Exploration Projects

Moulins and contact caves in the Gornergletscher (Switzerland): morphology and hydrology

Leonardo Piccini, Giovanni Badino

Contenuto: Il ghiacciao del Gorner è uno dei maggiori delle Alpi e quello dove i fenomeni pseudocarsici da fusione (criocarsismo) sono meglio sviluppati. In questo lavoro vengono descritte le caratteristiche morfologiche delle principali grotte e fornite indicazioni sulla loro evoluzione.

Contents: The Gorner glacier is one of the major in the Alps and it is that where the pseudokarst melting forms are better developed. In this paper the morphologic and evolutive features of major caves are described.

Key-words: ghiacciai, grotte endoglaciali, mulini, glacier, englacial caves, moulins, Gornergletscher, Switzerland.

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MOULINS AND CONTACT CAVES IN THE GORNERGLETSCHER (SWITZERLAND): MORPHOLOGY AND HYDROLOGY

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Abstract

The Gornergletscher is located in the mountain group of M. Rosa (Swiss Alps). The ablation zone is relatively flat and a few fractured; this morphological condition allows the surface drainage of meltwater. Supraglacial streams often plunge down into moulins that feed directly the englacial drainage. Repetitive investigations, since 1985, have allowed surveying more than 40 moulins and contact caves; some of them have been explored to the englacial water table (from – 30 to –140 m). The life of the moulins ranges from 3 to 5 years and it depends on the local ice flow rate: the faster the movement, the shorter the life period. Field observations suggest that an important role in controlling the development and the geometry of moulins is played by the level of englacial water.

Key Words: Glaciology, englacial hydrology, glacier caves, Gornergletscher

Introduction

In October 1985 and 1986 a group of Italian speleologists performed the exploration of deep moulins in the Gorner glacier (PICCINI & VIANELLI, 1987). In the following years Swiss, Italian and French cavers carried out new explorations of moulins and marginal contact caves (WENGER, 1994; PICCINI, 1999). Behind all these investigations, we can undoubtedly assert that the Gornergletscher is one of the most detected glaciers in the world by glacial speleologists, and that it is an exceptional site to study the evolution of moulins and their hydrological behaviour.

Since 1998 a new campaign of investigation was commenced by a group of Italian researchers coming from the Dipartimento di Scienze della Terra of Firenze, Dipartimento di Fisica Generale of Torino University and from the Associazione Culturale “La Venta”. The aim of this research is the hydrological and morphological characterisation of moulins. In this paper we presented a brief and preliminary note on the results.

Glacial morphology

The Gornergletscher is located in the Alpi Vallesi and it is made up by the confluence of different ice streams descending from the mountain group of M. Rosa. The whole glacial basin covers a surface of about 65 km^2 (from the I.G.S. map of 1996) with a maximum length of 14 km. The equilibrium line (ELA) is presently located about at 3250 m. The maximum thickness of the ice is probably more than 400 m, and the maximum width is about 2 km.

Below the elevation of 2600 m, the glacier is divided in three different ice streams by two major medial moraines. The central ice tongue, the largest one, is fed by the Grenzgletscher, whose accumulation zone is located between the M. Rosa (4634 m) and the M. Lyskamm (4562 m).

