Excursion guide

Mer de glace (Chamonix - Mont Blanc): from Little Ice Age to modern times

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Mer de Glace and the Little Ice Age: scientific background (1)

During the 19th and the beginning of the 20th century, the spectacular alpine glacial landscapes of the outgoing Little Ice Age attracted numerous visitors, painters and photographers. This rush was at the origin of a rich iconographic documentation, presenting the mountain valleys with glacier tongues advancing into forests and pastures with a scarce vegetation. At that period, many scientists considered the repeated fluctuations of alpine glacier tongues as a possible announcement of the next glaciation. This was the main motivation for the foundation of the "Glacier Commission" (now: "Cryospheric Commission") of the Swiss Academy of Sciences in 1893, half a century after Agassiz (1837) and the scientific community admitted the existence of ice ages during the recent Earth history. Since then, length variations of about a hundred glacier tongues are regularly monitored as well as volume variations of a smaller number of glaciers .

In the current debate on climate change and human impact on global warming, glacial variations and more particularly the variation in ice tongue and ice stream length are widely recognized as sensitive indicators of temperature fluctuations. According to Zemp et al. (2011) "the variations of a glacier front position represents an indirect, delayed, filtered and enhanced response to changes in climate over glacier specific response times of up to several decades . . .".

The Chamonix Valley and the Mont Blanc Massif are a kind of open-air museum showing the impact of the Little Ice Age ("Petit âge glaciaire", "Kleine Eiszeit") on landscapes from the middle of the 16th to the end of the 19th century, and of glacier retreat in modern times, either for natural reasons and/or resulting from human influence. Field observations of the extension of glaciers during the Little Ice Age and discussions on the modern human impact are particularly easy and instructive in this region.

This is why the Swiss Association of Energy Geoscientists (SASEG) has chosen glacier and climate history as one of the themes for its annual 2013 meeting and field trip in Chamonix. The present field guide is an adaptation of the SASEG document for general public use*.

Alpine glaciers, climate and geomorphology

The ice balance of glaciers depends mainly on three major parameters (Fig. 1):

•Deep atmospheric temperatures to cool down and preserve snow and ice from melting.
•Precipitations (mainly as snow) to provide the necessary ice volume.
•Geothermal flux. This heat flow provides a modest, but still significant energy input at the base of the glacier, and guaranties conditions of a wet glacier basis.

The current position of a glacier front depends on the ice movement and the change in ice volume: ice tongues are advancing through sliding and internal flow deformation of the ice.

A glacier tongue gets shorter, when melting of the glacier front is more rapid than the advance through sliding and internal flow. On a glacier, the accumulation and ablation zones are the areas with respectively positive and negative ice balance from the point of view of ice formation and ice melting.

** The scientific backgroud of this field trip was published as: Wildi, W., 2013, Glaciers as indicators of changing climate from Little Ice Age to modern times: Swiss Bulletin für angewandte Geologie, v. 18, no. 2, p. 77-82.*

Mer de Glace and the Little Ice Age: scientific background (2)

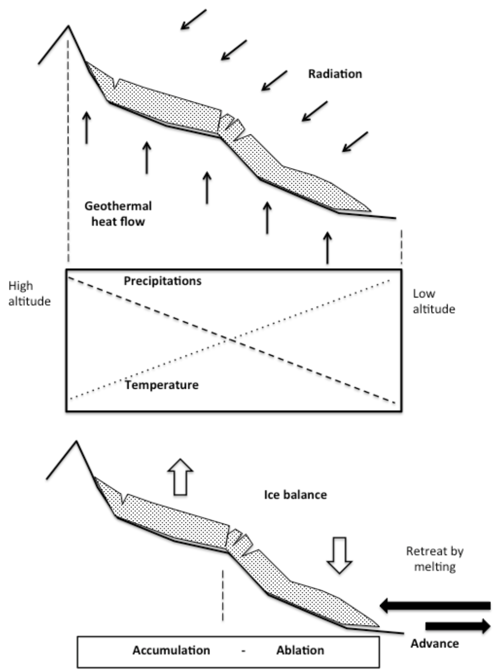

Figure 1: *Main parameters of the ice balance and glacier front position: temperature, precipitation and geothermal heat flow.*

