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Study of a debris torrent in the Dolomites, Italy

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ABSTRACT

The Dolomites are situated in a region characterised by the presence of widespread debris flows, which originate at the foot of sub-vertical rocky walls and involve the underlying debris talus. These flows are characterised by the scantiness of the planimetric surface in the watershed and, when they are not channelled, by the variability of the courses from one event to another. This paper describes the study of a channelled debris flow or debris torrent, which periodically jeopardises the built-up area of San Vigilio di Marebbe (Bolzano). This town is located on a large alluvial fan formed by the torrents Ermo and Fojedöra. The beds of both torrents are constantly full of debris, which is partly contained by many dams and mostly carried away by the water that undercuts the banks. The Fojedöra, in particular, which until 1971 ran through the town carrying with it considerable amounts of debris, regularly damaged the town. As a result of these incidents, the last part of the course of the Fojedöra was artificially diverted into the Ermo by the construction of a 4 m high and 320 m long dyke. In this way the flows, which continued to run through the torrent in the following years, were confined in the channel, and the only danger was that posed by the damming of the main channel into which the torrent Fojedöra-Ermo flows.

The last important event took place on 27 July 1995 following a short but bad cloud burst in the upper reaches. It mobilised a considerable amount of debris and gave rise to a flow, which was contained by the dyke, and temporarily obstructed the main torrent and the valley floor.

The aim of the study was to reveal the mechanisms that might trigger off the flows, to analyse the morphometry of the deposits in order to characterise these deposits in terms of grain size, and to assess the possibility of damage to the infrastructure. The work was carried out in the following phases:

- a historical reconstruction of past events from both historical documents and the "memories" of the oldest inhabitants of the town;
- a study of the precipitation records of two meteorological stations located near the landslide area; and
- a topographical reconstruction of the flow route in order to map the main morphological elements, such as channels, scarps, banks, and lobes, and to carry out the grain size analysis of sediments.

Detailed mapping of the alluvial fan by means of overlaying slope and land use maps was aimed at evaluating whether a possible flow that was not contained by the dyke might reach San Vigilio di Marebbe.

INTRODUCTION

Debris flows are a highly concentrated natural mixture of water and debris. They are formed during intense or prolonged rainfall and spread along the slopes or torrents, and, at times, cause considerable damage to infrastructure located along their course. Although they appear as a type of landslide according to Varnes' classification (1978), the literature often considers them as intermediate phenomena between landslides, in the strictest sense, and torrent sediment transport. The basic difference between debris flows and torrent sediment transport is that, while in the latter there is always the separation between the solid and liquid phases, in the former, despite the loss of water during deposition, there is never the separation between the two phases (Johnson 1970).

The rheology of these flows varies according to the percentage of fine material, grain size distribution of the debris, and the quantity of water. Thus, there may be flows with movement of a viscous granular nature, and those in which the prevalent movements are of inertial granular type (Pierson and Costa 1987).

Depending on whether the course of these flows develops on an open or planar unconfined hillslope or along a pre-existing channel, they are called slope debris flows, or channelled debris flows or debris torrent, where debris torrent means "a mass movement that involves water charged, predominantly coarse-grained inorganic and organic material flowing rapidly down a steep, confined, pre-existing channel" (VanDine 1985).

These flows are characterised by the scantiness of the planimetric surface of the basin of origin and, in particular for the slope debris flows, by the variability of the courses from one event to another. It is this variability, which determines the risk factors for various types of infrastructure located at the foot of the slopes involved in these phenomena, in that, besides the temporal unpredictability of the trigger of the flow, there is also the unpredictability of their course. On the other hand, slope debris flows travel for shorter distances, since they are not confined and are able to spread. In the process of spreading, their speed is decreased and they deposit their sediment load. Despite the predictability of their course, debris torrents, instead, may be more dangerous in that they can travel for long distances at high velocity sweeping away everything along their path.

In the Dolomites, many debris torrents originate at the foot of sub-vertical rocky walls and involve the underlying talus. These flows usually occur during intense pluvial events, which affect the talus and the overlying rocky walls. The runoff accumulates in steep gullies that convey it towards the debris deposits, causing sudden saturation leading to flows.

This work presents the study of a channelled debris flow, which periodically threatens the built-up area of San Vigilio di Marebbe (Bolzano). Until 1971, the torrent Fojedöra (along which the debris torrent moves) crossed the town bringing damage and destruction. In that year, a 4 m high and 320 m long dyke was built in order to deviate the final course of the torrent, and provide safety for the inhabitants and the buildings.

PHYSIOGRAPHY OF THE STUDY AREA

The built-up area of San Vigilio di Marebbe (Fig. 1) has grown up on a large alluvial fan in the Marebbe Valley, which extends as far as the Rudo Valley, in the Natural Park of Fanes–Sennes–Braies (Alto Adige–Bolzano). The alluvial fan was created by the torrents Ermo and Fojedöra, which are the tributaries of the torrent San Vigilio (Fig. 2).

The Fojedöra originates from Giogo di Monte Croce, at an altitude of 2,283 m, and flows in a south-westerly direction for about 4 km along the valley of the same name, picking up smaller tributaries, which descend from the surrounding mountains (i.e. Piz da Peres, Punta Tre Dita, and Monte Paraccia). Up to an altitude of 1,650 m, the torrent is devoid of water for most of the year due to the high permeability of the debris on which it flows (Fig. 2). The area of the watershed is about 3.5 km^2.