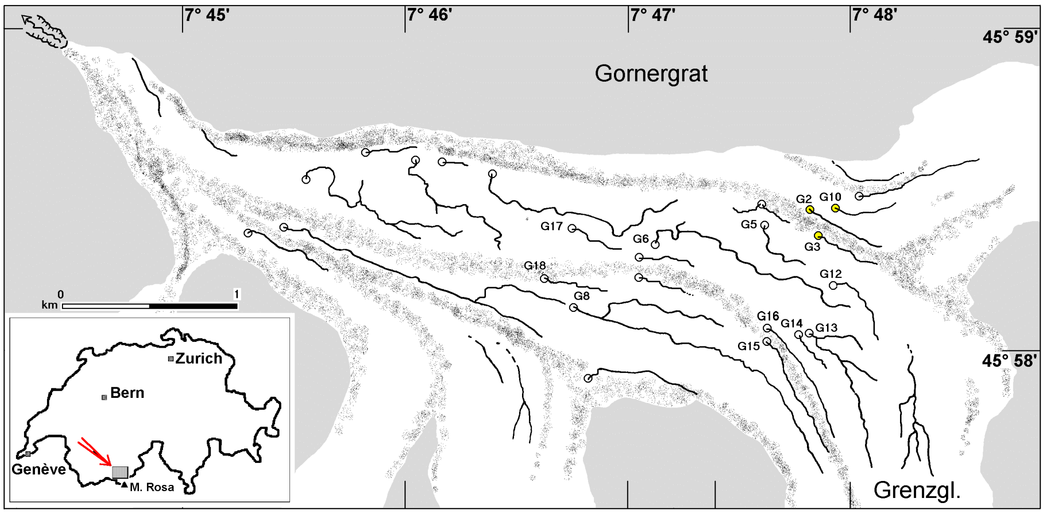

Fig. 1 – Sketch map of the ablation zone of Gorner, with the main supraglacial drainage. The small circles indicate the position of the moulins traced in 1999 and 2000.

In the ablation zone, between the altitude of 2400 and 2600 m, the glacier displays a wide flat zone, which has a surface of about 5.5 km^2. Here, the morphologic and structural settings of the ice allow the development of a remarkably structured network of supraglacial streams, which feeds several lakes and moulins (Fig. 1). Most of moulins are located in the confluence zone of the Grenzgletscher, where the entrances seem to be aligned along NE-SW lineaments. Another group of active moulins is located in the lowermost part of the glacier; some of them have wide feed basins (larger than 1 km^2), and experience large in-flowing discharges. All the moulins are located along extension zones controlled by the geometry of the glacier bed.

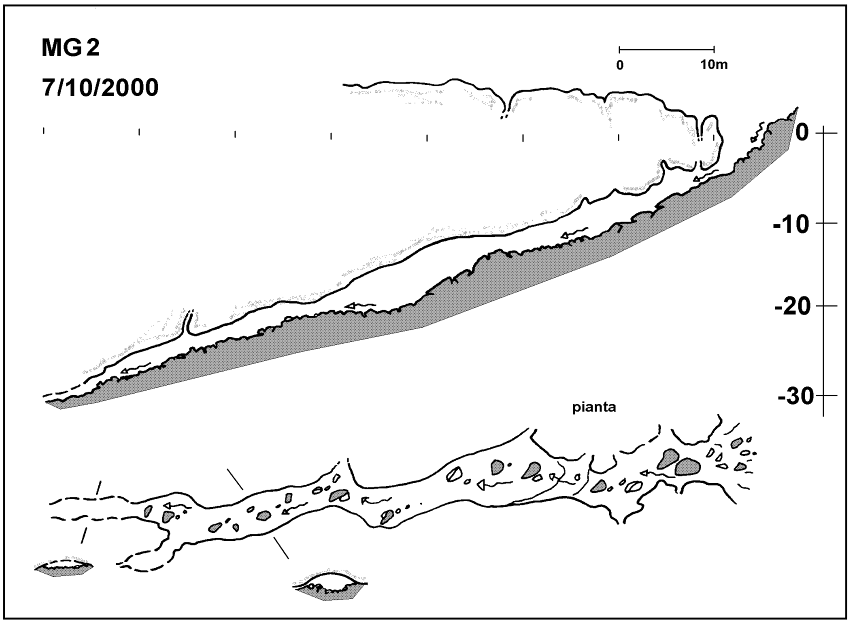

Fig. 2 –Profile and plan view of the marginal contact cave of Gornersee (survey L. Piccini & A. Romeo, October 2001).

Marginal caves and moulins

Two morphological and genetic types of glacier caves have been surveyed on the Gorner: marginal contact caves and supraglacial swallow-holes (ERASO & PULINA, 1992; PICCINI, 1999).

