Geo Factsheet

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AVALANCHES

Introduction

Avalanches are falling masses of snow that can contain rocks, soil or ice. Avalanches are natural phenomena, but become a natural hazard when they interact with people and their surroundings. Avalanches cause deaths and injuries and damage to property. They also impact on transport networks and livelihoods, particularly in tourism.

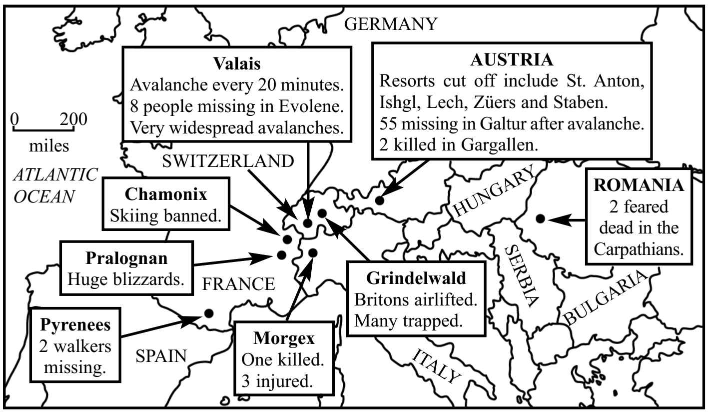
Distribution of avalanches in space and time

Whilst avalanches are widely distributed globally, they are most commonly associated with mountain environments. A number of factors contribute to avalanche formation in mountain areas:

- Heavy snowfall compresses and adds weight to earlier snow falls – especially on windward slopes.
- Steep slopes of over 25° but more usually between 30° and 40° reduce stability. Snow lying on slopes of lower angles tends to be more stable, and is less liable to be triggered off into an avalanche.

Specific weather conditions can lead to a concentration of avalanches, as happened in the Alps in February 1999. *(see Fig. 1)*.

Fig. 1 Avalanche and snow-related incidents in Europe, spring 1999.



Possible trigger factors included:

- a sudden increase in temperature, especially on sunny south-facing slopes, as occurs under Föhn wind conditions (warm compression winds).
- heavy rain falling on snow can lubricate the slope.
- sometimes after a very long cold dry winter (blocking anticyclone)
- as warm Atlantic air meets cold Polar air there is a heavy spring snow fall which piles up as ice to trigger avalanches.
- human factors such as vibrations caused by off-piste skiing or heavy traffic can trigger avalanches as in February 1999.
- deforestation to make way for new ski-runs can also reduce slope stability.

A survey of avalanches in the Alps suggested that February, with 32%, was the commonest season. It might be argued that avalanches will become more frequent when human-induced climate change (enhanced greenhouse effect) could bring increasingly stormy conditions and therefore more snow to Alpine areas. There is, however, little evidence yet to link any changes in avalanche frequency over a long-term scale with climate change.

There are few records for remote mountain environments in which avalanches are most common so we might not have the information on which to base such an evaluation. The increased frequency, if it does exist, may therefore be human-induced.

Physical characteristics of avalanches

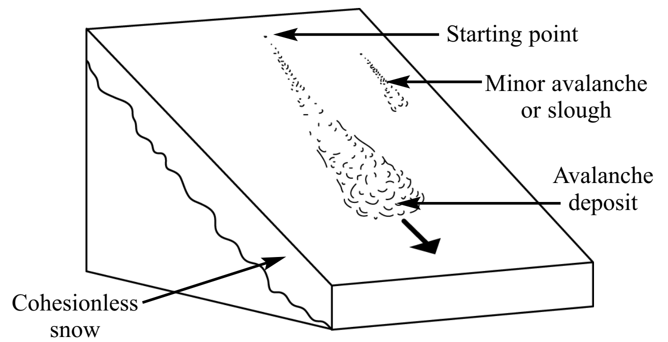
Avalanches result from a combination of geomorphological and meteorological conditions, and result when the forces holding snow on a slope are exceeded by those giving momentum to the snowpack. Avalanches tend to be triggered on slopes of between 30° and 45°. Snow lying on slopes of lower angle tends to be more stable, and snow usually cannot accumulate on steeper slopes.

