

## Landslides

### Water and gravity in action

Very punctually, with the arrival of the spring and autumn precipitations, the topic of landslides in our country returns. Landslides are a destructive phenomenon that cause damage to man made structures, often causing victims among the population and practically always causing often irreversible, dramatic modifications in the landscape. But what exactly are landslides? What are the causes of landslides? How can man defend himself from Nature? Can we do something to monitor them and keep them under control?

#### ***Landslides and landsliding***

**Landsliding** is a phenomenon in which rocks of different sizes or loose earth detach and move downwards. A landslide is the result of landsliding and consists of all the fallen material. The detachment and the movement of materials are due to one, very simple cause, that controls all our actions and movements: gravity. In Nature, two fundamental forces are opposed to gravity: friction and cohesion. Friction is the resistance that an object (a small pebble, a big mass, a house, part of a mountain) opposes to the force of gravity, that tends to drag it as far down as possible, while cohesion is the force that 'keeps together' particles (crystals, granules, bricks, layers of rock) that make up an object or a material. 'Geological' objects (masses of earth, layers of rock, sides and walls of mountains) are in a situation of delicate equilibrium between these forces: when gravity prevails over the other two, then the object, or the rocky mass, will move downwards. Many factors can interfere, naturally or due to man's intervention, to disturb this delicate and unstable equilibrium, either modifying the friction or the cohesion of the material or influencing the force of gravity by varying the weight of the material. The kind of movement and its speed, the volume of the material and the possible premonitory signs depend on just these factors. It is for this reason that it is difficult to classify the different types of landslides and even harder to try and foresee and prevent them. On many of these factors man has no control, but many of them, instead, derive from human activities, and it is on these that we can intervene to reduce the risks of landslide events and to limit their damages. As in the case of seismic risk, even landslide risk cannot be eliminated, but unlike earthquakes, on which we have no control and to which we can only react by limiting their potential damages as much as possible, many landslide events are more or less indirectly produced by man, so that in this field we have a wide margin of action as far as prevention is concerned.

### Causes

Even though gravity is the main 'motor' of landslides, there are numerous factors, mainly of geological and climatic origin, that make a soil or a mountain more liable to landsliding: these are the so-called predisposing factors. Among these, of particular importance are the geological nature of the material (the kind of rock, its resistance, if it is made up of coherent material like rock or loose material, like a sediment or soil), if it is fractured or modified – this would influence its resistance (intuitively, compact rock without fractures will have a greater resistance than a heap of stones made of the same material), but also the gradient of the slope on which they are situated plays an important part (even to those who are not geologists it is clear that a vertical wall of bare rock is potentially more dangerous than a gentle slope covered with soft grass...but this isn't always true, appearances can be deceptive!).

All these factors make some areas more hazardous than others, but usually for a landslide to occur, 'something' has to happen to disrupt the delicate equilibrium. The conditions that bring about a landslide are those that occur, at times unpredictably, and modify the equilibrium thus acting as a 'detonator' of a sort of geological 'time bomb'. Among the different triggering causes, the most tragically well-known are those connected to heavy and long-lasting rainfall, that bring about a reduction in friction and cohesion and an increase in the weight of the material. The phenomenon is more evident when landslides and land instability are the immediate consequence of long and violent precipitations, but the same cause can work in a hidden and secret way: an example is water infiltration on the bottom and sides of an artificial basin (this occurred in 1963 in the well-known disaster of the Vajont dam, for example). Even the melting of snow can

produce great quantities of water that saturate the soil making it unstable, as happened recently in Calabria.

Sudden movements, as in the case of an earthquake, can destabilise sides and masses of rock; it is for this reason that earthquakes and violent volcanic eruptions are often accompanied by landslides. Slow tectonic upward movements, however, can produce the same effect, probably even more insidiously.

Thawing phenomena can cause landslides and mud flows or the detachment of blocks of rock, because the cohesion provided by ice, that keeps materials together, disappears : this phenomenon can clearly be seen at high altitudes in the mountains or in permafrost areas.

Even phenomena of fluvial erosion at the foot of the mountain sides can start off landslide processes: ablation of material at the base, in fact, makes the masses on top unstable.