Marginal caves form at the contact between ice and lateral moraines or basal bedrock; most of them are small, impenetrable, and frequently affected by the collapse of the entrance.

The largest marginal caves (Fig. 2), more than 200 m long, are located upstream the confluence of Gornergletscher with Grenzgletscher. These caves act as subglacial outflows of a marginal ice-dammed lake, named Gornersee, which forms and is completely empty during the summer (ROTHLISBERGER, 1972, BEZINGE, 1973). A large tunnel, developed along the contact between ice and moraine or bedrock, makes up these marginal caves.

Moulins are usually structured like a vertical shaft, sometime followed by a high and narrow canyon.

The entrances have dimensions ranging from some tens of cm up to 10-15 m. An important morphologic difference concerns the evolution stage. The new moulins, at the beginning of summer, have small elliptical entrances, with the major axis in the direction of an extension fracture. At the end of the seasonal period of evolution (usually the end of October) the entrances exhibit an elongated shape because of the regressive erosion of the waterfall rim.

The vertical pattern of moulins varies from almost perfectly vertical (ice shafts) to horizontal (epidermic moulins) (Fig. 3 e 4).

Moulins form where a crevasse cuts a surface stream and the pattern of the first shaft is always controlled by the geometry of the fracture (HOLMULUND, 1988; BADINO & PICCINI, 1995). The lower part is often oriented in the direction of ice flow and so it is probably controlled by the hydraulic gradient.

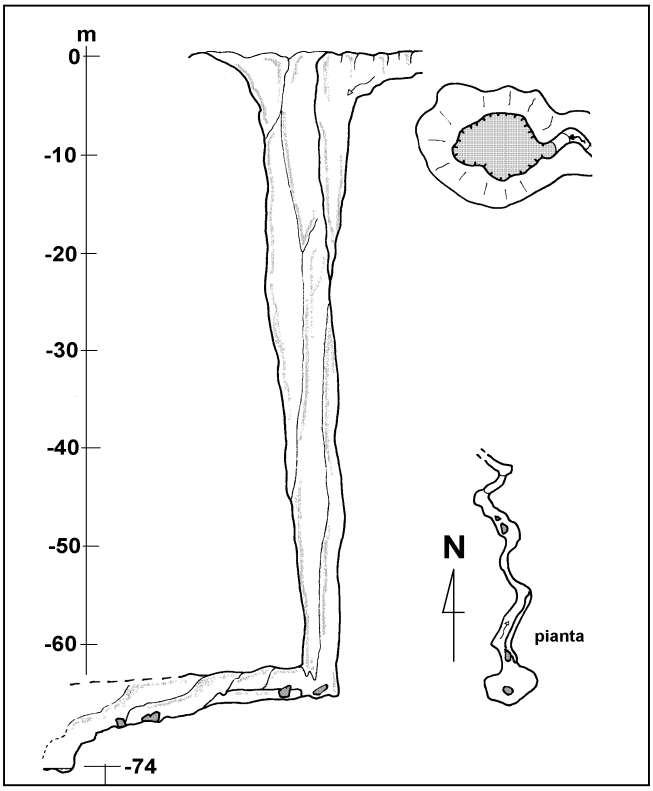

Fig. 3 – Profile and plan view of a typical vertical moulin of Gorner (G16: survey L. Piccini, October 1999).

In the upstream part of ablation zone, (2550-2600 m), the moulins have a vertical pattern, with a first shaft, 40-80 m high, followed by narrow and steep canyons. In the middle-low part of the ablation zone, the geometry of moulins is progressively less steep going down-glacier
Moulins are here characterised by a small first shaft, followed by a gently steep meandering canyon (Fig.5).