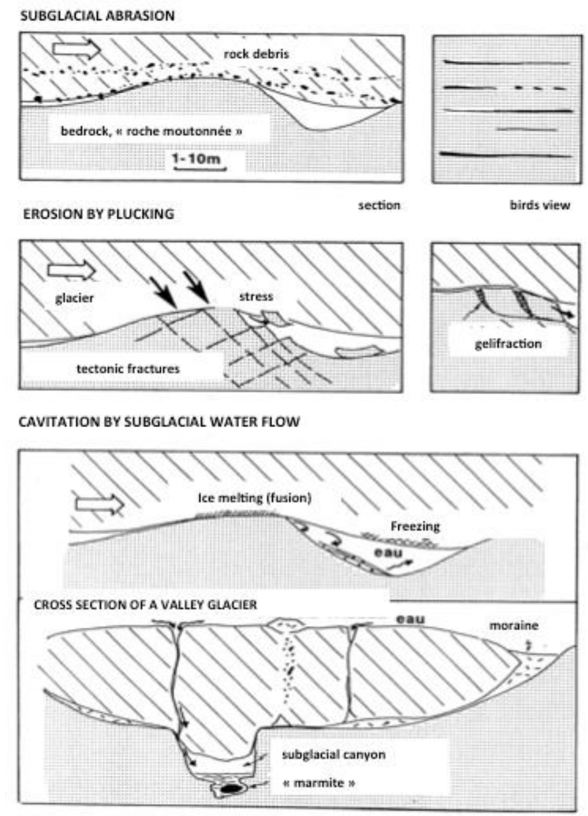

Figure 2*: Glacial erosion processes and morphologies*

Glacial erosion is by far the most important landscape forming process in the Alps and the alpine foreland. Three different processes may be distinguished:

•*Abrasion* by friction of rock debris at the interface between the sliding ice masses. This process produces fine sand and silt, which is then evacuated as "glacier milk" through the melt-water of the sub-glacial river. Measured and calculated erosion rates are in the order of 1-2 mm/year. "Glacial polish" at the bedrock surface produces easily recognizable hummocky morphologies (*"roches moutonnées")* that may last thousands of years of alteration and erosion.

•*Plucking* results from the pressure of the glacial load on the bedrock. Along pre-existing faults and fractures this process produces rock debris and blocks of different shapes.

Mer de Glace and the Little Ice Age: scientific background (2)

Figure 3*: Gelifraction morphologies, Aiguille Verte, to the NE of the Mer de Glace; altitude 4’122 m above mean sea level.*

- *Cavitation* of the bedrock through sub-glacial water, carving vertical gorges and “moulins”.

Gelifraction is responsible for landforms above the glacial surface (Fig. 3).

Outside of the meltwater streams, erosion products of glaciers may be deposited in places as till (non sorted sediments) and moraines (term that designates morphologies of till deposits). Lateral and frontal moraines of glaciers also contain material from slope deposits (scree and others) that may have been transported on the back of the glaciers.

Recent history of the Mer de Glace Glacier

With an elevation of 4810.45 m above sea level, the Mont Blanc is the highest mountain top in the Alps and gives birth to a number of glaciers, as well on its southern, Italian slope as on the northern, French side. The town of Chamonix is located at 1’050 m above mean sea level. The Mer de Glace (“Sea of Ice”) is the glacier of a lateral valley of the Arve River, on the northern slopes of the Mont Blanc Massif; it is the longest glacier in France. Its recent history is the focus of the present field trip.

The last ice age, called Würm, started some 115’000 years ago, and glaciers were back in their present position about 10’800 years ago. At least one major advance of the Arve and Rhone glaciers reached the Lyon area. During the “Last Glacial Maximum” (LGM), about 23’500 BP ago (Moscariello et al. 1998, Wildi et al. 2014), the Rhone Glacier did not go further than the Geneva basin. The maximum extension and limits of the Mont Blanc glaciers (Coutterand 2010) is well marked on both sides of the Arve Valley through the upper limit of glacial polish on the bedrock (Fig. 4). On the slopes of the Mont Blanc and Aiguilles Rouges massifs, south and north of the town of Chamonix, the surface of the Arve Glacier reached an elevation of about 2’200 to 2’300 m. As a simplification, one can state that a glacier is stable in volume, as long as it remains in an area where the average annual temperature is equal to or lower than about 0 ° C. This means that average temperatures during the maximum extension of glaciers during the last ice age were at least 10 ° C lower than now.

Mer de Glace and the Little Ice Age: scientific background (3)

During the Holocene, Alpine glaciers fluctuated from conditions of strong melting and very little remaining ice to conditions with glacier tongues up to about 1.5 to 2 km longer than now. These findings stem mainly from the analysis of tree trunks and peat that appear nowadays under the melting glacier tongues, or that are expelled by the sub-glacial streams. These organic remains indicate that, since the end of the last Ice Age, glacier tongues were clearly shorter than now during more than 5’400 years (table 1; Schlüchter & Jorin 2004) .

The last period of glacier advance was the so-called “Little Ice Age” (Matthes 1939) that followed the warm period of the Middle Ages. In the Alps, this period started with glacier advances in the 16th century. According to Zemp et al. (2011), maximum lengths were reached at Mer de Glace in the Chamonix – Mont Blanc area in 1600 and 1640 AD, and other advances took place at around 1720, 1780, 1820 and 1850 AD.