The torrent Ermo originates from Monte Paraccia and, until 1971, flowed directly into the torrent San Vigilio. With the construction of the dyke, which deviated the natural course of the torrent Fojedöra to the left, the torrent Ermo became a tributary of the Fojedöra itself and together they flow into the San Vigilio in the most easterly section of the fan, at an altitude of approximately 1,226 m. The area of the Ermo watershed is about 1.15 km^2 and the length of the torrential reach is about 1.3 km. This torrent also flows on very permeable debris (Fig. 2) and, therefore, the upper reach is almost always without water.

From the 1980s, a great number of check dams were constructed for both torrents–33 for the Ermo and 53 for the main reach of the Fojedöra. Only the creek that descends from Piz da Peres, completely running on a large and deep talus (Plate 1), was not provided with check dams. In fact,

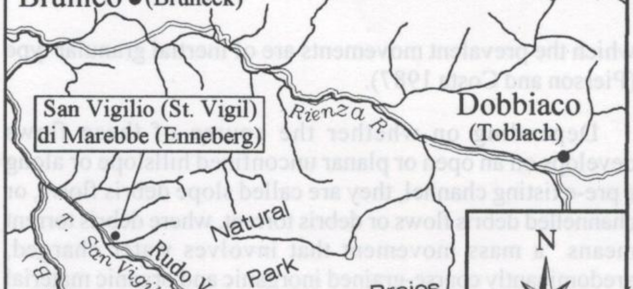

Fig. 1: Location map of the study area

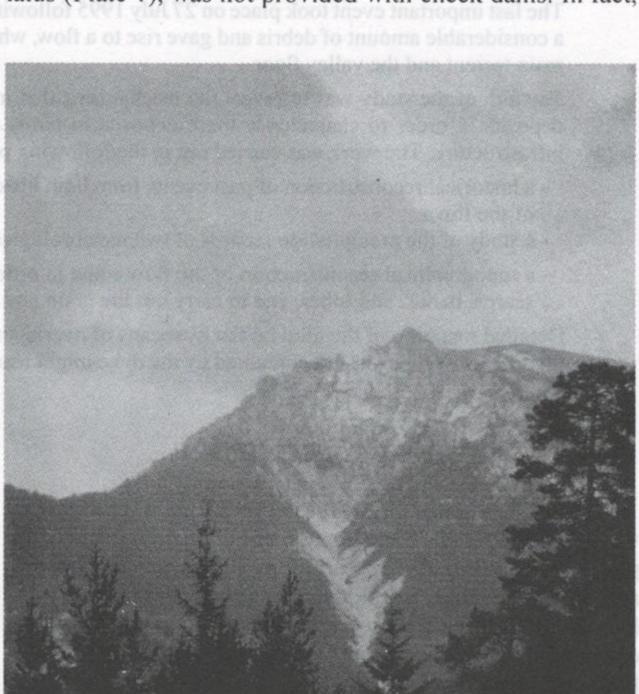

Plate 1: View of the creek Piz da Peres

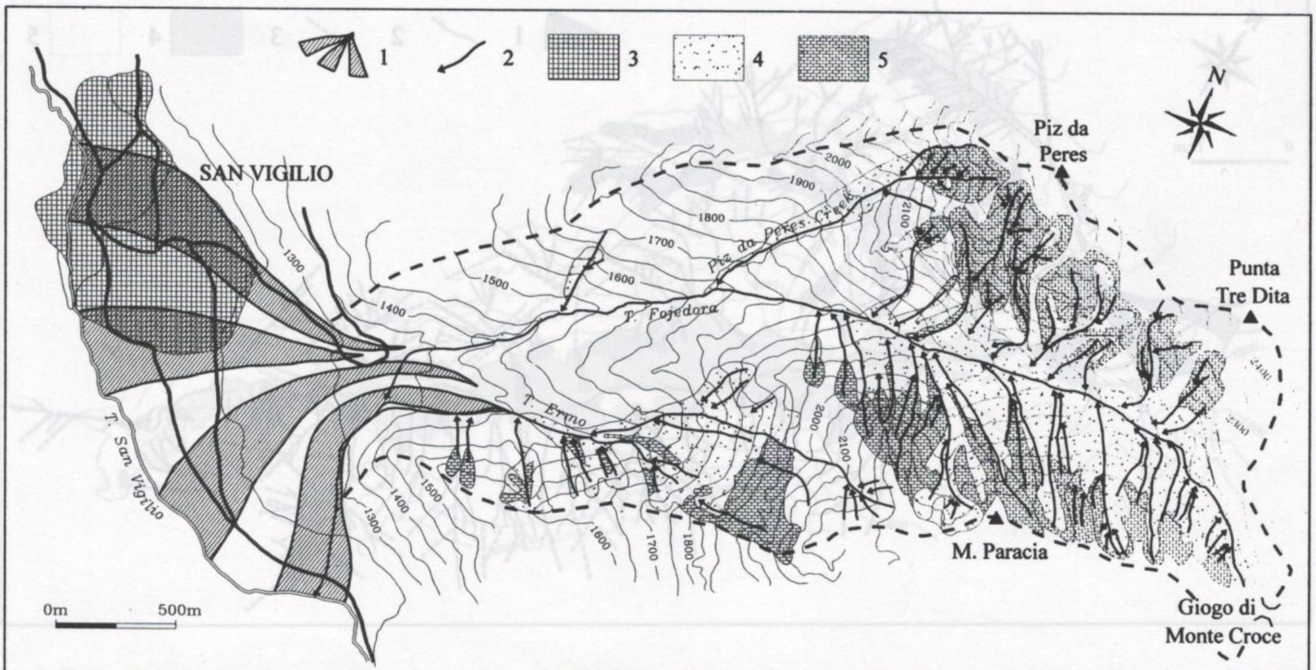

Fig. 2: Location of the debris torrents in the watershed of the Fojedöra. 1) Alluvial fan; 2) Debris torrent course; 3) Inhabited area; 4) Debris talus or cone; and 5) Rocky watershed of the debris torrent

during the last important event (which is described below) it was the main source of debris.