Unfortunately most of the triggering causes that provoke landslides are of anthropic origin: the increase in weight on one side of a mountain due to big and heavy constructions, uncontrolled deforestation that reduces the cohesion provided by the roots of trees, or, on the contrary, reforestation with unsuitable plant species (that are too heavy or their root system is unsuitable), the construction of roads and tunnels that 'cut' the mountain sides, the cementing of river-beds leading to accelerated erosion along the unprotected banks...the list could be even longer without taking into account the fact that among the 'natural' causes mentioned earlier, man can make his own contribution, like in the afore-mentioned case of water infiltrations or triggering subsidence phenomena connected to excessive exploitation of the water-table. There are some types of clayey soil, fortunately quite uncommon, and not present in Italy, that have the unique characteristic of 'becoming liquid', behaving like a very dense liquid when subjected to abrupt stimuli (behaving a bit like quicksand): in Scandinavia, where these soils are quite common, serious cases of landslides have occurred due to the vibrations created by the passing of a train that literally 'liquefied' entire hills!

## Many processes, many types

The conditions and causes for a landslide are so many and so varied that there are many different types of landslides. Their classification is, therefore, very difficult and complex. They can, however, be divided into (not taking the volume of the moving material into consideration):

- **falls:** these occur on rocky mountain slopes with the detachment of blocks of rock, like those taking place on many mountain tops in the Dolomites at present, and the one that took place a few months ago in the town of Fiumelatte, on Lake Como: these landslides are not very dangerous, because usually the volume of material is small, but they rarely give warning signals since the detachments are always sudden (even though, it must be said, the conditions of the sides or of the slopes can offer many clues regarding the probability of the phenomenon);
- **slides:** the volume of moving material of these landslides can be very big; they slide along a surface that can be relatively flat, like a stratified layer of rock, like in the famous 'marocche' of the Adige river valley, or a concave surface, in which the material follows a rotational movement;
- **flows:** loose material, like debris, soil, clayey terrains and volcanic ashes that easily absorb water can bring about flows, in which the materials flow downhill like a very viscous fluid. The movement can either be that of a slow flow towards the valley or take place in such a rapid and very violent way that they have earned the name of 'rock or debris avalanches'.

In between flows and floods there are a particular type of landslides known as debris flows or mud flows, that involve materials which are greatly saturated with water; these are particularly dangerous because of the speed at which they move and the extensive damage caused by the passage of the material: on our mountains, these phenomena build up

alluvium cones at the mouth of small and big valleys. Furthermore, because of their elevated position and the fact that they receive more sunlight than the surrounding lands, the areas on these cones have been greatly anthropized even though they are extremely dangerous, as can be seen, for example, driving through the Valtellina area.

During explosive volcanic eruptions, that produce a great amount of loose material, specially fine ashes, after strong rainfall or the melting of snow at the top of the volcano, often dangerous mud flows may be triggered off, the so-called lahars, that are particularly destructive because of the speed of the moving material (for example, in 1985 in Columbia, on the occasion of the eruption of the Nevada de Ruiz volcano).

### ***What a landslide looks like***

Even though a landslide often appears to be a very rugged and complex area, usually the scar is clearly visible, bounded by the scarp that marks the area where the detachment of the sides has taken place, often crowned and surrounded by fractures and cracks that have opened uphill and by a slump block made up of accumulated material. Whatever the kind of landslide, usually the latter is an irregular topographical area, with numerous depressions, often with a 'toe' that spreads at the base covering the terrain on which the landslide has slipped. It is very important to be able to recognise the shape of antique landslides because generally these phenomena tend to be repeated in time since the geological characteristics of the materials do not change.

### ***Fast and slow movements***

Landslides are often characterized by sudden movement, often at great speed, in which great masses of material are dragged downhill. These are surely the most dangerous landslides, because they rarely give the affected populations time to get out of danger. However, there are other movements that are very slow, which imperceptibly influence the lives of human beings, and are inexorable and unrelenting. Often they involve enormous masses of rock, at times, entire mountains, and take the name of deep-seated gravitational slope deformations. Usually, in the short term, they produce only small damages, like the opening of fractures and trenches and the deformation of the land, but they can be responsible for the triggering off of other types of landslides in areas inclined to these phenomena: connected to the deep gravitational deformations, therefore, there can be rockfalls and debris flows. In addition to this, the great volume of material that imperceptibly, but inexorably, slides downhill can cause serious damage to man-made infrastructures. An example of this can be found in the tunnels of the modern highway that connects Lecco to Valtellina: the slopes of Mount Legnone are sliding towards Lake Como causing continuous deformations of these tunnels and it is very difficult to solve this problem, as the solution would be to support the whole mountain!