The history of the Mer de Glace fluctuations has been reconstructed in detail by Nussbaumer et al. (2007). As shown in figure 5, glacier growth is very rapid between the years 1550 and 1600, with an advance of approximately 1’000 m (ca. 20 m/year). From 1600 to 1850, three main short melting and growth periods are at the origin of 600 – 700 m of glacier front changes. After the last maximum in 1852, the glacier tongue collapses by a length of about 1’200 m within 30 years (40 m/year). A rather stable glacier tongue with minor fluctuations is reported from about 1880 to 1930. The next phase of rapid melting between 1930 and 1970 corresponds to a glacial retreat of 800 m (20 m/year). The following plateau is from about 1970 to 1995. In the current phase of rapid glacier melting, the tongue of Mer de Glace is loosing an average of 35 m of length per year. Since the 1820 maximum, thickness reduction of the Mer de Glace in the valley section at the level of the Montenvers railway station is 180 m (Figs. 4, 7).

Periods of reduces glacier tongues (dating from trees and peat)	Calendar years (before 1950)	Duration (years)
10	9900-9550	350
9	9000-8050	950
8	7700-7500	200
7	7350-6500	850
6	6150-6000	150
5	5700-5500	200
4	5200-3400	1’800
3	Ca. 2700	100
2	2300-1800	500
1	1450-1150	300
	Total	5’400

***Table 1**: Periods of reduced alpine glaciers, age of trees and peat remains (adapted from Schlüchter & Jorin 2004).*

Mer de Glace and the Little Ice Age: scientific background (4)

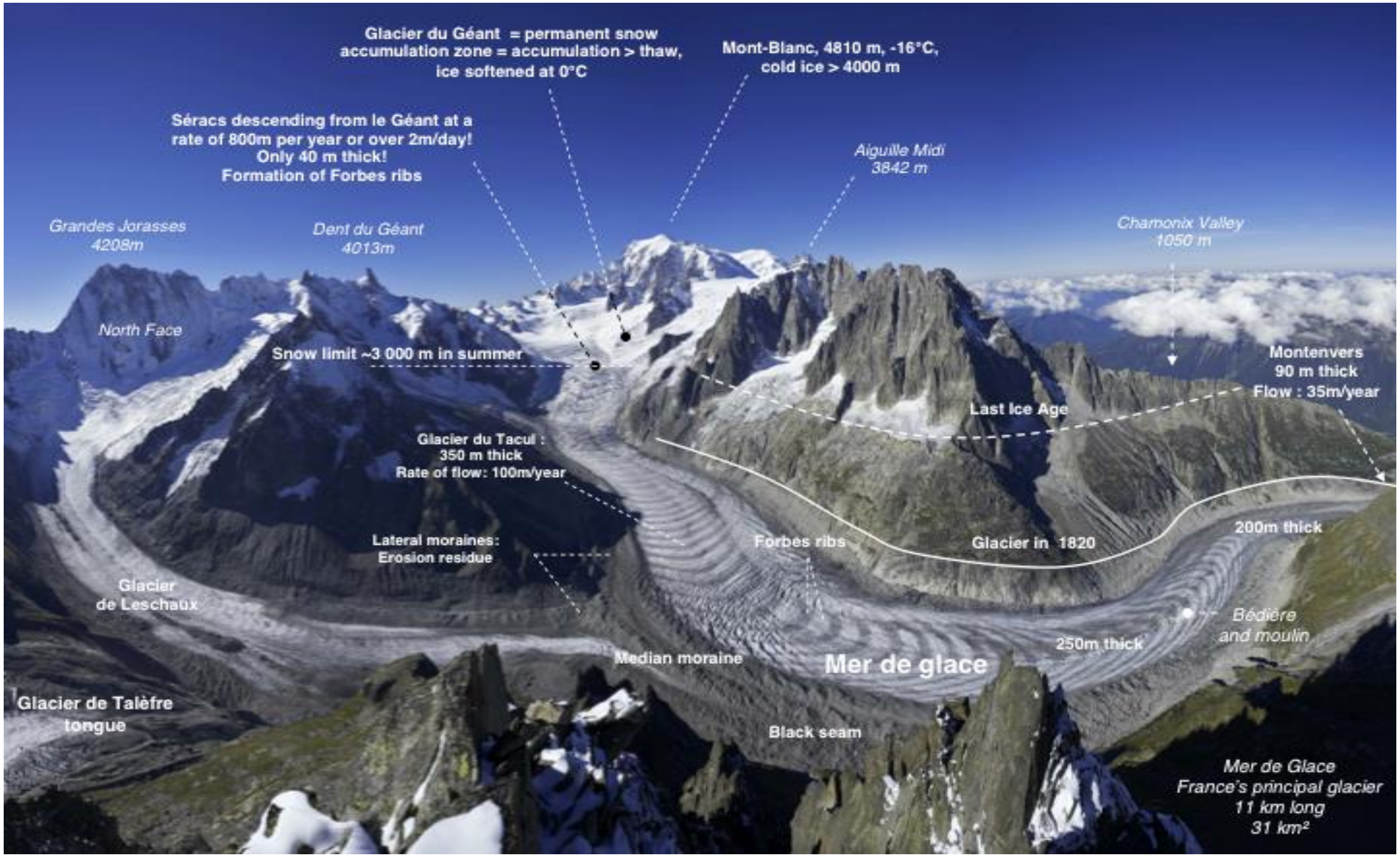

Figure 4: *The Mer de Glace Glacier and Mont Blanc seen from the Le Moine summit (looking towards the West); ice limits during the last ice age (Würm), and maximum ice extension during the Little Ice Age are indicated by glacial abrasion of the bedrock. Foto: Jean-François Hagenmuller , interpretation: Luc Moreau***

