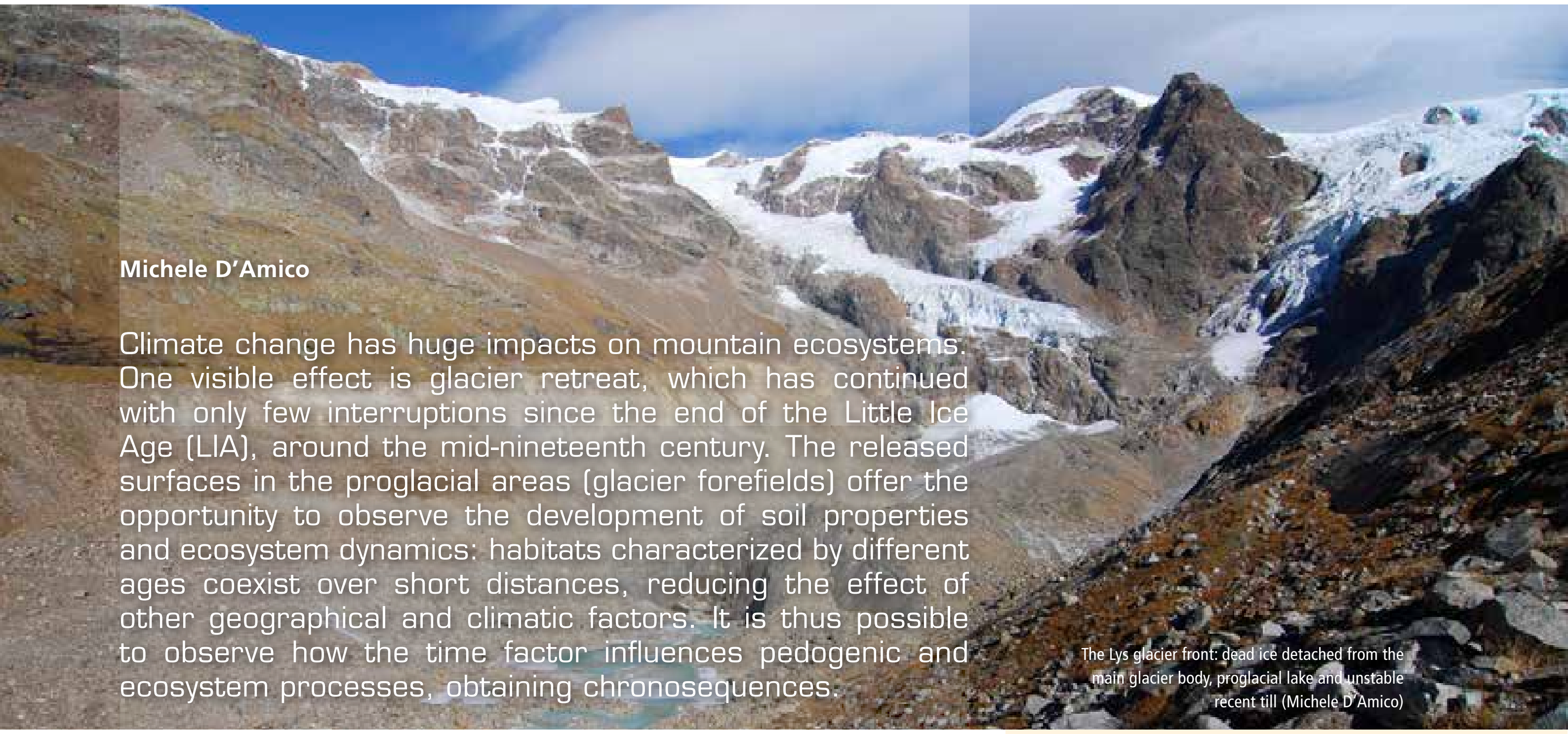
Soil genesis in recently deglaciated areas



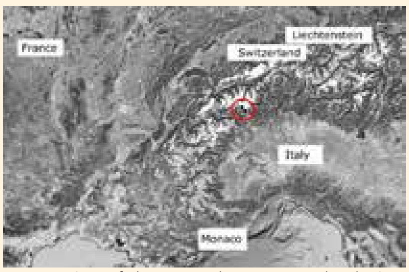
Michele D'Amico

Climate change has huge impacts on mountain ecosystems. One visible effect is glacier retreat, which has continued with only few interruptions since the end of the Little Ice Age (LIA), around the mid-nineteenth century. The released surfaces in the proglacial areas (glacier forefields) offer the opportunity to observe the development of soil properties and ecosystem dynamics: habitats characterized by different ages coexist over short distances, reducing the effect of other geographical and climatic factors. It is thus possible to observe how the time factor influences pedogenic and ecosystem processes, obtaining chronosequences.