## **How the Italian territory is affected**

Italy is one of the countries with a high risk as far as landslides are concerned. This derives from the geological characteristics of our territory. In the first place, as much as 77% of our territory is made up of mountainous and hilly areas, this is a destabilising factor in itself. In addition, the territory is geologically young and very active, with many areas presently rising, like many parts of the Alps and Apennines, and with numerous volcanic areas with high seismic risk, all conditions that increase the risk of landslides. To add to this, vast areas are covered by recently formed loose deposits, often of clayey nature, as in many areas of the Apennines; these materials are very sensitive to both the pull of gravity and to imbibed meteoritic waters, therefore, they are a natural characteristic of our country, rooted in its geological history. However, the disquieting news of current or feared landsliding events increases constantly year by year. This does not necessarily imply that the number of land slides is increasing: it is the number of landslides that are reported that is increasing and these hit the headlines of the newspapers as the anthropic pressure on the territory is constantly increasing. The areas that are inhabited on permanent basis have increased. These were once used for agriculture and sheep farming. There is also an increased interest in the high mountain areas for tourism, while on the other hand all maintenance and environmental recovery activities have been abandoned, such as the controlled felling of trees in the woods and the cleaning of the torrent beds. Unfortunately we are losing a precious heritage of farming culture and wisdom: even though they did not have many opportunities to study or use sophisticated testing instruments, our grandfathers had a deep-rooted knowledge of the mountains, and the old "malghe" as the shepherd's huts in the

mountains are called in the Alps, or old farmhouses were rarely to be found in dangerous positions with the risk of landslides and floods.

With the exception of the Po valley, the Puglia and Sardinia regions, all the Italian regions are exposed to the risk of landslides, and with the constant expansion of urban settlements, the municipalities that are exposed to the risk of landslides are constantly increasing.

Consequently it is necessary, in many regions, to comply with the regulations that require a geological and technical survey before planning the towns and dealing with new unauthorized buildings. Also the decision to evacuate, or in more severe conditions, to move entire urban settlements, often has to face much opposition, due to comprehensible economic reasons, and also due to human reasons, unfortunately even in the presence of severe and clear situations of danger. Therefore it is quite clear how a natural situation that is already extremely favourable for severe landsliding phenomena, is further aggravated by anthropic factors.

## Risk or danger?

When studying landslide phenomena, it is opportune to distinguish between the risk that is tied to the probability that an event may occur, and the danger of the event, which instead is tied to material damages that the phenomenon can provoke, and the toll of human lives. Enormous landslides in uninhabited areas modify the landscape irreversibly, but are not particularly dangerous, instead, a single mass that balances on a mountain-side above an urban centre can be very dangerous, even though the volume is small, because it might fall directly on things or people, provoking severe economic and human damages. In general, this is the criterion used when deciding the type of preventive interventions and protections to be carried out in an area that is subject to landslides. Landslides, therefore are not all of the same "value". However it is important, specially in the case of landslides with a large volume, to evaluate all the consequences of the landslide event well, including all possible changes in the landscape and other geological processes. It isn't rare, in fact, that in its fall, the landslide may obstruct a waterway, provoking the formation of a lake, that is generally unstable, and this may consequently cause severe floods if it overflows (as in the case of the Val Pola landslide, in 1987, in Valtellina) or it may provoke an inundation if it falls directly into a natural or artificial water basin (as in the case of the Vajont dam). Some landslides falling into the sea or underwater events, can provoke giant waves or tsunamis, like the one many geologists have foreseen for the collapse of the Cumbre Vieja volcano on La Palma island in the Canary Islands.

## Studying landslides

Often landslides are highlighted in the headlines of the news, described as sudden catastrophic events that occur with no warning signals on the population that is totally unaware of the danger. Actually, due to all the considerations listed above, landslide events are certainly not unpredictable and their unpredictability is only the result of a poor knowledge or a questionable sensational policy of the information media. As in the case of earthquakes, what cannot be foreseen is the exact time in which the landslide will occur, the precise course it will take and the exact volume of material that will fall, but it is certain that in many areas the signs of a possible detachment are quite evident. Knowledge about the landslide mechanisms generally enable the identification of the triggering causes, and very often the rescue units such as Civil Protection Office are warned preventively, particularly when meteorological events that can trigger landslides and landslips take place. Areas that are potentially at risk, are often monitored, some for many years (the movements of the Spriana landslide, in Valtellina, have been known since 1589, in case of a collapse, the entire city of Sondrio would risk being flooded). Monitoring involves scrupulous and continuous observations. The premonitory signs that announce an imminent detachment or movement are often slow and imperceptible, at least in the initial phases, and can be recorded only through instrumental observations, therefore only a constant control of the territory enables the collection of this precious information, which cannot estimate a precise date of the event, but which however provide data regarding the possible acceleration of movements and deformations taking place. Observation and measurement of the deformations of the land are surely the most reliable method to evaluate the activity of a landslide and the onset of the landsliding