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Mer de Glace and the Little Ice Age: scientific background (5)

Discussion

The climate history during the Little Ice Age has been investigated by several authors, and in particular by Le Roy Ladurie (1967). This author enumerates a number of exceptional climate events, at the origin of famine, social unrest etc. A decreased solar activity and repeated volcanic activity have been put forward as causes of this 350 years long climate crisis.

With respect to glacier melting, the rates of glacier tongue shortening from the end of the last maximum of the Little Ice Age until now may be compared with those of the Rhône Glacier and other Alpine glaciers at the end of the last ice age: The glacier position is near the city of Geneva at 20'500 years BC (Morcariello et al. 1998). The glacier front was back to its current position in Gletsch, about 180 km from Geneva, at 8'800 years BC. These data indicate an average rate of shortening of the glacier front of about 20 m/years. The current rate of 35 m/year for the Mer de Glace is somewhat higher, but still in the same order of magnitude, and comparable with the rates from 1850 till 1880. Therefore, overall the current glacier melting is not an exceptional event in the recent history of the Alps.

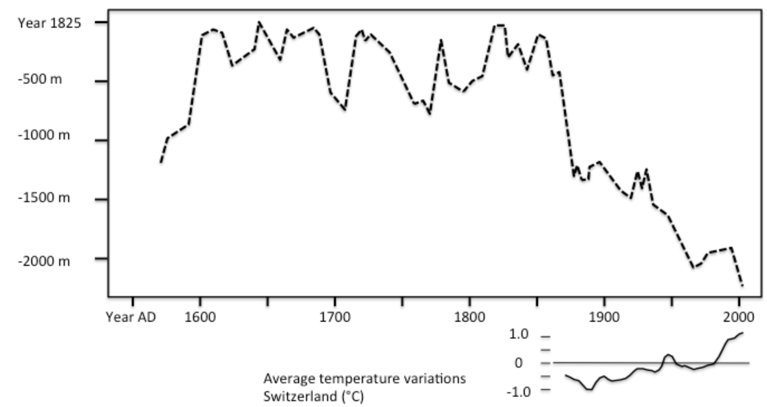

Figure 5: *Fluctuations of the Mer de Glace ice tongue from 1550 to 2001 AD (Nussbaumer et al. 2007, interpolated curve; the reference point of 1825 is an erratic block) and 20 year gliding average temperature variations (instrumental measurements) for Switzerland 1864 – 2012 , reference period: 1961 – 1990.*

Aknowledgements: The author would like to thank Jean-François Hagenmuller and Luc Morau for the authorisation to reproduce figure 2. Georges Gorin made a careful revision of the paper.

Field trip (1)

The field trip is subdivided into two parts:

Part a: Visit of the Montenvers and Mer de Glace Glacier
Part b: Glacial front and fore-land during the Little Ice Age; glacial retreat from the Little Ice Age till modern times

a) Montenvers – Mer de Glace

Travel with the Chamonix - Montenvers train from an altitude of 1035 m above mean sea level up to 1913 m (Fig. 4). This ride takes about 25 minutes.

Stop 1, Montenvers: From the terrace of the Montenvers railway station, one has a beautiful view on the Mer de Glace Glacier and the surrounding mountain tops (cover photo of this guide and figures 5 and 7) . The maximum ice level during the last ice age corresponds to the upper limit of glacial polish on the rocky slopes. The glacier limit of the Little Ice Age (year 1850) corresponds to a vegetation limit. Within this limit, rocks are not yet completely covered by lichen, algae and other vegetation, and show a light-coloured weathering.

Walk or travel down to the glacier (cable car: travel fare is included in the train ticket Chamonix – Montenvers; the ca. last 50 m of elevation have to be walked anyway). Along the stony footpath and on aluminium stairs, one can observe the age of glacial retreat since 1850, marked by written indications. At the same time, the cover of the rocks through algae and lichen, and in particular through the green-fluo coloured *Rhizocarpon geographicum* (Fig. 8) becomes more and more sparse, the closer one gets to the glacier. These lichen grow on siliceous rock surfaces about 25 years after the surface has been freed by the melting of the glacier. The diameter of lichen colonies then grows with a constant velocity for several decades. Thus, lichens are rather good tools for the dating of recent glacier melting. Since 1850, the thickness of the ice stream has lost 180 m in the Montenvers transect.

