Ice

How ice forms

Since most of the Earth's ice does not come from frozen pure water, the ice we see generally consists of ice crystals mixed with a number of impurities, including dissolved salts absorbed in the ice crystal network (like sea water salts in sea ice), fragments of debris, atmospheric dusts, fragments of rock or soil trapped among the crystals, and minute air bubbles imprisoned during the freezing phases or as the snow was transformed into ice. The study of these impurities enables us to obtain important information about the formation processes and about where the ice comes from and even about the composition and temperature of the atmosphere at the time of ice formation.

Snow transforms: glacier ice

The formation of the ice of a glacier begins with snow deposition. Snow, with its star or hexagon shaped crystals, contains a great quantity of air, and has a very low density (this is why we sink in so easily, furthermore because of this, snow has a great capacity to absorb sounds, a snowy landscape seems strangely "silent").
As soon as it falls to the ground, snow begins a transformation that leads to the modification of the shape and size of the crystals and a progressive decrease in the number and size of the empty spaces, increasing the density. This transformation is known to skiers, who well know the difference there is in skiing on powdery winter snow or in spring snow that is transformed and granular! The main factor responsible for the transformation of snow is melting, by which single crystals are enveloped in a film of water, which melts the sharp tips giving them a more rounded shape. The variations in the shape and the presence of water in the gaps between the crystals provoke a gradual decrease in the empty spaces between the snow grains, also favoured by the compacting effect of the weight of the overlying layers of snow. If there is a refreezing of the melted waters, the size of the pores decreases further and the larger crystals become bigger at the expense of the smaller ones, which disappear. The transformations are very rapid when the snow is subjected to many cycles of melting and freezing, they are slower if the temperatures remain low : in the latter case the transformations occur by effect of sublimation, a process that requires a longer time (this is why plentiful snowfall in winter can lead to a high risk of avalanches, as persisting low temperatures do not allow the transformation and stabilization of the snow layers). Therefore snow is transformed into a not very compact mass of rounded ice crystals called old snow, or more elegantly known as névé or Firn (German term) if it remains for more than a year. Firn is characterized by a density over 0.54 and porosity under 40% . The transformation of snow into Firn is more rapid when there are a greater number of freezing and thawing cycles : approximately 4 months in the Andes, one year in the Alps, 4 years in Southern Alaska, twenty years in Greenland (source: Smiraglia, 1992). The size of the grains and the density increase and the porosity decreases with age. The transformation of Firn into glacier ice takes place when the empty spaces that are present no longer intercommunicate : ice becomes impermeable and the air that is present remains trapped in bubbles between the crystals. When the mass of ice begins to flow , the air bubbles are further compressed and the density of the ice increases up to approximately 0.91 g/cm3 (compared to 1 for water). The transformation of Firn into ice is even slower and always depends on temperatures.

The physical properties of ice

Ice has a singular property, which is apparently banal, but which has important repercussions on the life of the entire planet. While most substances decrease in volume when changing from the liquid state to the solid state, the property of water is that it is less dense in the solid state than in the liquid state: in fact, maximum density of water is reached at a temperature of 4°C.
This implies that ice is lighter than an equivalent quantity of liquid water, therefore ice floats on water : this can be seen when sipping a drink in a glass full of ice cubes. However, in nature, the same phenomenon can be seen in the icebergs and in the formation of sea and lake ice.
If ice did not have this property, ice formed on the surface of a sheet of water (a lake or a sea) would sink, accumulating

on the bottom. This would finally form thick deposits of ice on the bottom of seas and lakes, which would soon be transformed into large masses of ice, and the summer heat would only produce a minor layer of liquid water near the surface. The consequences of this property on the life of our planet are therefore very easy to imagine.
As a result of this property, when water freezes its volume increases. This is easy to test, when we put a bottle of water in the freezer, the pressure of the ice can break the bottle - if the bottle is full, the ice does not have space to expand and the container cannot deform, as in the case of a glass bottle. In nature, this process is very important : the pressure of water freezing inside small cracks in a rock can be so great that the rock breaks into small fragments. This process, called cryoclastic weathering (from Greek cryo, kryos : cold and clast, klastos : broken), (freeze-thaw weathering or frost shattering) is responsible for mechanical weathering of rocks in the high mountains, and produces large stretches of sharp debris, which are a characteristic feature in mountain landscapes above the limit of arboreous vegetation (that mountain climbers and excursionists call "screes" – those who are familiar with the mountains know how tiring it is to walk on this large gravel!).

How much does ice weigh?

Like an object that floats on water, analogously the Earth's crust "floats" in equilibrium on the viscous plastic rocks of the underlying mantle. A decrease in the weight of the crust, caused, for example by the removal of rocks due to erosion, makes the rocks lighter and the crust rises, while an increase in the weight makes the crust sink even deeper into the "soft" and viscous mantle, by a process called isostasy. The formation of thick layers of ice, (as in the glaciations of the past), causes an overload on the ice covered crust, and the result is that it sinks into the mantle, various hundreds of metres, in some cases even below sea level. Knowing the average density of ice and its thickness, it is easy to calculate its weight at the base. At present, due to the weight of the ice-sheet, which reaches 4.5 km in some parts, the Antarctic has sunk over 900 m. Radar measurements carried out in Greenland show that one third of the rock base is below sea level and the weight of the accumulated ice has pushed the rock downwards by over 600 m in some parts. As the large ice-sheets retreat after the last glaciation, the territories that are freed of the weight of the ice have started to rise. For example, the region around the Hudson Bay has risen over 300 m in a little over 10,000 years after the Laurentide ice-sheet retreat. This rise is not over as the territory still has not reached its height before the last glaciation. Also the Scandinavian peninsula is still rising at a rhythm that reaches 9 mm per year in the middle of the Gulf of Bothnia. The delay in the response to the removal of the load is due to the viscosity of the material of the mantle, which has a certain amount of inertia. The rise after the end of the last glaciation is greatly camouflaged by the rise in the sea level as a consequence of the melting of large quantities of continental ice.