleton plot (cf. Stokes & Smiley, 1968). These diagrams permit the drawing of parallels between trees with different individual ring widths. The visible degree of reduction of the ring growth in comparison with the normal growth of each individual tree is plotted on a four-stepped scale which shows reduction rates from 40% to more than 86% (Fig. 2), following Schweingruber *et al.* (1986) and Kaiser & Kaiser-Bernhard (1987), who only needed a three-stepped scale for their purpose. Figure 3 shows part of such a phase-diagram of suppression with cores from 20 different trees of the study area. It covers the years from 1830 to 1989 and includes several reduction periods with different intensities, starting about 1883, 1896, 1932, 1953, and 1976.

Two of these suppressions, the events from 1932 to 1934 and from 1975 to 1980, are common even in the cores of undisturbed trees. Since, due to climatic variations, even the growth-ring sequences of undisturbed trees show

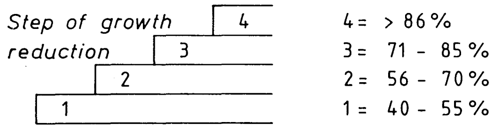

Fig. 2 Reduction of tree ring growth shown on a four-stepped scale representing reduction rates from 40% to more than 86%.

a shift from phases of normal to both reduced and increased tree-ring diameters, a phase-diagram for 20-40 dominant undisturbed trees with normal growth conditions must first be established for each study area and compared with that of the buried trees. Only this procedure makes it possible to distinguish between suppressions due to burial or to other causes.

By analysing the phase-diagrams for both the debris-buried and the undisturbed stand of trees, it is possible to produce diagrams depicting the onset of suppression periods of more than four years duration plotted against the percentage of affected trees, where only peaks rising above the 5% level of "ground noise" are considered (Fig. 4). A comparison of both diagrams shows that the suppression phases evidenced by the buried trees for the years 1885-1886, 1898-1900, 1905-1909, 1918, 1925-1926, 1941, 1954-1957, and 1959-1960 do not recur in the diagram representing the undisturbed trees. This feature allows debris flows to be identified as the cause of the reduction phases with a high degree of certainty. The spread of dates marking the beginning of each reduction phase and covering a time-span of two years and more can probably be explained by the assumption that trees that are already physiologi-

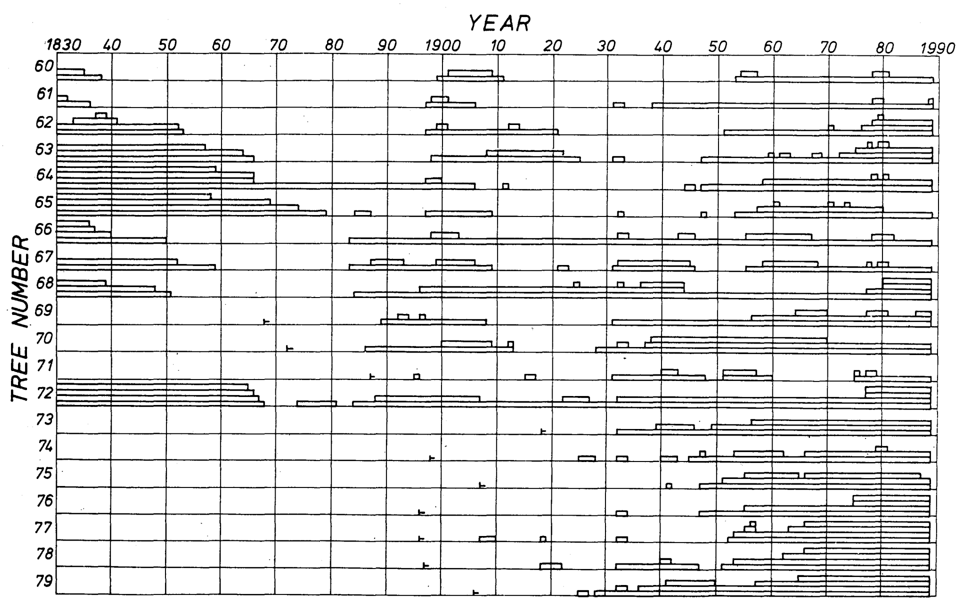

Fig. 3 Part of an original phase-diagram of suppression with cores from 20 different trees in the study area.