Stop 2, Mer de Glace, ice tunnel: A new ice tunnel is dug every spring (Fig. 9) and sometimes adapted again during summer, depending on the advance of the glacier tongue through flow and sliding on the bedrock. Ice structure in the tunnel area shows clear stratification, underlined by numerous gas inclusions forming white strata (Fig. 10). However, one has to be aware that these strata do not represent depositional features, but are the result of reformation and recrystalization following zones of perturbation by serac falls (avalanches) and similar processes. Inclusions of rock debris (Fig. 11) are rare, and ice is generally extremely pure. This may partly be explained by recrystalisation, but is certainly also a primary feature of this glacier. On the other hand, rock debris, sand and silt are transported on the top and at the base of the glacier.

The walk down to the glacier, the visit of the ice tunnel and the return ride by the cable car will take normally about 1 ½ hours, but depend of course on the physical condition of the visitor. We recommend to count half a day for part (a) of the field trip.

Field trip (2)

a) Montenvers – Mer de Glace glacier
b) Glacial front and foreland during Little Ice Age; glacial retreat from the Little Ice Age to modern times

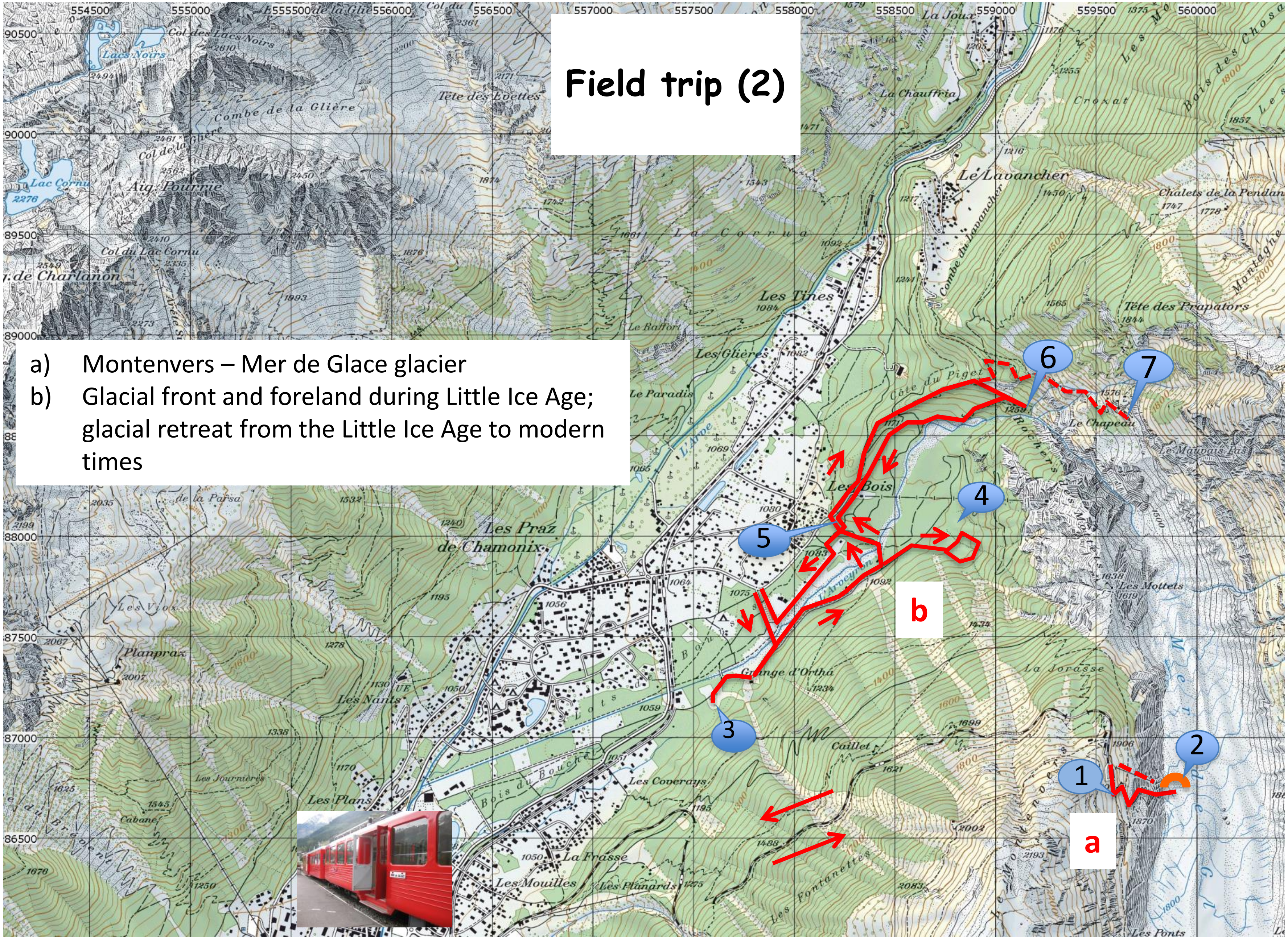

__Figure 6:__ Topographic map of the field trip (© 2014 swisstopo, BA14069).

Field trip (3)