Avalanches are classified in two main ways: by their **failure mechanism** *(Fig. 2)*, and by the **type of movement** involved.

Fig. 2 Failure mechanisms.

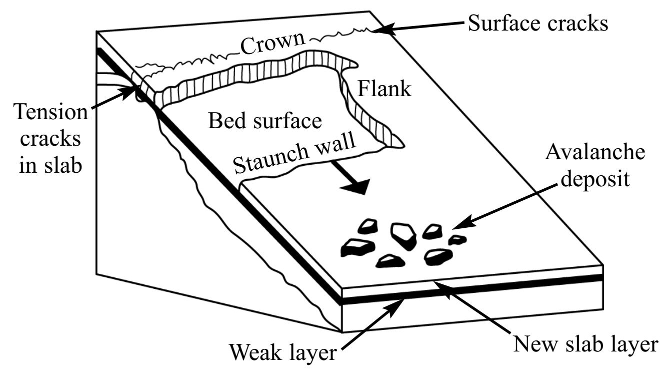
There are two types of failure mechanism:

Loose snow avalanches



These consist of loose powdery snow crystals, when a small amount of snow becomes unstable and "sluffs" downslope, coming to rest a few metres away.

Slab avalanches



Slab avalanches involve large masses of cohesive, strongly bonded snow breaking away from the underlying snowpack. These avalanches can be very large, up to 10m deep and 10,000 m^2 in area, and so create the greater natural hazard. As they move downslope, as much as 100 times the original slab may be incorporated into the movement. The total mass involved may therefore be as much as 10 million m^3.

Three types of movement are recognised:

- ***Powder avalanches***. These move as aerosols, involving fine-grained snow, and behave like a gas. They move very rapidly (between 20m s^{-1} and 70m s^{-1}), and the track which they take can be unpredictable. They are very destructive.

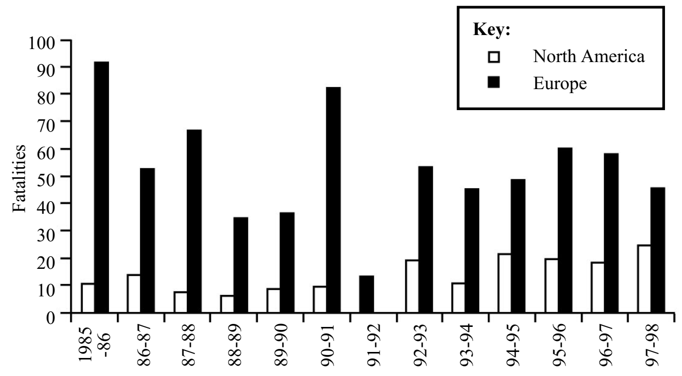
- ***Dry flows.*** These avalanches flow as fluid motion, involving coarser grained snow and can incorporate some blocks of snow. They tend to follow well-defined tracks. Speeds range from 15m s^{-1} to 60 m s^{-1}.

- ***Wet flows.*** These comprise wet thawing snow, and move as dense masses of slush and snow. They follow well-defined tracks, and are relatively slow moving (5m s^{-1}, to 30m s^{-1}). They can be destructive as a result of the large masses involved.

Avalanches as hazards to people
Deaths, injuries and damage resulting from avalanche activity have increased over the last 50 years in all areas of the world. However, the rates of increase vary with each type of impact, and in different localities *(Fig. 3, right)*.

Avalanche deaths and injuries have risen sharply in Europe and North America as a direct result of the increases in winter sports activities. Figures for Switzerland show that on average 40 people die from avalanches each year, over 80% of whom are involved in winter sports. Figures for the United States show much lower death rates (15-20 p.a.), but the proportion of recreational deaths is the same.

Fig. 3 Deaths attributed to avalanches in Europe and North America 1985-98.



