# Preliminary Results of the Glacio-Speleological Expedition on Tyndall Glacier

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## Abstract

In the months February and March 2000 the "Associazione La Venta" organized a speleo-glaciological mission on the Tyndall Glacier (Patagonia, Chile). In the ablation zone a well-developed surface drainage network occurs and supraglacial streams plunge down into moulins. The major streams have a wide catchment area and experience a discharge of some $m^3 s^{-1}$; these streams feed huge moulins located about 7 km upstream the front of the glacier. The two largest moulins experience 24 hours cyclic phenomena of rising and decreasing of the internal water level. Probably this kind of behaviour cannot be explained only by the input discharge changes, and we presume that the deformation of the englacial conduit plays also a relevant role. Along the East margin of the glacier we discovered also three large glacier caves formed at the contact between ice and lateral moraines or basal bedrock.

**Key Words:** Glaciology, englacial hydrology, glacier caves, moulins, Tyndall Glacier, Hielo Continental

## Introduction

In the months February and March 2000 the "Associazione La Venta" organized a speleo-glaciological mission on the Tyndall Glacier (Patagonia, Chile). The mission benefited of a grant by the Italian Foreign Affairs Ministry, and it was realized with the help of the Magellan University di P.ta Arenas (Chile) and the logistic support of the "Torri del Paine" National Park.

The investigated zone was the lower part of the ablation zone, below the elevation of 700 m a.s.l., where a preliminary analysis by aerial photos permitted to individuate a well developed surface drainage network (Fig. 1).

The base-camp was installed in a lateral valley, reachable by 5-6 hours walking from Guardieria Grey, on the bank of Laguna Grey. From the base camp, it was possible to gain easily the medial sector of the glacier at an altitude of about 600 m. The first tours allowed to recognize the areas where thermokarst processes have the maximum development and to individuate the best paths to reach them.

## The Tyndall Glacier

The Tyndall Glacier is one of the widest valley glaciers that originate from the Hielo Continental Sur.

It is located at 51° 05' and 51° 17' of South Latitude and at 73° 16' and 73° 28' of West Longitude. The total length is about 22 km, with a width of 10 km at the northern part and a width of 2 km at the front. The flow direction is SSE. Altitudes ranges from 1500 m, at the diffluence from the icefield, to 200 m at the front.

In the ablation zone, below 800 m of altitude, the glacier exhibits a rugged topography, due to transverse bands of fractured ice, where the high sun melting forms a dense network of parallel sharpen ridges. These rugged bands are separated by relatively planar and a few fractured zones where a surface drainage of meltwater can develop. Supraglacial streams feed some flat depleted areas where the water is absorbed by small fracture. In some cases meltwater plunges down into moulins that feed directly the englacial drainage network.

The glacier is divided in two major ice streams by a thin central moraine. Along the moraine the glacier is just a little lower in respect of lateral areas; in this area, a large amount of meltwater converges.

Thanks to the high insulation and rain, the surface melting is very high. During the period of our mission we measured a melting ablation of about 800 mm, with a mean ablation of 70 mm/d, and a maximum daily ablation of 120-130 mm/d. According to these few data we can suppose that in the warmer months (February and March) the ablation can easily exceed 2 m per month.