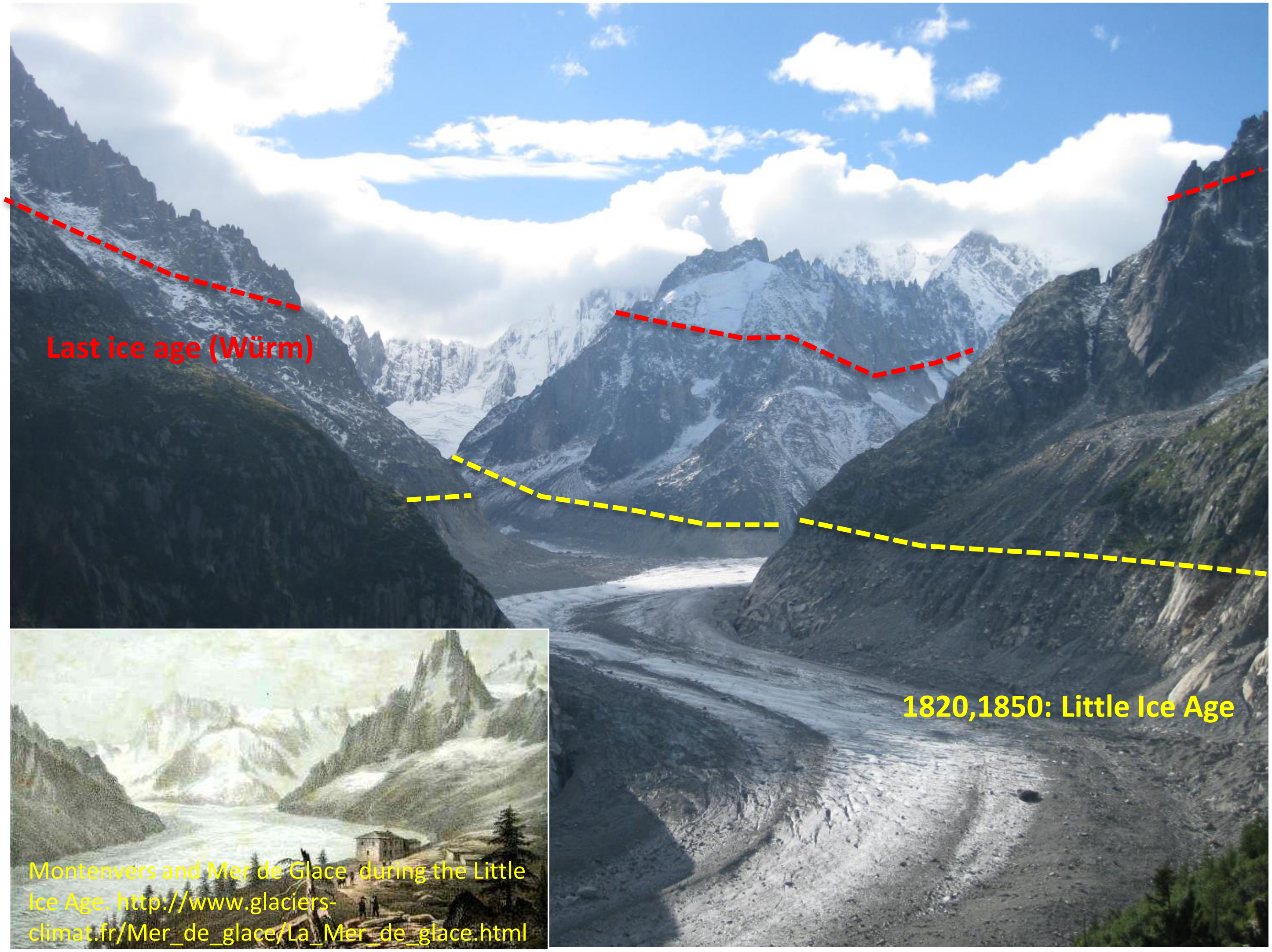

Figure 7*: View of the Mer de Glace valley and glacier from the terrace of the Montenvers Railway station. Glacier levels during the Little Ice Age and last ice age (Würmian).*

Field trip (4)

__Figure 8:__ Rhizocarpon geographicum on a granitic rock surface. These lichen colonies show a constant growth rate. They may therefore be used for the dating of glacial melting.

__Figure 9 a) and b):__ Entry of the ice tunnel in 2013 and entries of the previous years (left of entry 2013). The distance between entries reflects the velocity of the ice tongue movement.