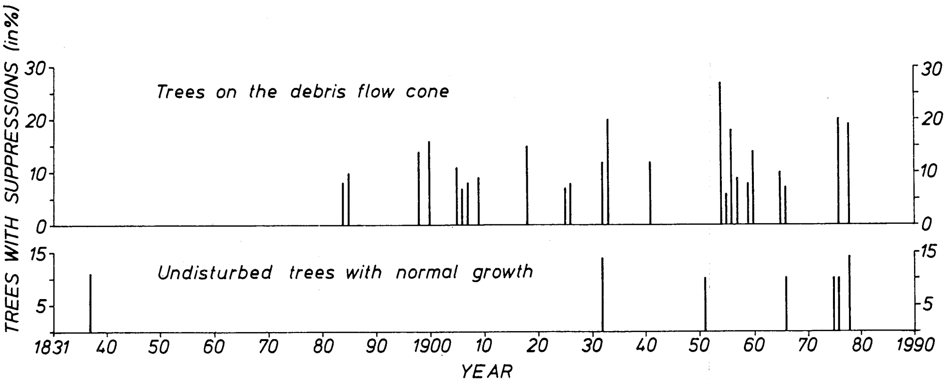

Fig. 4 Onset dates of suppression periods for both the debris-buried and the undisturbed stand of trees, plotted against the percentage of affected trees.

cally weakened react immediately to burying by debris, whereas healthy trees need several years to reach the reduction level of 40% ring-width, as demonstrated by a number of cores.

Much more difficult, however, is the interpretation of suppression phases which occur in the growth rings of both the debris-buried trees and the undisturbed trees. This is the case with the phases beginning in 1932-1933, 1965-1966, 1975-1976 and 1978. The growth reduction of 1975-1976 was probably caused by a debris flow, because one occurrence of a debris flow has been established through a core taken from a tree growing at the lower end of the debris cone. The peak of 1978, however, seems to have been climatically induced, because only those trees of the buried population which had been physiologically weakened by the debris flow of 1975-1976 reacted. This is illustrated by the fact that in 1978 it was exclusively trees with reduction levels 3 and 4 for 1975-1976 that reacted with additional growth reduction. For the phases 1932-1933 and 1965-1966 both debris flows and climatic conditions appear to be the cause of suppression. The significant peaks evident for the unburied trees in 1932 point to a climatic effect, whereas the growth reduction in 1965 in the buried population, occurring one year later in the undisturbed stand of trees, together with the extent and location of suppression zones on the debris cone point to the effect of a debris flow.

In conclusion, it is proposed that debris flows can be identified and dated with sufficient precision by comparing the growth rings of the buried trees, especially the onset of growth reduction, with the growth rings of neighbouring undisturbed trees. Suppression phases may, however, also be triggered by the influence of both climatic and geomorphological effects. In such situations, additional facts have to be considered to determine the importance of each effect.

THE SPATIAL DISTRIBUTION OF DEBRIS FLOWS

With the help of the phase-diagrams of suppression it is possible to reconstruct the spatial distribution on the cone of each of the 12 debris flow events which occurred since 1830. First, all those trees which have been affected by the debris flow in question are marked on a ground-plan of the cone. Unaffected trees are not marked. While several of these events affected nearly all parts of the cone, others buried only one side of it, or had split into several narrow lobes with intervening undisturbed areas. For example, the debris flow of 1953 (Fig. 5) affected nearly the whole cone with only narrow gaps remaining on the right side, in the middle zone, and on the outer left side. Although the debris flow of 1975 (Fig. 6) affected nearly all parts of the cone too, it separated into seven narrow lobes with undisturbed zones between them.

In attempting to reconstruct the debris flow of 1925 (Fig. 7), another problem appears. Many of the trees on the cone are younger than this particular debris flow and thus cannot be used for studying the event. This problem increases with each event further in the past. That is why the distributions of the 1896 flow and all the older flows remain uncertain. We can merely draw the conclusion that the older debris flows affected at least parts of the cone.