Source: *Colorado Avalanche Centre*

Property damage is increasing too, as pressure to expand villages and recreational facilities in mountain areas increases. Annual property losses for the USA are about $1 million, and for Switzerland about $20 million. These figures are not a true estimate of the actual total cost of avalanche damage, since indirect costs (damage to local tourism activity, transport delays, etc) will increase the total by several times.

As winter sports activities increase and climate changes, we may see increasing rates of death and damage over the next few decades.

Case study 1: The Galtur avalanche.
The Galtur avalanche in Western Austria (February 1999) was one of the most destructive events in recent years. It was a powder avalanche which began moving high on the slopes above the village. Snowfall in the preceding days had exceeded all records and at the time more than 4m of snow lay on the slopes.

It is estimated that 170,000 tonnes of snow were involved in the initial movement. As the mass moved downslope it reached speeds in excess of 80m s^{-1}, and incorporated more than twice the original mass before hitting the village. The leading edge of the avalanche was more than 100m high when it struck with terrifying force.

Concrete buildings were flattened, filled with choking powder snow, and wooden structures shattered like matchwood. 31 people were killed and seven modern buildings destroyed.

Fig. 4 shows the sequence of events associated with the massive Galtur avalanche. Table 1 shows the potential effects of avalanches. Galtur could be regarded as large on this scale.

Table 1 The potential effects of avalanches.

Size	Potential effects	Order of magnitude estimates: Vertical descent	Volume (m^3)	Occurrence Frequency
Sluffs	Harmless	< than 10m	1 – 10	10^4 per year
Small	Could bury, injure or kill a person	10 – 100m	10 – 10^2	10^3 per year
Medium	Could destroy a timber-frame house or car (localised damage)	100 – 500m	10^3 – 10^4	10^2 per year
Large	Could destroy a village or forest (general damage)	500m – 1km	10^5 – 10^6	One per decade
Extreme	Could gouge the landscape (widespread damage)	1 – 5km	10^6 – 10^9	Two per century

Fig. 4 News from the Galtur Avalanche.

20th January 1999
A sequence of three severe storms brought warm Atlantic air which on meeting with Arctic air led to very heavy 5m deep snow. Winds if 120km/hr piled snow up in the mountains.

23rd February 1999
A wall of snow 5m high smashed through the centre of Galtur just after 4pm. It crushed cars, hurling them across roads. Many houses were completely buried. The snow and ice cleanly sliced off the top of one building. Snow was still falling heavily at night, with another 50cm expected by morning.

24th February 1999
The avalanche which hit Galtur last night is reported to have killed at least 8 people, with up to 30 others missing. Residents managed to dig out alive about 20 people, although several of the survivors were said to be in a critical condition. Outside help could not at first reach the town as the main road had been blocked by an earlier avalanche, and bad weather prevented helicopters from flying in.

25th February 1999
The death toll from Tuesday's avalanche was put at 16, with 29 people still missing. Austrian television showed scores of rescuers using either long metal probes or specially trained sniffer dogs in an attempt to detect survivors buried under masses of snow. A steady stream of helicopters took pallets of fresh fruit, vegetables and other foodstuffs into Galtur, returning with survivors and tourists. Estimates suggest that 2,500 tourists had been helicoptered out of town.

27th February 1999
Rescuers today recovered the body of a German girl believed to be the last of 38 people killed by Tuesday's avalanche. Roads to the town were open for the first time in over a week. Weather forecasters said the threat of further avalanches was diminishing as higher temperatures had reduced the amount of snow on mountainsides. Officials in Galtur claimed that $20 million had been spent on avalanche protection structures. Local records showed that the town had been destroyed by an avalanche in 1689 when 250 people were killed.

Mitigation measures

Avalanches clearly represent a significant hazard in some parts of the world, and the frequency and size of impact may be increasing. What can we do to minimise the impact?