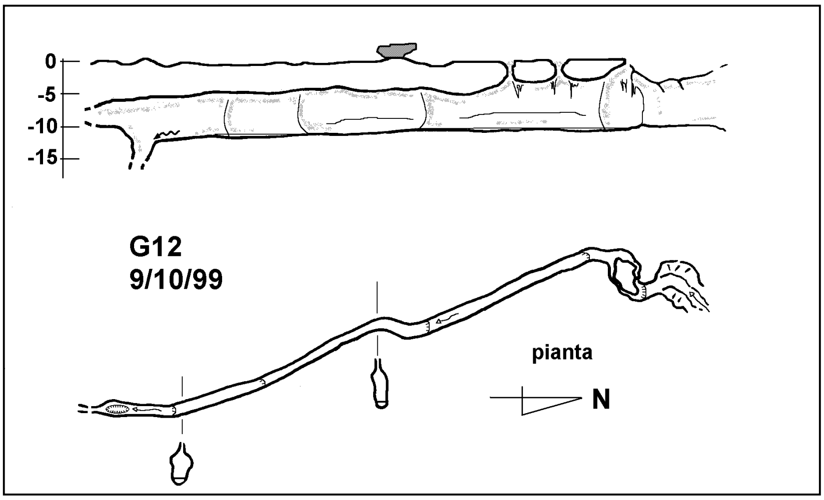

Fig. 4 – Profile and plan view of a horizontal moulin of Gorner (G12: survey A. Romeo, October 1999)

According to our surveys the depth of moulins does not seem to be influenced by the in-flow discharge. In our opinion, the different geometry of moulin mainly depend on: (i) the local stress distribution, (ii), the mechanical properties of ice and (iii) the fluctuations of englacial water level, which lead the first evolution stage. The first factor is probably the most important, but a relevant contribute of the others cannot be excluded (BADINO, 1995).

Hydrology and evolution of moulins

Thanks to the E-W orientation, the Gorner experiences a high insulation, for that reason the surface melting is probably more than 3 m a^{-1} of water in the ablation zone. Supraglacial runoff begins in May, by the melting of snow, and continues to the end of October. Usually, at the end of June the glacier surface is free of snow beneath 3000 m. According to our measurements, we can assume a surface ice melting of 20-30 mm d^{-1} in the months July and August; in October surface melting reduces to few millimetres. During the summer time, the meltwater specific discharge ranges from 0.23 to 0.35 m^3 s^{-1} per km^2 (Piccini, 1999).
A network of supraglacial streams, located mainly near the medial moraine, drains melting water.
The largest streams, whose feed basins are wider than 1 km^2, have a maximum discharge of 1-2 m^3 s^{-1} and a minimum discharge often lower than 10-20 l s^{-1}. In the period of maximum melting, the total discharge of infiltration through moulins probably reaches 10 m^3 s^{-1}.
During the high-melting season (June-September), the largest moulins experience diurnal fluctuations of discharge, which displays a minimum, early in the morning, and a maximum, late in the afternoon. The ratio between minimum and maximum flow is frequently more than 1:100, but the diurnal excursion of discharge heavily depends on daily weather conditions.
In the period of minimum discharge, when moulins are accessible, the depth of water level ranges from few meters to more than 100 below the ice surface. Indeed, the water table has a complex geometry and it is possible to find very different levels in moulins only few tens of meters far. .