The geology of the two basins is characterised by the presence of Triassic rocks: the Werfen Formation (Scythian), Contrin Formation (Anisian), and Sciliar Dolomite (Upper Anisian–Lower Ladinian), intensely deformed by thrusts (Bosellini et al. 1996; De Zanche V. et al. 1992; Senowbari et al. 1993). The Sciliar Dolomite in particular, which is very fractured, is the main source of debris that forms the very deep talus at the foot of the walls. A photo-interpretation map of the main geomorphological elements was prepared for the entire Rudo Valley (where the torrent San Vigilio is located), including the transversely lying Fojedöra Valley (Fig. 3). This map demonstrates a good agreement between the channels of the debris torrents and the main fractures.

CHRONOLOGY OF THE DEBRIS TORRENTS

The following chronology of damage by the Ermo and the Fojedöra was obtained from the historical documents found in the archives of the village of San Vigilio and from testimony provided by some of the local inhabitants. Both of the torrents have always produced debris flows, but while the torrent Ermo has never constituted a risk to the village of San Vigilio, the torrent Fojedöra, before it was artificially deviated, had periodically been the cause of damage and death.

Historical debris flows in the Ermo

Towards the end of July 1874, a violent storm brought a mixture of mud and stones into the valley. In 1915, after a bad storm of heavy hailstones, which occurred on the slopes of Monte Paraccia towards the end of July, a large quantity of material descended from the torrent, which covered the fields with four metre deep gravel. In 1934, once more following a storm in the month of July, a flow of coarse debris deposited about one metre deep gravel. On 25 July 1937, another storm that lasted for about 30 minutes produced another flow, which covered a 150 m wide area with earth, mud, and stones. Again, towards the end of July 1945, rain and hailstones dragged into the valley another debris flow. It contained a large quantity of pine branches and raised the streambed by one metre.

Historical debris flows in the Fojedöra

The villagers describe the disaster stories of the torrent from 1150 to 1293, and again in 1500 almost like a legend. The debris flows repeatedly buried the entire village or most of it. The verity of these events is often proved today during the laying of foundations for new buildings when tiles or bricks of old dwellings come to light.

On 9 August 1845, a great landslide covered a part of the village, burying several houses. Between 1872 and 1971, in almost every summer, the floods and debris flows in the torrent caused heavy damage. On 27 July 1995, towards the

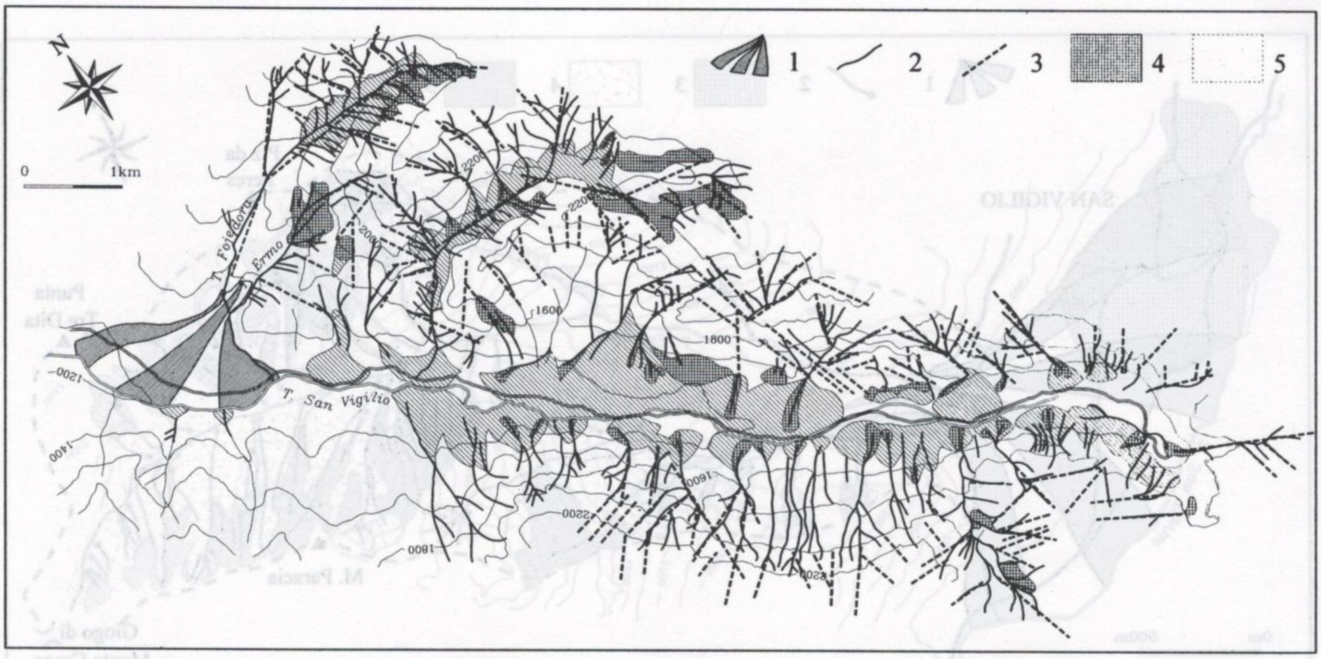

Fig. 3: Location of the debris torrents and main lineaments in the Rudo and Fojedöra Valleys. 1) Alluvial fan; 2) Debris torrent; 3) Fracture; 4) Active debris cone; and 5) Stabilized debris cone

evening, a violent storm with heavy rainfall and hailstones, originating at Piz da Peres and Monte Paraccia, caused a debris torrent that, as it descended along the courses of the Fojedöra–Ermo, was only just contained by the dyke and temporarily obstructed the torrent San Vigilio and the road of the valley bottom as well as damaged a wide pastureland.