Several measures are currently used:

- Since the majority of deaths occur amongst recreational skiers, snowboarders etc. restricting such activities at times of high risk is a clear priority. This can be done by **closing avalanche prone slopes**, issuing warnings and so on. However, this depends on expert knowledge of the snow conditions, daily **monitoring** of dangerous slopes, and those concerned having confidence in the accuracy of warning systems.

- An alternative strategy, which is commonplace in many mountain recreation areas, is to **trigger small avalanches** under controlled conditions before the snowpack builds to a dangerous state. These 'artificial' avalanches are usually triggered remotely by small explosive charges fired from a large gun, or emplaced by skiing wardens. This system is commonly used in Whistler, British Columbia, at the beginning of each skiing day.

- **Controlling avalanche activity.** Several measures are used to control avalanches. Stabilising the snow pack in the starting zone is one solution. This prevents the snow pack achieving the momentum to begin to move. Planting trees and building snow fences are two common strategies. Other measures may be used to deflect avalanches away from buildings or to slow the rate of movement, thereby reducing the destructive force *(Fig. 5)*.

  The purpose of the structures in the accumulation and starting zones is snow retention; the purpose of the structures in the track and run-out zones is avalanche deflection. Only one or two devices are likely to be in place in a particular avalanche-prone locality.

- At the largest scale, **planning** where and where not to build in mountain areas is clearly critical to minimising damage to buildings and infrastructure. However, such planning must be a) based on accurate records of previous avalanche activity, and b) reinforced by legislation and punishment for infringing the planning laws.

  Despite careful planning, sometimes avalanches still catch communities out. A prime example of this was the Galtur avalanche which struck the village of that name in Austria in 1999. The avalanche which struck far exceeded anything in the historical records on which plans had been based, and killed 31 people in the village.

  Enforcing legislation has been a problem in the United States, where planning laws are not as easily enforced as in Europe. This can lead to speculative development in mountain areas known to be at risk from avalanches.

  In many areas a system of zoning occurs *(see Fig. 6)*. Buildings and transport routes can be designed to withstand avalanche impact when no alternative locations can be found.

Fig. 6 An example of the zoning system used in Switzerland.