event. Using aerial photography and from satellites, combined with precise measuring instruments, such as the GPS, it is possible to observe the variations in the shape and topography of the land, the opening of fractures and cracks, and it is possible to measure the shifting of preset points, which are sometimes for this purpose fixed into the ground, compared to observation points that are surely not involved in the movement. With the help of special instruments such as strain gauges and deformation gauges, it is possible to evaluate the progressive aperture of fractures or the movement of rocky blocks away from the sides, or to measure the deformations more in detail, thus identifying the position of the surfaces that could possibly slide. Also the study of the level of imbibition of the soil provides important data, because many landslide phenomena are triggered by this factor. Naturally also a keen observation of the weather forecasts is part of the monitoring of a landslide-area, or an area that could potentially lead to a landslide. As it may be seen, for experts in this sector, landslides, in most cases are actually not at all unpredictable and sudden phenomena.

### The earth moves: what to do?

Structures built to defend the land from landslides are constructed with the aim of restoring stability of the slopes, eliminating the causes of the movement or reinforcing the materials. For this purpose, different structures can be constructed as a defence, depending on the type of landslide, the geological characteristics, the terrain and the risk:danger ratio.

The aim of some of the defensive structures is to eliminate or minimize some of the triggering causes, as for example the creation of drainage structures to take away excess water from land that is at risk by putting the water courses on a steady state, growing new plants and new trees, or consolidation of material, alternatively, protective structures can be built to prevent movement of the material, by constructing supporting walls, valleys and falling masses prevention nets, through consolidation work in the case of loose soils or fragmented rocks, and mounting tie-beams to hold back unstable blocks, and structures for fending off unstable material (that is made to fall artificially, in a controlled manner). However, when the volumes of material that are involved are large, the task of keeping landslide phenomena under control becomes more difficult. When, as in the case of deep-seated gravitational slope deformations, the volumes amount to the whole mountain, the only prevention that is possible is to move away all settlements and human activities from the area. This is often a difficult and painful choice because it is not easy to convince the inhabitants to abandon their homes, their fields, or their work activities.

### Prevention

Two main attitudes are observed when in the face of natural disasters. On one hand there is a tendency to minimize or ignore the risks till the calamity takes place, and then rapidly seek shelter or accept the whims of nature with atavic resignation. On the other hand there is an attempt to understand how the natural systems work, and to foresee the possible situations of risk, to prevent the occurrence of the phenomenon by avoiding behaviours that can aggravate the situation, creating opportune protection and monitoring structures, predisposing evacuation plans in case of real danger. All this, naturally involves large economic and social costs, and very often preference is given to a postponement of the prevention and protection expenses, without bearing in mind that the interventions to check a disaster that has taken place involve costs that are generally much greater than the prevention interventions, without considering that it is impossible to find a remedy for certain types of damages, such as the loss of human lives, works of art or landscapes. Finally, in recent times, also due to new laws regulating the development of constructions in areas at risk, and mainly due to the sensitization effort carried out on the public opinion, there is a greater awareness on the part of the public administration and the population. In the case that prevention is chosen as a defence against landslides, there are many types of interventions that can be carried out. Depending on the type of movement and materials, these will be more or less expensive and more or less effective. However a complete final recovery of a landslide-area is still impossible to carry out at present. The correct attitude when faced with these phenomena, therefore is to take note of the same, study them and better understand them, monitor them through an efficient network, and intervene, wherever possible, with opportune structures to defend the land and to avoid all attitudes or human activities that may in some way contribute to

triggering or aggravating the phenomena. This can also include the abandoning of particularly dangerous areas or having to renounce building structures that interfere too greatly with the delicate natural equilibrium. Information regarding the real risks and possible interventions is fundamental, because the population is also involved in the choices that are made with greater awareness, even if at times they may be difficult and troubled, as in the case of having to renounce building in an area that is devastated by landslides.