ANALYSIS OF THE DEBRIS TORRENT OF 27 JULY 1995

The study of the event of 27 July 1995 was carried out in the summer of 1996. Therefore, some information was undoubtedly missing (e.g. the finer fractions of the transported material). It affected the precise estimation of the total transported volume. On the other hand, this study may be an example of how much reliable information can be collected in the field, even after a time lapse of months or years. Of paramount importance during the collection of data was the help offered both by the inhabitants of San Vigilio, who were eye witnesses of the event, and the Corps of Foresters, who provided equipment, information, and documents of the event.

Precipitation analysis

The climate of the area is affected by the disturbances coming from the Atlantic Ocean, the Mediterranean, and the cold regions of Russia. Normally, the heaviest rainfall is recorded during the summer or late springtime. Fig. 4 shows the mean monthly precipitation recorded by a weather station situated a few km from San Vigilio, for the period ranging between 1921 and 1980. The records of the station of San Vigilio, which exist, however, only from 1984 onwards, lead to the same conclusions.

For San Vigilio, the month of July 1995 was rather hot, with seasonal temperatures slightly above the mean. As far as the precipitation is concerned, storms occurred during the first three days of the month, and then again in the week of 10–17 July. During the remaining days, the temperatures were very high, which allowed the ground to dry out completely. On 26 July, there was a brief storm and, finally, on the 27th at 7 p.m., while in the village it had not rained at all, on the slopes of Piz da Peres and Monte Paraccia a violent storm arose with hailstones, but, naturally there was no trace of this in the data collected on San Vigilio. Towards 8 p.m., the inhabitants of the village heard a loud boom and at the same time the torrents of Ermo and Fojedöra deposited a great quantity of debris in the valley bottom, dragged down the bridge of the road to the Natural Park of Fanes–Sennes–Braies, and obstructed the torrent San Vigilio. The whole event did not last longer than half an hour. In a few hours, a small lake had formed on the valley bottom that would have overflowed if had there not been timely intervention with scrapers (Plate 2).

Description of the course of the debris torrent

The study of the course of the flow was carried out by constructing bed cross-sections, chosen at the places where there were visible changes in the inclination or the width of the bed itself. The samples for grain size analysis were also collected from the same places (Fig. 5).

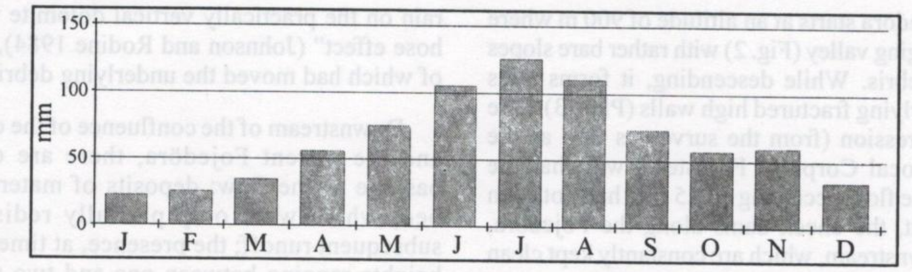

Fig. 4: Mean monthly precipitation for a period of sixty years

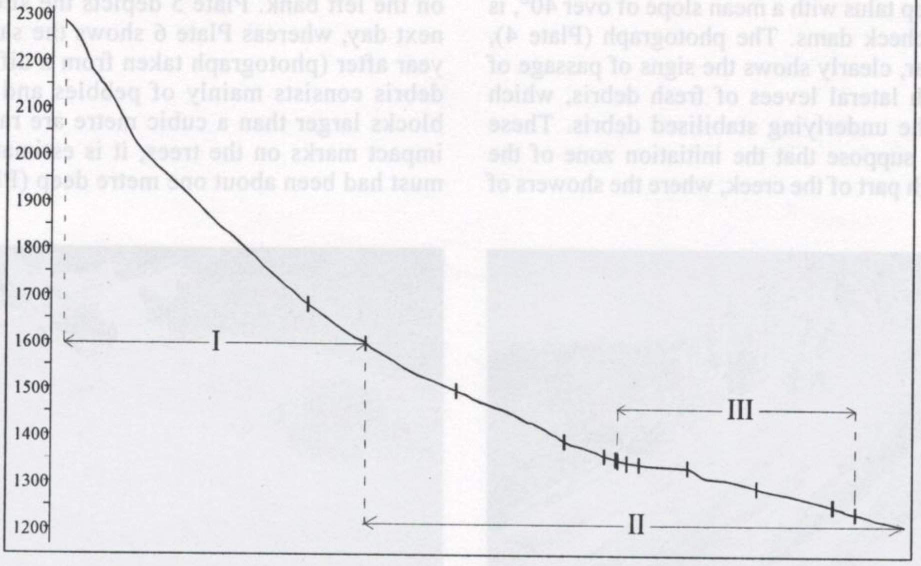

Fig. 5: Longitudinal profile of the creek Piz da Peres and the lower course of the torrent Fojedöra. The vertical segments mark the points where the samples were taken. I) Creek Piz da Peres; II) Lower course of the torrent Fojedöra; and III) Course of the torrent parallel to the dyke

Plate 2: View of the lake formed after the debris torrent deposition. The final reach of the torrent Fojedöra is seen in the background.