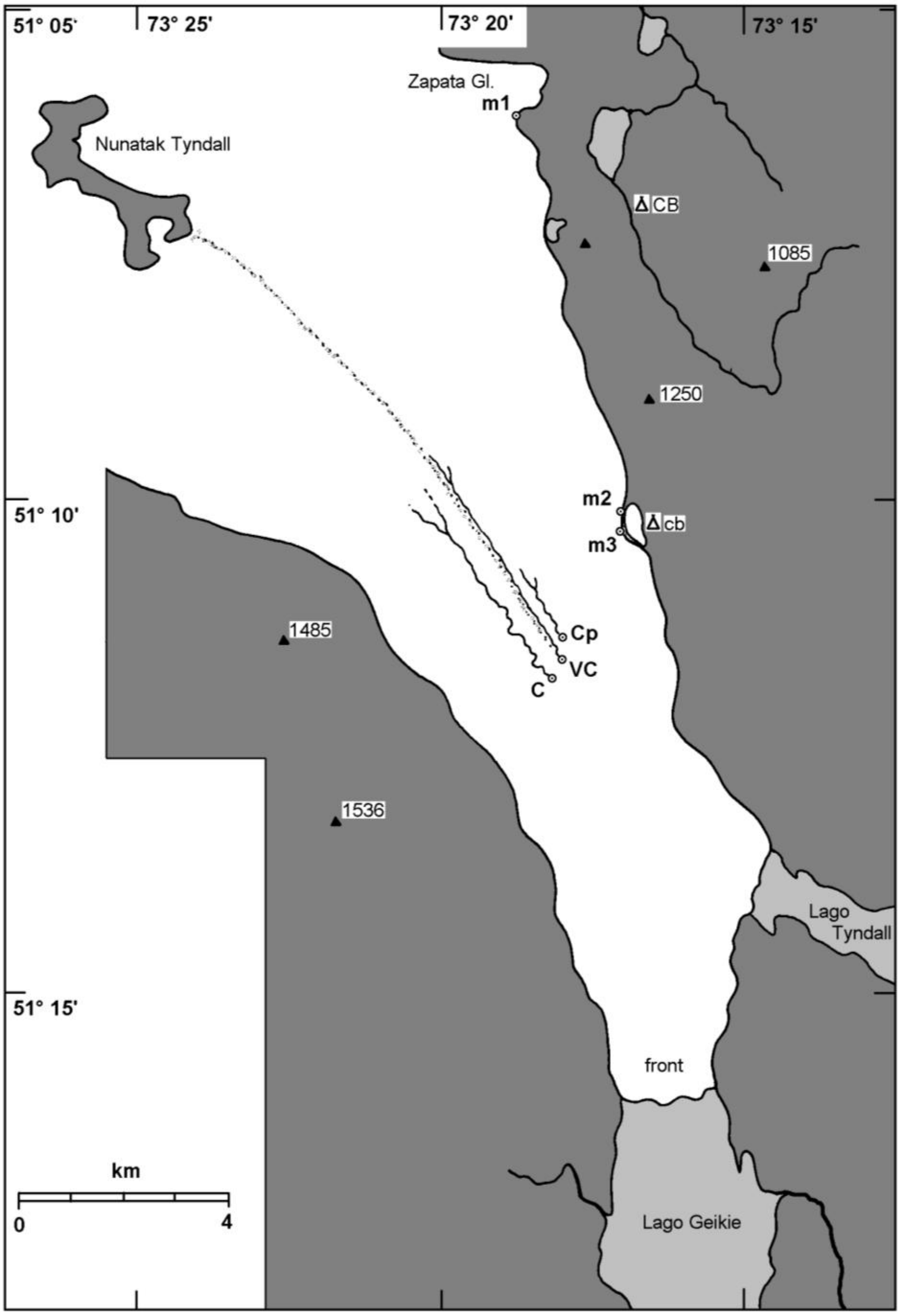

*Fig. 1- Sketch map of Glacier Tyndall, with the position of major streams and moulins: C) moulin "Capo"; VC) moulin "Vice-capo"; Cp) moulin "Capino"; CB) base camp; cb) advanced base camp; m1-m2-m3) marginal contact caves.*

## The Moulins

During the surveys on the glacier, we have traced approximately 50 moulins. About the half of these were localised in the area close to the base-camp, but most of them were small and narrow shafts, no more than 20 m deep. The most developed moulins and the largest ones were discovered about 10 km downstream, in a wide flat area where several streams flow coming from NNW. In particular three large streams flow in the central depleted part of the glacier. They have a wide catchment area and experience a discharge of some

$m^3 s^{-1}$; these streams feed huge moulins located about 7 km far from the front, just upstream a transverse band of fractured ice.

We named the three moulins "Capo" (the boss), "Vicecapo" (Vice-boss) and "Capino" (the little boss).

The "Capo" is probably one of the largest moulin ever discovered in the world. The feeding stream runs in a large ice-valley, about 100-150 m wide and 20-30 m deep, that we followed upward for 4 km without see the end. We have reason to believe that this stream begins from Nunatak Tyndall, about 12 km upstream. The discharge of "Capo" river probably reaches 6-8 $m^3 s^{-1}$ during the high-melting periods.

The entrance of this moulin is a deep canyon, 4-5 m wide and about 15 m deep. The stream falls into the moulin with an impressive waterfall that made any attempt to descend into it impossible.

The "Vicecapo" is just a little smaller. The stream flows in a rectilinear incision about 40-50 m wide and 10-15 m deep; discharge ranges from 1 to 3 $m^3 s^{-1}$, in the warmer days. The entrance is a spectacular shaft, 6 x 10 m in the upper part, which was sounded till a depth of 103 m.

The "Capino" is a deep shaft where a stream of about 1-2 $m^3 s^{-1}$ falls down. An attempt to descend into it stopped at a depth of 40 m because of the power of the waterfall.

In this area we discovered about 30 minor moulins, with entrances ranging from a dimension of some m to 20 m in plan. Most of them develops on ESE-WNW transverse fractures and are formed by a shaft 15 to 40 m deep. Only one moulin has a horizontal pattern.