The Lys glacier front: dead ice detached from the main glacier body, proglacial lake and unstable recent till (Michele D'Amico)

After deglaciation, the till is attacked by many processes, such as loss of soluble compounds, acidification, weathering of primary minerals. They are enhanced after the onset of colonization by pioneer plants, when accumulation of organic matter initiates the differentiation in horizons characterized by different chemical and morphological properties.

The chemistry and mineralogy of the till and the phytoclimatic belt influence the development of soils and the associated ecosystem, while temperature and rainfall influence the speed of this development. In general, Podzols are the climax soils on sialic materials under subalpine vegetation, while Cambisols develop below other vegetation types. More humid climates favour quicker pedogenesis and plant community turnover. For example, in perhumid coastal Alaska high rainfall leads to the formation of weakly developed E and Bs horizons after only 70 years, and "real" Podzols after 230 years. Here, E horizons immediately appear after the establishment of spruce. In the Alps, Dystric Cambisols are normally found on 250–300-year-old surfaces, while more than 1 300-3 000 years are needed for the development of Podzols. However 500 years were calculated on stable slopes.



Location of the Lys and Verra Grande glaciers forefields. Northwestern Italian Alps (Michele D'Amico)

The Lys and Verra Grande forefields, located in contiguous valleys in the Monte Rosa massif, in the northwest Italian Alps, clearly exemplify the effect of parent material on soil development and vegetation succession. The Lys glacier forefield has a sialic till, dominated by gneiss, while the Verra Grande forefield is dominated by serpentinite, which represents more than 90 percent of the material in the eastern part of the forefield and the 100 percent in the western one. The effect of different vegetations on pedogenic trends and chemical properties development is also visible: in the Lys forefield, parts of the morainic system are colonized by subalpine forests, while others are covered by anthropogenic pastures or alpine grasslands above the timberline. The retreat of both glaciers started in 1821, but increased only after around 1860, with minor advances in 1922 and 1985.

The Lys glacier forefield, well colonized by subalpine larch forest, with a portion above timberline (Michele D'Amico)

Initial soils have near-neutral pH values, thanks to the abundance of freshly ground, highly reactive primary minerals. After the onset of vegetation, acidification proceeds quickly, together with the accumulation of organic matter. Base status was reduced to below 50 percent in more than 65 years.

Under grassland, organic matter accumulation in the soil surface leads to the formation of A horizons, with a maximum thickness and organic carbon content in 260- and 130-year-old soils, respectively above and below the timberline, while weathering in subsurface horizons led to the formation of cambic Bw in the same time frame. Well-developed pre-LIA soils were characterized by thick and well-developed brown Bw horizon with strongly acidic pH values (Dystric Cambisols (Humic)).

According to the World Reference Base (WRB) the soils up to 65 years in the forefield were classified as Skeletic Eutric Regosols. For the development of Dystric Cambisols under subalpine anthropogenic grassland, 190 years were necessary, whereas 260 years were needed in the less favourable environment above the timberline.

The soil changes were associated with vegetation succession: Skeletic Eutric Regosols supported a pioneer community rich in basophilous species, which tended to disappear below Skeletic Dystric Regosols. Quasi-climax grassland dominated by *Carex curvula*, *Nardus stricta* or *Festuca varia* colonized mature Dystric Cambisols.

Below timberline, where the grazing pressure is low, subalpine larch (*Larix decidua*) forests with *Rhododendron ferrugineum* colonize the moraines in around 60 years. After the establishment of subalpine forest, pedogenesis increases greatly in speed and radically changes direction: thin bleached E horizons appear in 90-year-old soils, evidencing an initial podzolization. Morphological and chemical data verify the incipient translocation of iron (Fe) and aluminium (Al) towards weakly developed Bs horizons. The calculation of chronofunction for Fe and Al translocation showed that around 500 years are necessary for the formation of Haplic Podzols. The soils under subalpine forest on the LIA materials were classified as Skeletic Dystric Regosols, while "climax" soils were Ortsteinic Podzols (Skeletic), developed on late glacial moraines.