DISCUSSION

As can be seen in Table 1, the median recurrence interval of debris flows on

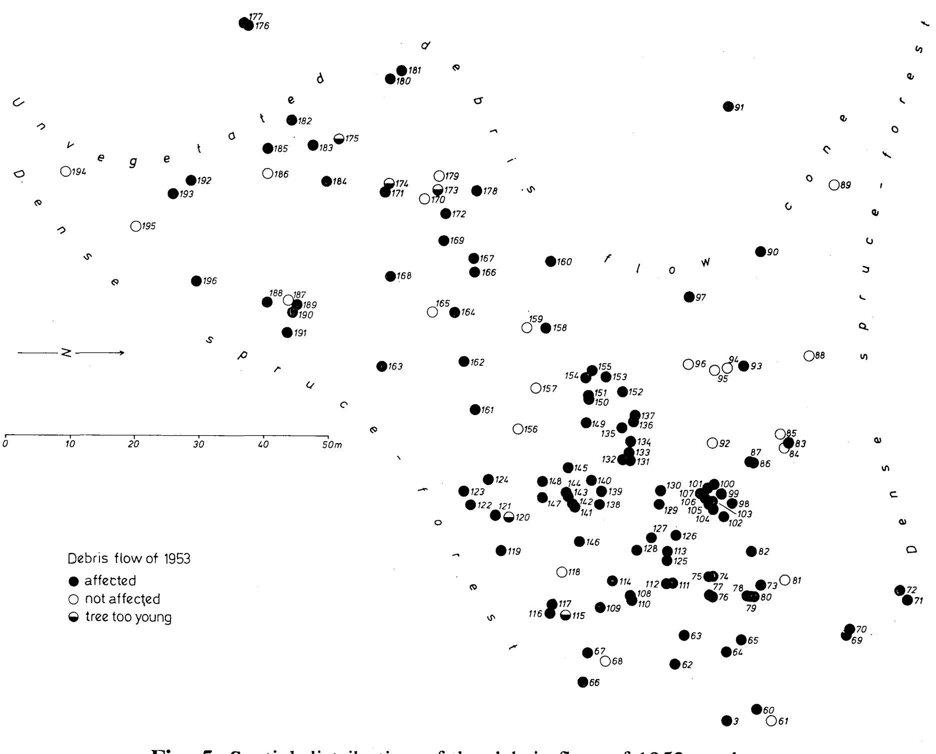

Fig. 5 Spatial distribution of the debris flow of 1953 on the cone.