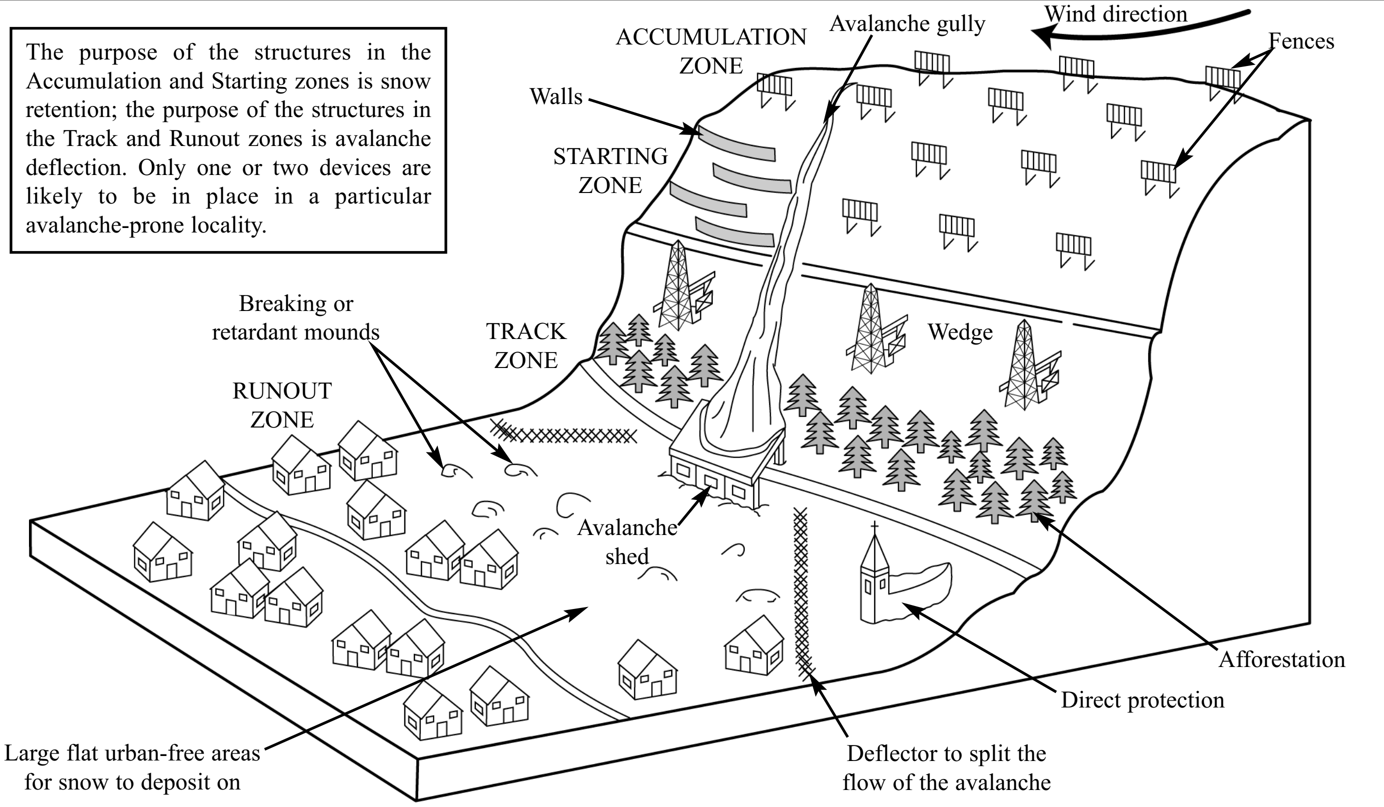
High-hazard (red) zone
- *Any avalanche with a return interval of less than 30 years.*
- *No buildings or winter parking lots allowed – special bunkers needed for equipment.*

Potential-hazard (blue) zone
- *Avalanches with return intervals of 30 – 300 years.*
- *Public buildings that encourage gatherings of people should not be erected. Private houses may be erected if they are strengthened to withstand impact forces. The area may be closed during periods of hazard.*

No-hazard (white) zone
- *Very rarely affected by avalanches. Return interval greater than 300 years.*
- *No building restrictions.*

Fig. 5 Measures to mitigate (reduce the impact) of avalanches.

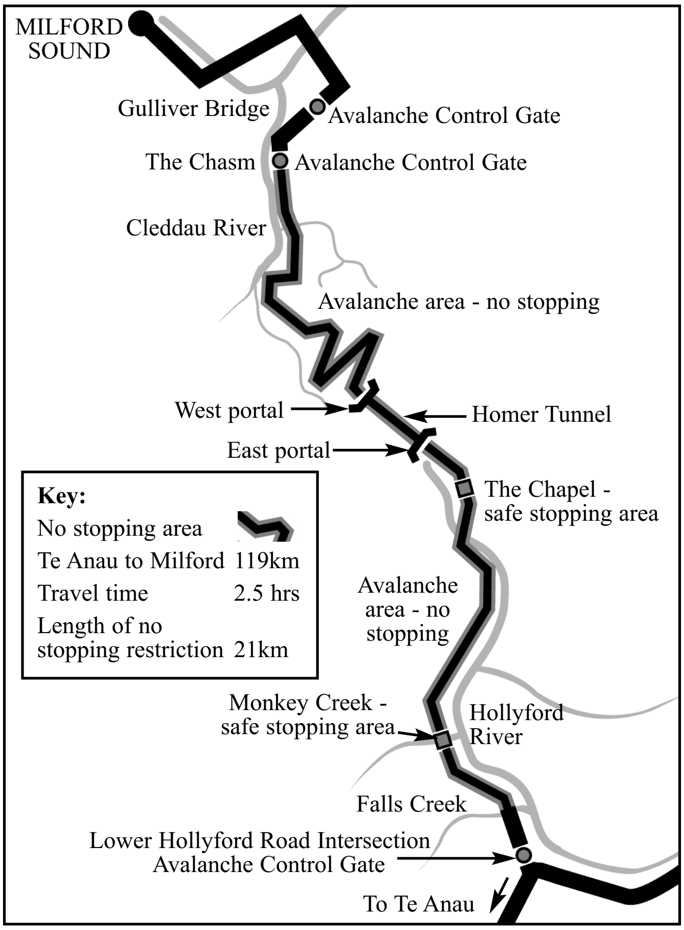
The purpose of the structures in the Accumulation and Starting zones is snow retention; the purpose of the structures in the Track and Runout zones is avalanche deflection. Only one or two devices are likely to be in place in a particular avalanche-prone locality.