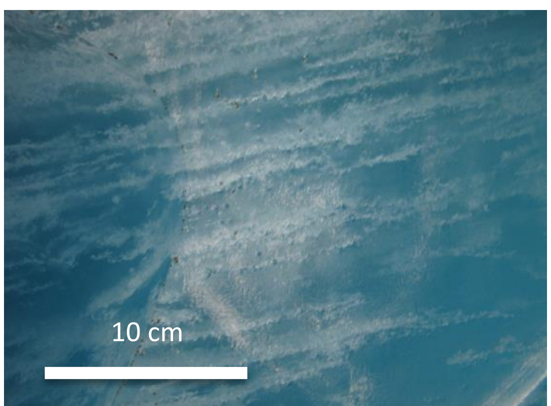

__Figure 10__ (left): Gas (mainly air) inclusions in the ice (ice tunnel) forming white bands of stratification-

__Figure 11__ (right): Rock debris in the glacial ice (length of the largest debris is about 10 cm).

Field trip (5)

b) Glacial front and foreland during the Little Ice Age; glacial retreat from the Little Ice Age till modern times

The trip starts close to the heliport of Chamonix – Les Praz, about 15 min. by foot from the railway station of Les Praz, NE of the town of Chamonix. Good walking shoes and the ability to climb 200 m (stop 6) or 500 m (stop 7) on partly quite steep and stony footpaths are needed. This trip shows the morain ridges and the deep sub-glacial canyon of the Arveyron River, the sub-glacial and pro-glacial river of the Mer de Glace Glacier, from the Little Ice Age till now.

First, cross the bridge over the Arveyron River and turn right. At the Ferme d'Ortha, the road crosses the outflow of the hydroelectric plant using part of the water of the sub-glacial river of the Mer de Glace Glacier. About 500 m after the bridge:

Stop 3, Pierre d'Ortha: This is a granite block derived from the central part of the Mont Blanc Massif. This erratic block has been deposited by the Mer de Glace Glacier tongue at the end of the last ice age, during the Dryas III stage (approx. 10'700 – 8'700 years A.D.). This granite block is one of the arguments to prove the extension of glaciers during the last ice age. It has long been exploited for construction purposes, as one can observe thanks to the marks left by the chisel and hammer during exploitation (fig. 12, ref. http://www.geologie-montblanc.fr/itineraire.html).

From the Pierre d'Ortha follow upstream the small road ("Chemin des carrières") on the left bank of the Arveyron River. After almost 1.5 km, a wooden panel indicates the "carrières" (quarries, Fig. 13).

Stop 4, carrières: The quarries are in fact workshops located on a moraine of the Mer de Glace, deposited during the 17th century. Inhabitants used this quarry of granite blocks for construction work in the town of Chamonix. Blocks were first given a provisional shape before they were transported to the town. This work is explained on panels along a short round trip in the forest (Figs. 13 and 15). This visit takes about half an hour.

From the "carrières" walk back to a farm house and cross the Arveyron River over a small bridge.

Stop 5, glacier front at the maximum of the Little Ice Age: The wash-out plain of the Mer de Glace glacier during the Little Ice Age extends from the heliport to the limit of the forest, where ridges of huge granite blocks mark the maximum extension of the Mer de Glace during the Little Ice Age (Figs. 16, 17 and 18). The morphology of these ridges is of chaotic style; nowadays a young forest is covering the whole area.

Field trip (6)

Climb one of the well indicated footpaths to the “Gorges de l’Arveyron”. The most instructive paths follows the moraine crest of the maximum extension of the Mer de Glace ice stream (“Côte du Piget”, Fig. 16).

Stop 6, Gorges de l’Arveyron: After 30 to 40 minutes, one reaches the rocky platform of “Gorges de l’Arveyron”. From this promontory, one has a nice view towards the gorge (canyon) eroded by the sub-glacial melt water of the Arveyron River during the last ice age (Fig. 19). From this place one also clearly identifies the difference in erosion processes between fluvial erosion in the steep gorge, glacial polish on the valley shoulders and gelifraction on the cliffs of the higher summits.

Return back following the more or less horizontal footpath. The way up to the “Le Chapeau” is steep and takes about 1 hour.

Stop 7, Le Chapeau: From the terrace of this resting place at 1576 m above mean sea level, one has a nice view on the glacier front of the Mer de Glace, about 200 m below in the glacial valley, and on the recent and current pro-glacial moraine ridges and lakes (Fig. 21).