The torrent Fojedöra starts at an altitude of 900 m where it forms a small hanging valley (Fig. 2) with rather bare slopes on the dolomite debris. While descending, it forms talus cones from the overlying fractured high walls (Plate 3). One year after, the impression (from the survey as well as the testimony of the local Corps of Foresters) was that the initiation zone of the flow occurring on 25 July had not been in this area. In fact, the check dams along the Fojedöra, located slightly downstream, which are constantly kept clean by the staff of the "Bacini Montani" of Bolzano, were practically devoid of new debris the day after the event.

The situation was very different along the creek (descending from Piz da Peres), which being completely positioned on a deep talus with a mean slope of over 40°, is not stabilised by check dams. The photograph (Plate 4), taken after one year, clearly shows the signs of passage of the flow with high lateral levees of fresh debris, which accumulated on the underlying stabilised debris. These findings led us to suppose that the initiation zone of the flow was in the high part of the creek, where the showers of rain on the practically vertical dolomite walls had a "fire-hose effect" (Johnson and Rodine 1984), and the violence of which had moved the underlying debris.

Downstream of the confluence of the creek Piz da Peres and the torrent Fojedöra, there are evident signs of passage of the flow: deposits of material in the stream bed, which were only partially redistributed by the subsequent runoff; the presence, at times, of levees, with heights ranging between one and two metres, either on one or both sides of the banks; and lobe deposits by the flow outside the torrent bed. In particular, at an altitude of 1,355 m, following the tangent of a bend that the bed makes towards the right, the flow had invaded the fir forest on the left bank. Plate 5 depicts the site situation of the next day, whereas Plate 6 shows the same situation one year after (photograph taken from a different spot). The debris consists mainly of pebbles and gravel, whereas blocks larger than a cubic metre are rare. Based on the impact marks on the trees, it is estimated that the flow must had been about one metre deep (Plate 7).

Plate 3: Debris cones in the upper reaches of the torrent Fojedöra

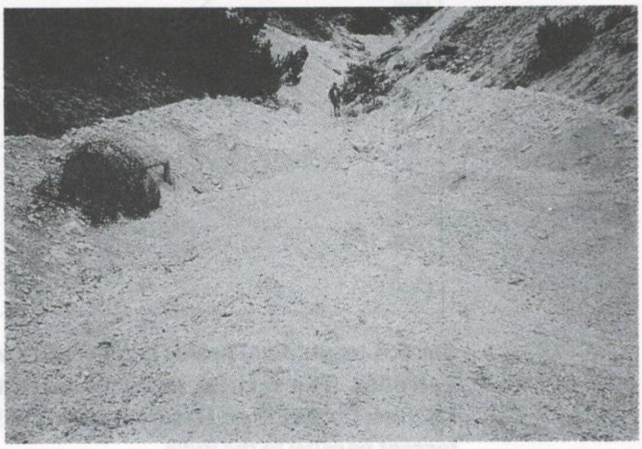

Plate 4: Levees left by the debris torrent in the creek Piz da Peres

Plate 5: The fir forest invaded by the debris torrent. Photograph taken the day after the event

Plate 6: The same as Plate 5, but taken from another spot a year after

A dyke begins at an altitude of 1,340 m and it diverts the torrent Fojedöra leftwards. Here, most of the material was deposited against the dyke itself. The velocity of the flow was such that a small part of the debris was able to pass over the dyke to invade the outer fir trees growing on the alluvial fan (Plate 8). One year after, there was practically no trace of the debris that had accumulated against the dyke as well as that which obstructed the San Vigilio, since it had been removed and used as building material.