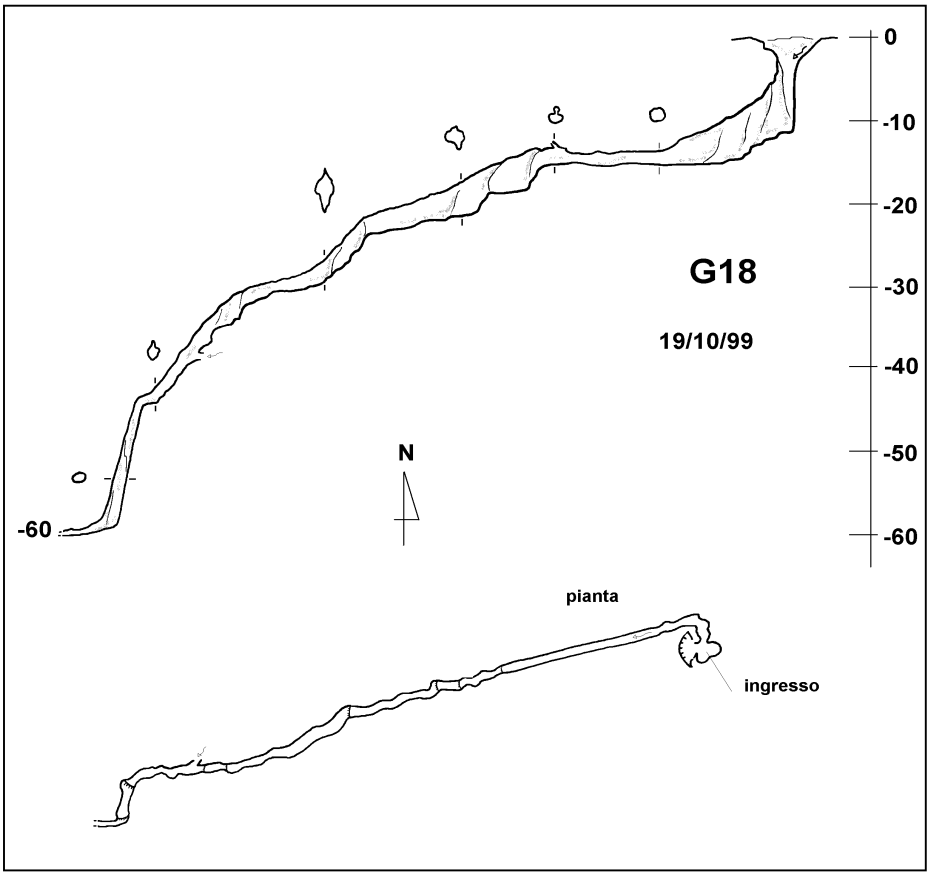

Fig. 5 – Profile and plan view of an inclined moulin (G10: survey Ass. La Venta, October 1999)

Namely, we don't know much about the high-discharge conditions. In particular we don't know how much the water rises in the moulins
In the beginning of the melting season we can observe two kinds of moulins: the reactivated ones, heritage of the previous year, and the new moulins, formed by the capture of a stream feeding an older moulin.
The formers don't show relevant modification during the evolutionary season, probably because they can use the previous englacial drainage conduit, which is preserved during the winter, although reduced in the dimension. Thus, when the moulin is reactivated the water table rapidly falls to the ordinary summer level.
In the new moulins, the connection with the englacial network is, in the initial stage, characterised by a low hydraulic conductivity and thus the water table is very near to the surface and descends slowly with the progressive widening of the water-filled conduits.
Repetitive surveys of the same moulins along a period of one year have shown that the internal geometry is subject to seasonal changes controlled by the hydrodynamic and by the collapse of ice in the deepest part.
In particular we observe an upward retreat of the waterfall base-pools and the change of inclined conduit into a sequence of shaft and horizontal passages.

Conclusions

On the ground of our investigations we can assert that the spatial distribution of moulins remains almost the same year after year and that the main morphological features show also only little

differences. This fact suggests that the position and the pattern of moulins depend on the distribution of stress inside the glacier and on the effect of this on the surface topography and hydrology (HOLMULUND, 1988; BADINO & PICCINI, 1994).
Most of the supraglacial channels survive during the winter, thus every spring the drainage network is reactivated with only small differences from the previous year. At the beginning of the melting season the moulins are completely filled by water, the pressure of water is probably responsible of the reactivation of moulins, unless a new moulin is formed upstream. So, the development of moulins is the consequence of the seasonal evolution, during the all the period when the cave is active (BADINO, 1995).
Our observations seem to indicate that in the last 15 years the number of moulins and their period of life are increasing. Further studies are necessary to understand well the cyclic life of moulins, whose increasing could be referred either to a lower movement rate of the glacier or to different climatic conditions.

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