Case Study 2: The road to Milford Sound in New Zealand.

The Milford road (Fig. 7) is one of the highest Alpine roads in New Zealand and provides the only vehicular access link to Milford Sound, an outstanding 'fjord' tourist attraction in Southern New Zealand. The avalanche zone along the road extends for 21kms, with frequent avalanches from the Holly Ford and Cleddau Valley (see Fig. 7). As can be seen from Fig. 7, the road management involves a combination of control gates to close the road, areas of no stopping and safe stopping areas for people to rest and take pictures.

Fig. 7 The road to Milford Sound.



The Avalanche Programme is necessary so that the road can be kept open year round to permit all-year-round tourism and fishing. The case study shows how avalanche management is the key in this area. The programme relies on ***prediction*** *based on very detailed* ***monitoring****. The specialist avalanche control team predicts the avalanches using a three-point scale (see Table 2).*

Table 2 Avalanche Hazard.

Avalanche hazard	Probability of avalanches	Precaution
Low	Unlikely	When a low avalanche hazard is posted, the road is open.
Moderate	Possible	There is a risk of avalanches reaching the road and the road could be closed at short notice.
High	Expected	The road is closed.

The avalanche hazard is the prediction of the probability of avalanches occurring and is expressed as a level of danger. You must consider this before entering the avalanche area.

The avalanche hazard forecast is compiled from information that includes:
- *existing avalanche start zones snow-pack conditions (snow pit studies).*
- *current weather data (from automated roadside and high-level weather stations which provide data from mountain tops.*
- *predicted weather forecast – to forecast new snow or high winds.*
- *local knowledge and observation via rangers etc.*

Avalanche ***control*** *is carried out in two ways:*
- ***Passive control*** *involves not allowing traffic to stop inside the avalanche area (see map) with mandatory advice to fit chains in the avalanche area.*
- ***Active control*** *is achieved by helicopters placing the explosives from above, in the avalanche start zone, to release avalanches before they occur naturally. This happens in high-risk periods which leads to the closure of the road.*

Driver education is key with advice leaflets on 'Before setting out on the road' and 'What to do in an avalanche emergency' encouraging a responsible attitude amongst road users.

Exam Question

With reference to named examples of an avalanche event explain how both physical and human factors contributed to the disaster. *(10 marks)*

Answer Guidelines

Use Galtur to identify factors such as meteorological conditions and local geomorphological conditions. Human factors such as trigger actions of high-level skiers, deforestation or speculative building in risk zones may also be significant.

Further research

BBC 1999 The Galtur avalanche. Horizon, November 1999.

McClung, D. and Schaerer, P. (1993) The avalanche handbook. The Mountaineers/ Cordee, Leicester, England.

Useful Websites

www.lawine.org This is a European website, giving access to other specific organisations responsible for avalanches in the Alps. Some of these sites include webcam coverage of active avalanche sites.

www.avalanche.org This is a North American site, covering all aspects of avalanches in the American Rocky mountains.

www.pbs.org/wgbh/nova/avalanche/html This excellent site covers many aspects of avalanches, including some video imagery.

Acknowledgements

This Factsheet was written by Dr. David Croot, who lectures in physical geography at the University of Plymouth.

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