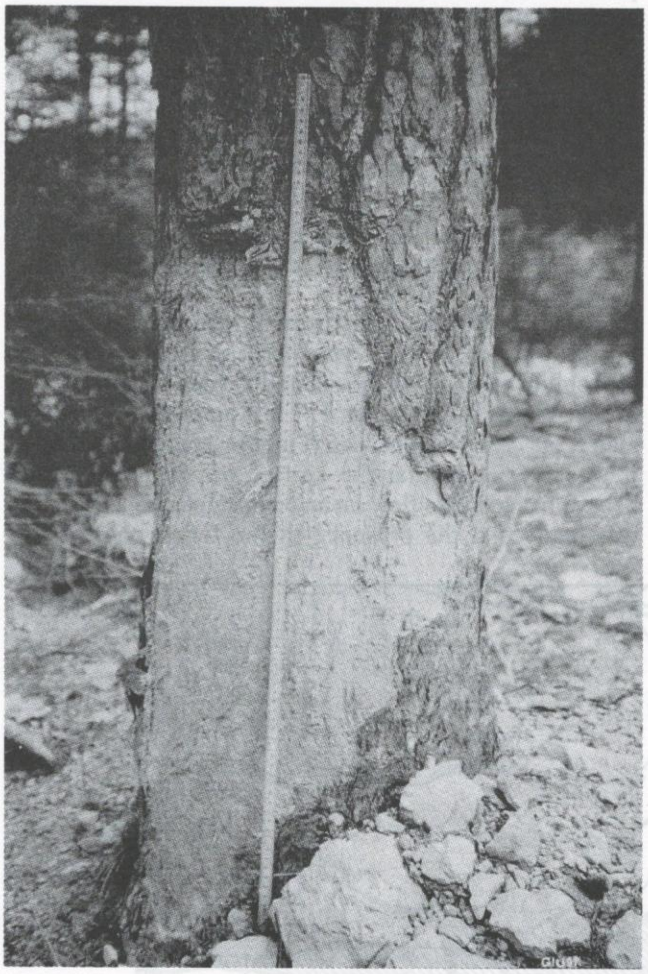

Plate 7: Barking of a tree by the impact of the debris torrent

Grain size distribution analysis

In order to identify the difference in the grain size distribution among the various types of deposit (eliminating the uppermost part, which had been washed away by the subsequent precipitations), samples (ranging between 10 and 12 kg) of levees and lobes were taken. All the samples were finer than pebbles, as was observed for practically the whole length of the Fojedöra. Fig. 6 shows the grain size distribution curves for each type of deposit, whereas the results are summarised in Table 1.

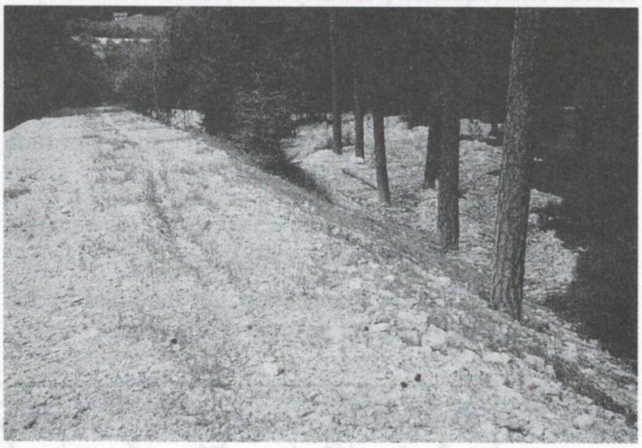

Plate 8: Debris overflow beyond the dyke. The torrent Fojedöra is to the left of the dyke.

Table 1: Grain size distribution of the debris deposits

Deposit	Gravel (%)	Sand (%)	Silt-clay (%)	D_{50} (mm)
Lobe	70–100	0–23	0–4	8–19
Levee	72–100	0–34	0–0.5	4.5–25.5

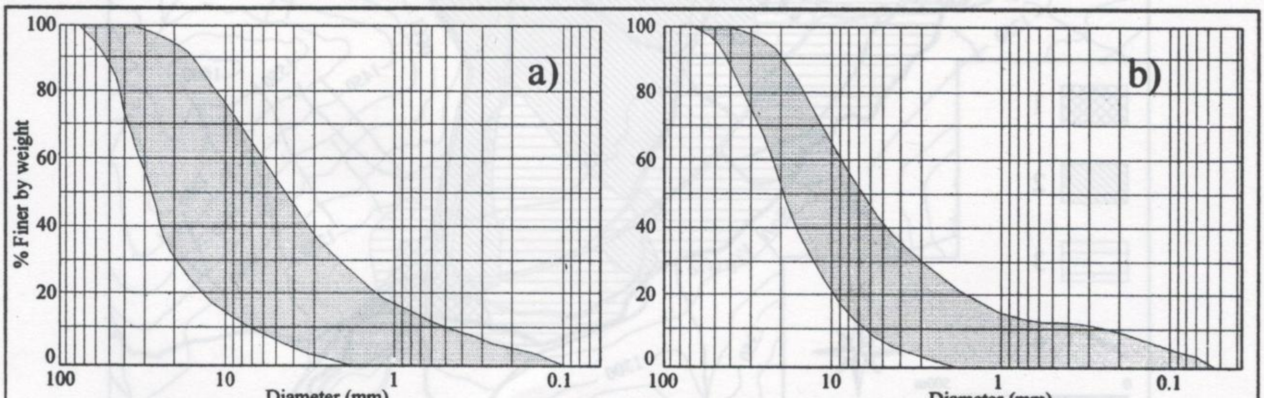

Fig. 6: Grain size distribution of the levees (a) and the lobes (b)

As may be seen, the levees present a more evident variation in the fractions. The most representative particle size is the gravel in both types of deposit, although it can not be excluded that the lack of finer material is partly due to the time lapse between debris deposition and the sample collection.

Field estimates of velocity

Assessment of velocity of a debris torrent may be carried out on a section, which corresponds to a bend in the torrent bed. The centrifugal force, in fact, is such that the external part of the flow is raised compared to the internal part, often leaving traces on the banks, which allow us to apply the forced vortex equation (Aulitzky 1989; Jacob et al. 1997):

$$v = (gRh/w)^{0.5}$$

where v = velocity of the flow, g = gravitational constant, R = radius of curvature of the streambed, h = superelevation of the flow, and w = width of the flow.

The assumptions to be made which render the equation valid are as follows (Jacob et al. 1997):

- the shape of the channel was not modified by the events following the passage of the largest surge;
- the two mud or gravel-lines found on the respective banks were marked by the same part of the maximum surge; and
- the bend geometry was smooth and regular enough to avoid or reduce the shock waves.

At the time of the field survey, the superelevation phenomenon could be seen in the flow bend in three different sections, and the application of the aforementioned equation yields the results presented in Table 2. As may be seen, the values obtained are compatible with the data reported in the literature, which give velocity variables ranging between 3 and 12 m/s for debris torrents, with peaks reaching up to 20 m/s for mud flows (Seminara and Tubino 1993).