## Hydrodynamic Behaviour of Large Moulins

During the investigations on the Tyndall glacier, we frequently observe phenomena of rising and decreasing of the water level inside moulins of the lower zone. In some occasions the filling-in of water involved all the moulins and was probably caused by a raise of englacial water level due to an increase of the surface melting. In others cases we observe the filling-out of only some isolated moulins, probably due to a temporary local occlusion of the englacial drainage conduit (BADINO, 1995).

A particular behaviour was observed in the two largest moulins, the "Capo" and "Vicecapo", which experience a water raising-decreasing phenomena of about 24 hours. Only in one occasion we had the possibility to follow a full cycle, measuring the level of the water inside the first shaft of "Vicecapo" and the discharge of the in-flowing stream. The measure of water level and discharge are presented in Fig. 2.

At 13.00 of February 28, the water-level was 91 m below the rim of the entrance and it was raising at a rate of about 20 $m\ h^{-1}$. At 18.00 the moulin was almost completely full, with the level of water just 5 m below the rim.

The water stood at the maximum level for less than an hour, than the level began to decrease with an accelerating rate. At 23.00 the level was at –103 m, the limit of our possibility to measure it.

Assuming constant dimension in the plan of the shaft of about 50 $m^2$, we can calculate the amount of water stored in the moulin and the discharge of englacial drainage. In the Fig. 3 we can see that the immobilized water reaches the maximum value just an hour before the maximum of removed water drainage.

The increasing of hydraulic pressure produces an accelerating flow that ranges from 1.4 to 2.3 $m^3 s^{-1}$.

Probably this kind of behaviour cannot be explained only by the input discharge changes, because there is not a linear relationship between the water level and the removed water discharge. We presume that the deformation of the englacial conduit play also a relevant role.

Unfortunately the error of the measurements and the lack of minimum levels do not allow making a mathematical model of the hydrodynamic behaviour of this moulin. Probably, further studies and a more precise measure of level and discharge could allow getting experimental measurements of the deformation rate of englacial conduits (BADINI, 1995).

## Marginal Contact Caves

Along the East margin of the glacier, we discovered several glacier caves formed at the contact between ice and lateral moraine or basal bedrock (ERASO & PULINA, 1992). Most of them were small and impenetrable, and frequently affected by the collapse of the entrance.

Three of these caves could be surveyed for more than 100 m. One of them was located in the Zapata Gl.,two others were near the advanced base-camp (Fig. 1). The former is a typical marginal cave, about 130m long, which is formed by a small lateral creek.

The two longest marginal caves, named “Pesce superiore” and “Pesce inferiore”, were explored for more than 200 m, and they are respectively an out-flowing cave and an in-flowing cave. The upper one probably act as on over-flow emergence that is activated when the surface melting exceed the capacity of basal network to drain the infiltration water; in this case, usually during rainy days, a flow of about 3-4 $m^3 s^{-1}$ comes out of the cave and fills a lateral basin forming a lake. The lake improves its level till the water flows over a rock threshold and falls in a lower small basin, where subglacial conduits capture the water again.

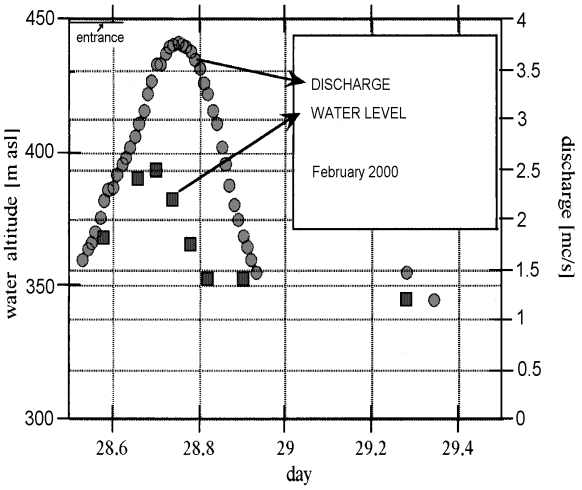

*Fig. 2*

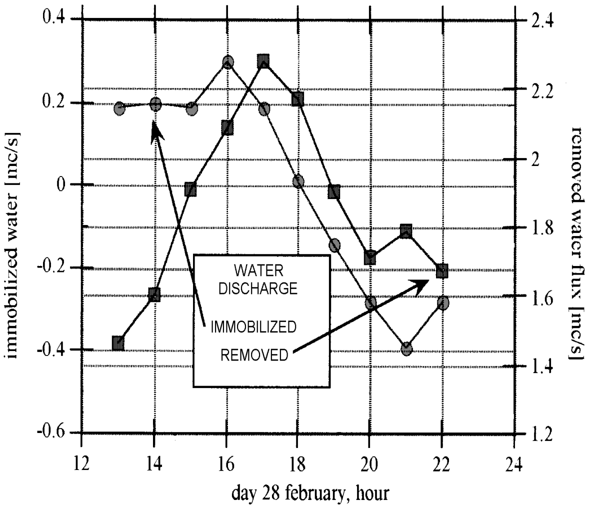

*Fig. 3*

***Fig. 2 – Discharge and water level vs time in “Vicecapo” (entrance altitude 448 m a.s.l.)***
***Fig. 3 – Immobilized and removed water discharge vs time in Vicecapo***