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Field trip (7)

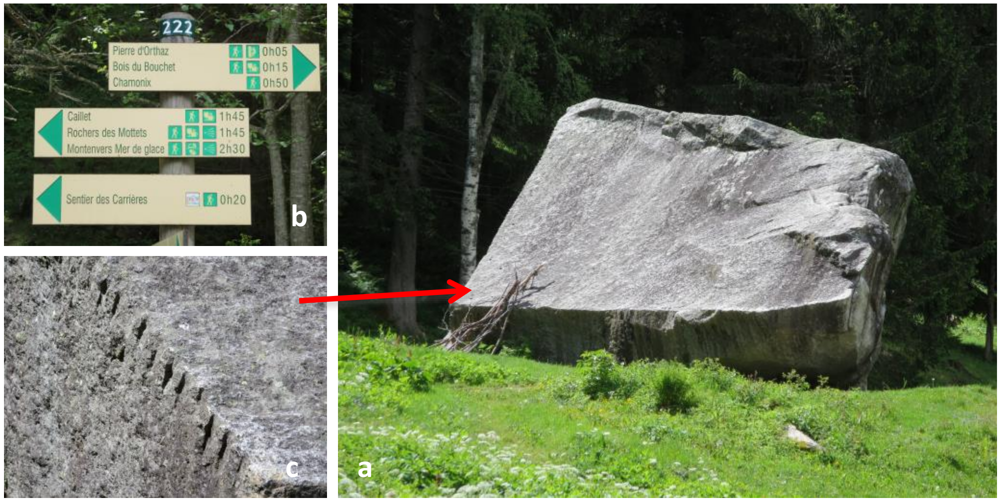

Figure 12 a, stop 3: *Pierre d'Ortha; b: orientation pannel at the Arveyron bridge; c: chisel and hammer marks on the Pierre d'Ortha.*

Figure 14: *Arveyron River with dams and braided channels. Pro-glacial flood plain of the Little Ice Age.*

Figure 13, stop 4: *"Carrières": carved blocs and explanation panel*

Figure 15: *House constructions with carved granite blocs. Memorial for the scientist H.B. De Saussure in Chamonix town centre.*

Field trip (8)

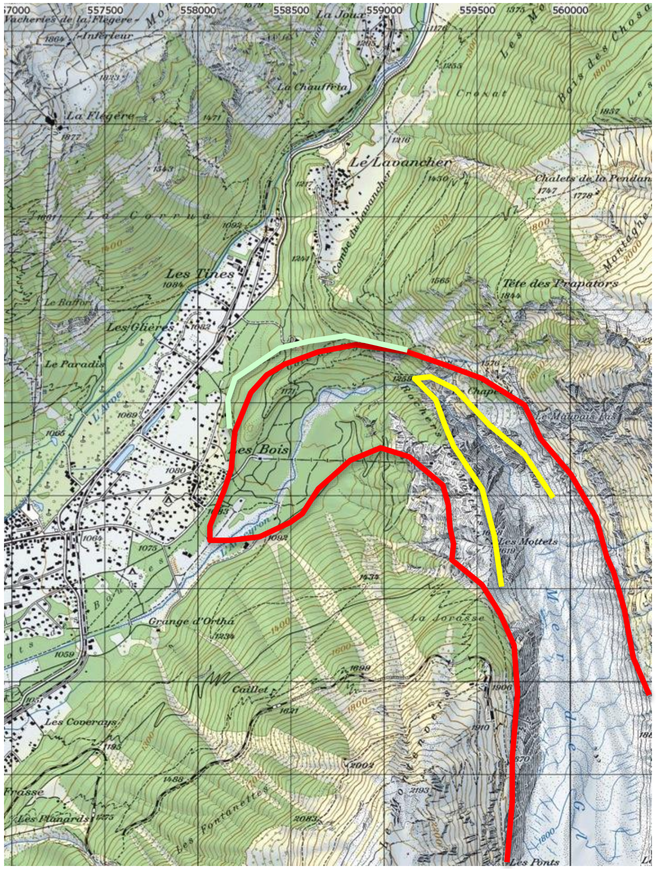

Figure 16: *Three extension of the Mer de Glace glacier : Red: year 1821, Green: 1644,Yellow: 1895. D'après S. Nussbaumer (div. web sources). © 2014 swisstopo (BA14069).*

Figure 17: *Mer de Glace – Les Praz Gravure S. Birmann 1826*

Figure 18, stop 5: *Moraines, maximum extension of the Mer de Glace during the Little Ice Age*

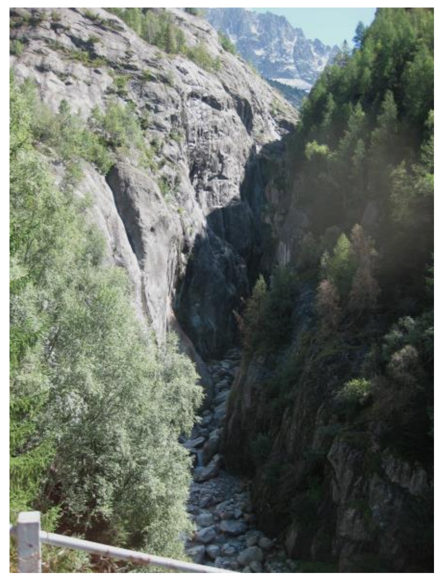

Figure 19, stop 6: *"Sources de l'Arveyron"; former sub-glacial canyon of the Mer de Glace.*

Figure 20, stop 7: *Current front of the Mer de Glace ice stream and pro-glacial lakes; view from "Le Chapeau".*