ANALYSIS OF HAZARD OF A FLOW UNCONTAINED BY THE DYKE

Since, part of the debris torrent spilled over the dyke in the event of 1995, it was necessary to evaluate the probability of arrival of the unconfined debris at the village of San Vigilio in the future. For this purpose, a vegetation map (Fig. 7) and a slope map (Fig. 8) were prepared. Since it was presumed that the spilled out material would behave like a debris flow on an open slope, the assumption was made that the presence of the forest could block

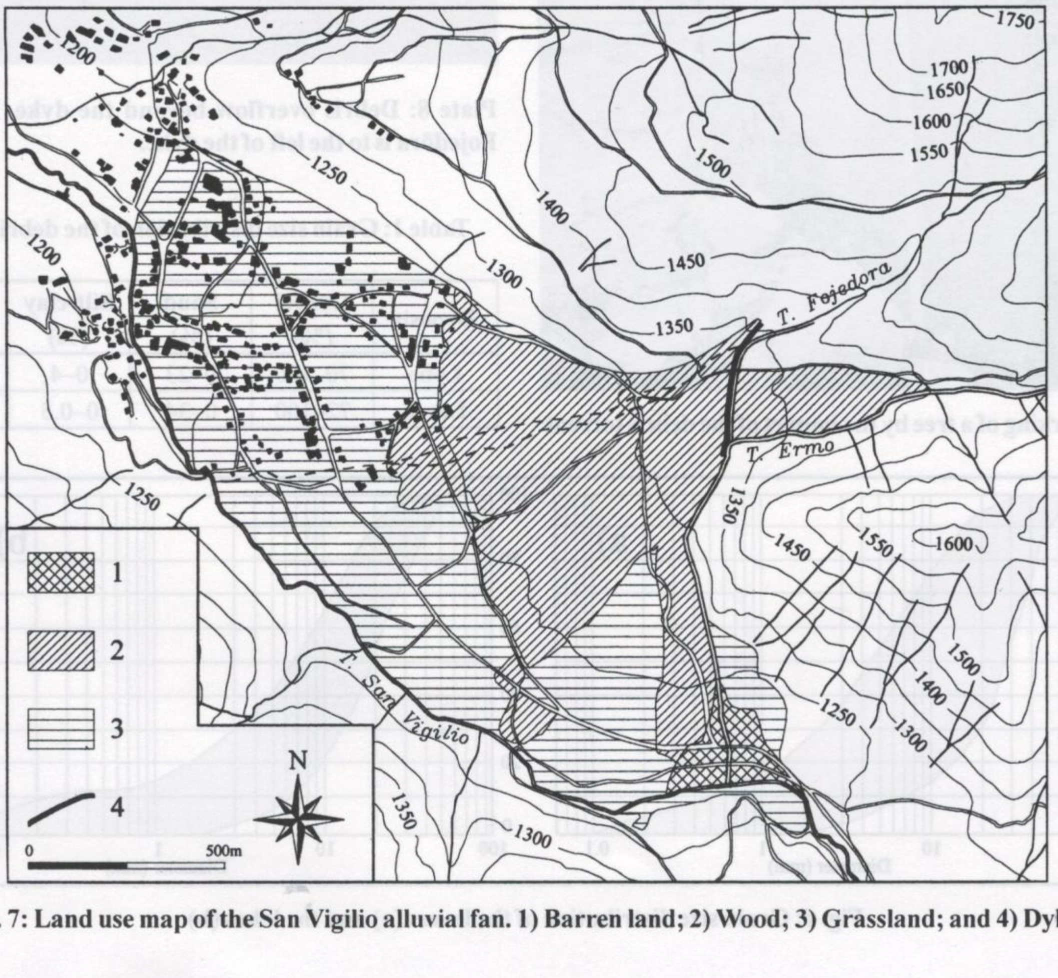

Fig. 7: Land use map of the San Vigilio alluvial fan. 1) Barren land; 2) Wood; 3) Grassland; and 4) Dyke