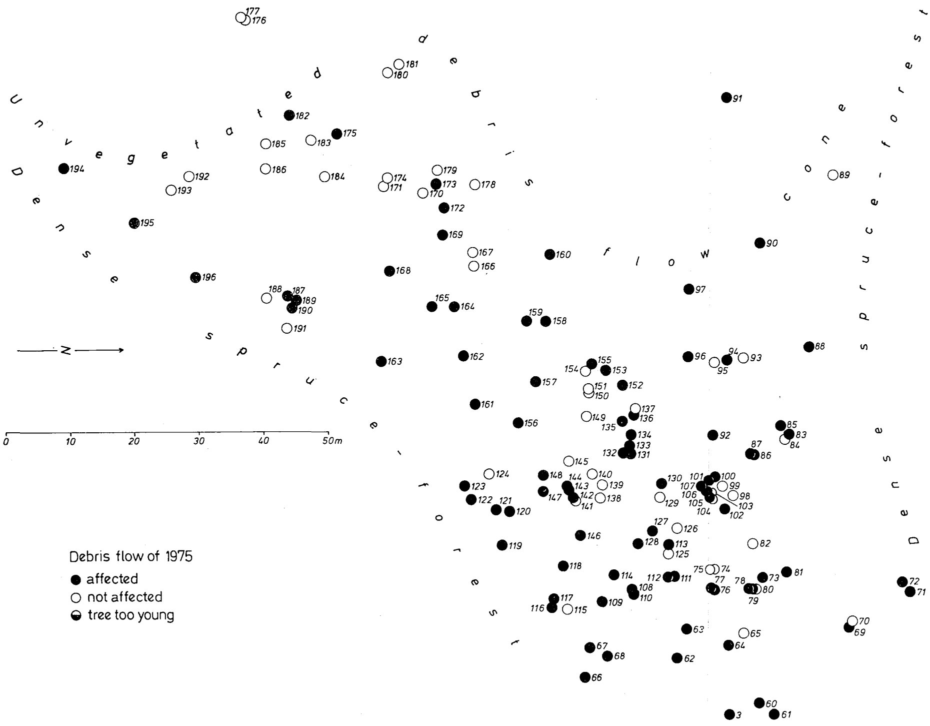

Fig. 6 Spatial distribution of the debris flow of 1975 on the cone.

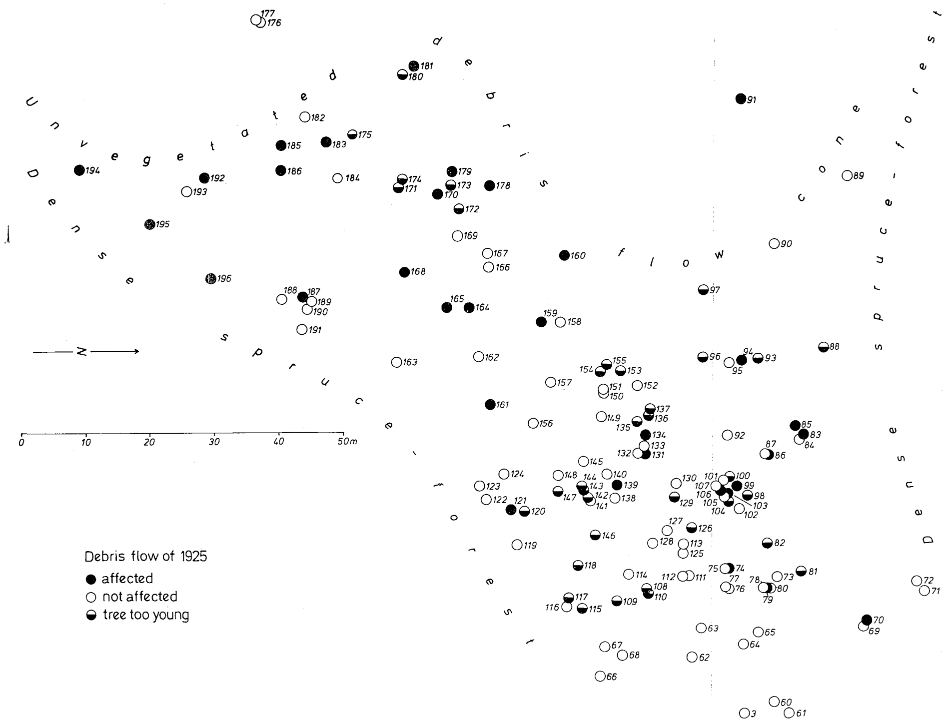

Fig. 7 Spatial distribution of the debris flow of 1925 on the cone.

Table 1 Intervals between the debris flows of 1884-1989 in the Wildsee area.

Date of debris flow	Interval in years	Date of debris flow	Interval in years
1884		1940	
	12		13
1896		1953	
	9		6
1905		1959	
	12		6
1917		1965	
	8		11
1925		1976	
	6		13
1931		1989	
	9		
1940			

this cone is about nine years for the time-span between 1884 and 1989, with the length of intervals ranging between six and 13 years.

There is no evidence of any trend towards an increase or a decrease in the frequency since the end of the last century. Before 1830 however, debris flows seem to have affected this part of the cone very infrequently. Only two events, in 1826 and 1574, could be identified by analysing the oldest living spruce tree on the cone, which started growing in 1435. This uncertainty in dating older events may, however, be caused by a lack of further information due to the natural deaths of many buried trees during the long time-span of nearly 400 years, and may further be caused by the separation of debris flow cones into active and inactive segments, as already mentioned above. Nevertheless, this method of dating debris flows by analysing the suppression phases of all the buried trees on a cone may help to provide an indication of its minimum activity and of the spatial distribution of the various debris flows on its surface.

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