The Verra Grande forefield, with the bare western lateral moraines and the eastern ones colonized by pioneer grassland (Michele D'Amico)

Despite the short distance from the Lys forefield, the Verra Grande forefield has a very different appearance. The western part of the LIA moraine system is almost devoid of vegetation: only a few trees and shrubs grow on bare soil. The eastern part is more vegetated, but the ground is covered by pioneer grassland species, with only a few scattered larch trees. Only limited flat and particularly stable surfaces have larch forests. The typical subalpine vegetation is developed on older surfaces.

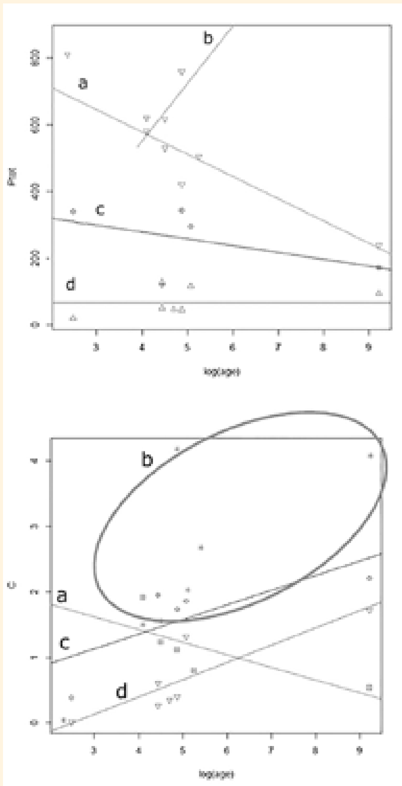
This great difference is due to the pure serpentinitic substrate on the western moraines and to small gneiss inclusions in the eastern ones. Typically, plant productivity is limited by high magnesium (Mg), low phosphorus (P) and by high heavy metal contents on serpentinite (the so called "serpentine syndrome").

The slow vegetation succession is tightly linked to the slow pedogenesis: soils younger than 190 years are classified as Skeletic Eutric Regosols, even if thicker and darker A horizons are developed on the eastern moraines. Soils developed on older Holocene materials are Podzols on the eastern moraines, Dystric Cambisols on the western ones.

Thus, a quicker pedogenesis can be observed where a small amount of gneiss is included in the serpentinitic till compared with where serpentinite is pure, but soil development and vegetation succession are much slower than on more "favourable" lithologies, in the Lys glacier forefield.

A complex net of mutual feedback relationships between chemical properties of parent materials, plant succession, speed and direction of pedogenesis can be observed on terrains released by melting glaciers since the end of the LIA. From the two former examples, it is possible to outline the following general rules on the main drivers of early pedogenic processes and speed:

- Initial chemical properties and nutrients of the unweathered substrate influence the speed of colonization by pioneer vegetation.
- Different early vegetation cover influences organic matter accumulation, soil acidification and leaching.
- Grassland soils tend towards Cambisols, forest soils towards Podzols.



Total phosphorus and organic carbon contents in the soils developed on LIA moraines on gneiss, (a) under forest vegetation, (b) on gneiss under grassland, (c) on serpentinite with small gneiss inclusions, (d) on pure serpentinite. The age is log-transformed to better show the trends over time

- This different acidification induces a different speed in species turnover, slowing down or accelerating the entrance of subalpine *Ericaceae* and conifers (*Pinophytae*) which are associated with the onset of podzolization.
- Human activities, such as grazing, induce variations in plant succession which are correlated with variations in pedogenic trends and in the chemical development of soils.
- On harsh substrates (*e.g.* serpentinite), small inclusions of other rocks can dramatically improve the initial conditions by adding small quantities of nutrients, favouring quicker plant colonization.
- The small initial variations influence the pedogenesis throughout the soil development, soils around 11 000 years old are Podzols on slightly "richer" substrates, and weakly developed Dystric Cambisols on pure serpentinite.