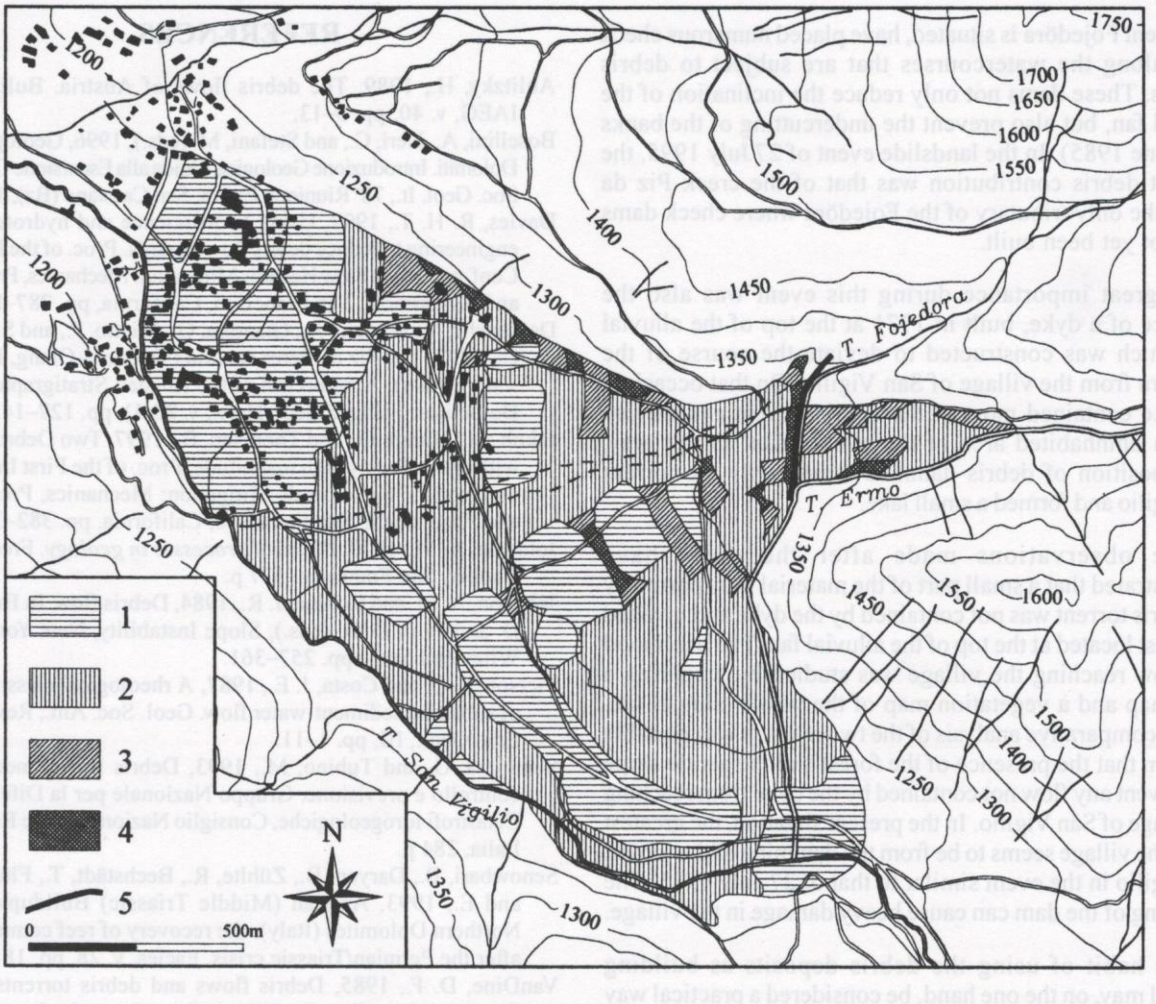

Fig. 8: Slope map of the San Vigilio alluvial fan. 1) < 5°; 2) 5° – 10°; 3) 10° – 15°; 4) > 15°; and 5) Dyke

Table 2: Maximum velocity values obtained in three different sections by applying the forced vortex equation (Aulitzky 1989; Jacob et al. 1997)

Elevation (m)	r (m)	h (m)	w (m)	v (m/s)
1355	50	1.4	9	8.73
1320	200	0.5	10.5	9.66
1290	250	2	16.7	17.14

the flow of the debris, just as a very gentle (less than 10°) slope allows deposition (VanDine 1985).

The analysis of vegetation revealed that the fir forest extends over an area of 0.8 km², corresponding to 34% of the entire alluvial fan. To be more exact, the forest is situated on the highest part of the alluvial fan, just behind the dyke. Therefore, it is believed that, even if the forest is not very dense, its presence may block the passage of a debris flow.

Most of the alluvial fan has the slope angle between 5° and 10°, which also favours the debris deposition. The village of San Vigilio is located mainly on a slope below 5°. The areas with gentle slopes surround a few places that have slopes steeper that 10°. Therefore, any possible debris flow beyond the dyke would most likely come to a halt before reaching the village.

CONCLUSIONS

The study intended to report an event of channelled debris flow or debris torrent, by placing it in the context of predisposing and triggering factors, and evaluate the possible risk to the village of San Vigilio, which was built on an alluvial fan periodically invaded by debris flows. The predisposing causes were most definitely identified in the presence of a large quantity of debris, which forms large and deep deposits with rather steep slopes, often over 35°.

The most important triggering factor of the debris torrent is the "fire-hose effect" produced by heavy summer showers on the talus which strikes the overlying rocky walls with violence (Johnson and Rodine 1984). The local authorities, which manage the Alto Adige territory, where the valley of the torrent Fojedöra is situated, have placed numerous check dams along the watercourses that are subject to debris torrents. These dams not only reduce the inclination of the alluvial fan, but also prevent the undercutting of the banks (VanDine 1985). In the landslide event of 27 July 1995, the greatest debris contribution was that of the creek Piz da Peres, the only tributary of the Fojedöra where check dams have not yet been built.

Of great importance during this event was also the presence of a dyke, built in 1971 at the top of the alluvial fan, which was constructed to deviate the course of the Fojedöra from the village of San Vigilio. On that occasion, the dyke contained most of the debris torrent and carried it to an uninhabited area of the alluvial fan. In this way, the deposition of debris dammed temporarily the torrent San Vigilio and formed a small lake.

The observations made after the event have demonstrated that a small part of the material transported by the debris torrent was not contained by the dyke and invaded the forest located at the top of the alluvial fan. The likelihood of a flow reaching the village was studied by preparing a slope map and a vegetation map of the whole alluvial fan. From a comparative analysis of the two maps, it was possible to affirm that the presence of the forest and the gentle slope can prevent any flow not contained by the dyke from reaching the village of San Vigilio. In the present situation, the greatest risk to the village seems to be from the damming of the torrent San Vigilio in the event similar to that of 27 July 1995. The breaching of the dam can cause heavy damage in the village.

The habit of using the debris deposits as building material may, on the one hand, be considered a practical way of solving the problem of this debris, which periodically descends from the torrent Fojedöra, but from the point of view of long-term prevention of environmental damage, it may create erosion of the torrent San Vigilio, which would be deprived of an important part of sediment transport (Davies 1997).

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