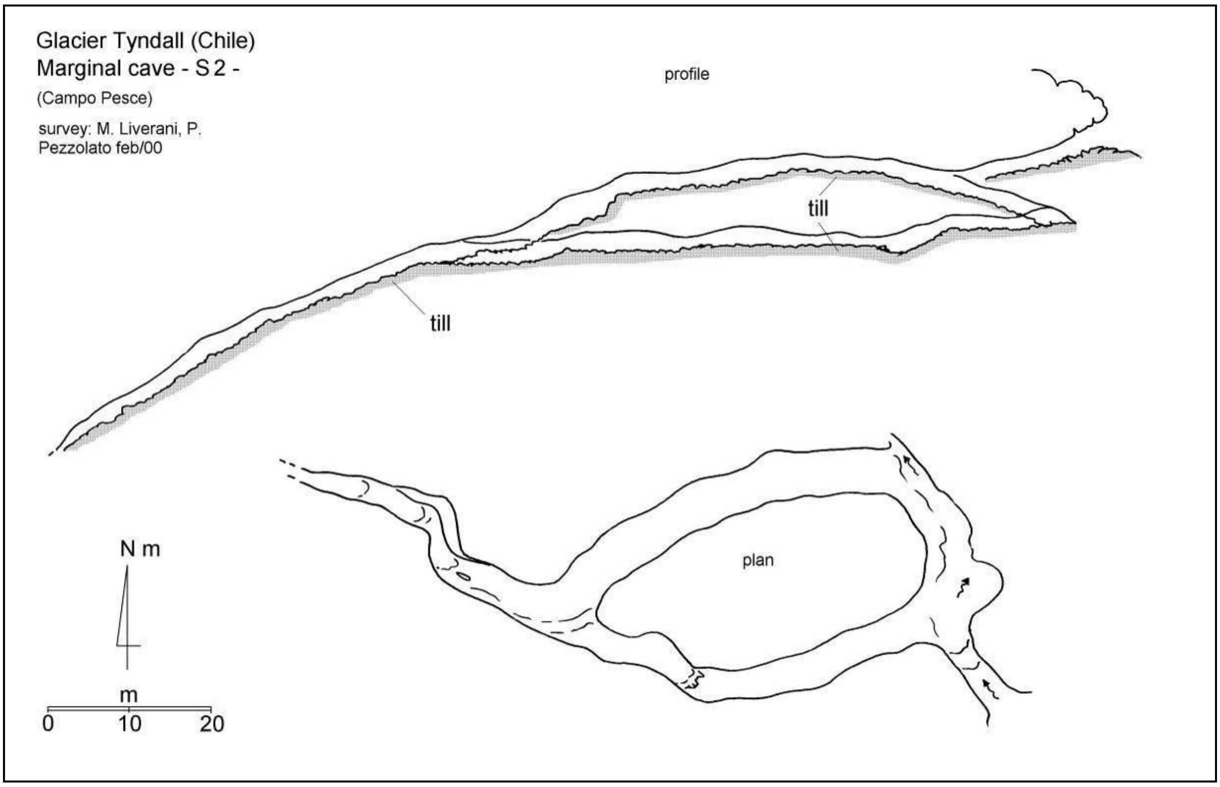

***Fig. 4 – Topographic profile and plan view of the major marginal caves explored in the Tyndall Glacier (survey by Ass. La Venta, March 2000).***

## Conclusions

A first preliminary investigation on Tyndall Glacier has allowed verifying the occurrence of well-developed supraglacial drainage and related thermokarst caves. In particular, three streams flowing in the central part of the glacier, feed large moulins, among the major moulins ever discovered in the glacier of South America.

Two of these englacial caves experience a cyclic large-scale oscillation of internal water level. This particular phenomenon seems to be controlled not only by the discharge fluctuations but also by a cyclic rearrangement of englacial drainage conduit as a response of diurnal changes of discharge.

A detailed monitoring of water level and of discharge fluctuations could permit to better understand the mechanism of ice deformation due to water pressure changes.

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