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Glacial landscapes of the Val d’Hérens (Valais, Switzerland)

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Content

Preface : the valley of the pyramids

We cannot imagine the Alps without their snow-white mountain peaks in front of a blue sky. And the glaciers tongues creeping down into the valleys in a ceaseless flow, which remains invisible to the naked eye. These mountains attracted the first tourists and climbers in the 19th century. During the same period, glacier advance in the valleys and on the pastures demonstrated to researchers the need for a better understanding of the glacier world.

In the early 19th century J.P. Perraudin, hunter and explorer of mountain crystals, observed the advance of the Giétroz Glacier, invading pastures and building new moraine ridges (Fig. 2). Alerted by Perraudin, Ignaz Venetz, engineer of the Canton Valais, discovered the formation of a glacial lake that emptied in 1818 , flooding the upper Vallée de Bagne.

Figure 1:*the pyramids of Euseigne are the key emblem of the Val d’Hérens and its glacial history. These “demoiselles" (ladies) wear a hat corresponding to the residues of glacial ground moraine of the last ice age, at the meeting point of the Val d’ Hérence and Val d' Hérémence glaciers .*

During the annual meeting of the Swiss Society of Natural Sciences (SHSN) in Lucerne, Ignaz Venetz emitted the revolutionary idea that glaciers may have had in the past a much larger extension than that observed by himself and his contemporaries. Louis Agassiz took up the idea of an extension of glaciers outside the Alps. In his speech to the SHSN in 1837, published in 1840, he depicted the climate change responsible for the extension of an ice cap that would have covered most of the northern hemisphere. Between 1840 and 1845, the glacial theory was adopted worldwide.

This is why and how was started the development of the “glacial theory” and the science of glaciers called “glaciology”. The latter is based, at least partly, on glacier observations in Valais.

Since then, things have changed. Glaciers had advanced in the valleys during the 16th century, at the beginning of the period known as the "Little Ice Age”. After a number of fluctuations they reached their last maximum extension in 1850. Afterwards, glacier tongues retreated again. And even though they have not yet reached today the reduced position they occupied in Middle Ages times, one observes the trend of current climate change towards a return to a warmer climate period. And because any change is a challenge in people’s mind, there is a strong public interest for the glaciers and their transformation.

In the Val d’Hérens there are neither the longest glacier tongues, nor the highest mountain peaks of the Valais. But this valley offers, through its landscapes, glaciers and rivers, and also its flora, extraordinary conditions for the observation of natural processes and landscape changes. The valley reveals to our eyes ideal didactic conditions to study the facts and processes of the recent glacial history.

This guide presents a brief introduction to the main elements of glaciology, from ice formation mechanisms to erosion of the bedrock through ice and water. The following chapter focuses on the ancient glaciations and the next one on the imprints left by the warm Middle Ages period and the history of the Little Ice Age.

The guide finally proposes field visits on the theme of glacier return in the Alps at the end of the last glaciation. Four sites along the road from Sion to Evolène illustrate this period. Finally, a field trip follows the way of the retreating Mont Miné end Ferpècle glaciers from the Little Ice Age till now.

***Figure 2**: the Gietro Glacier between Mont Pleureur and Mont Mauvoisin, glacial lake (Val de Bagnes, VS), painting by H. C. Escher, le 23 July 1818. Drawing and watercolor, 26 x 26,5 cm , collection ETH Zurich (n° 223 = Inv. C XII 13b).*

1. Introduction to glaciology

1.1 From snow flakes to ice

Water chemistry and physics

- **Chemical formula**: H_2O, dihydrogen monoxide, hydrogenol, hydrogen hydroxide, dihydrogen oxide.
- At sea level, water is found in **3 states** according to temperature conditions:
  gas > 100°C < liquid > 0 °C solid
  vapour water ice
- **Density**: varies according to temperature, pressure and state:
  99 °C: 958.4 kg/m^3 (liquid, at 100 °C: evaporation)
  4 °C: 999.973 kg/m^3 (liquid, highest density)
  0 °C: 999.841 kg/m^3 (liquid)
  0 °C: 917 kg/m^3 (solid: dilatation of ca. 10% when freezing)
- Fusion **(melting)** energy of ice is 333 $kJ \cdot kg^{-1}$

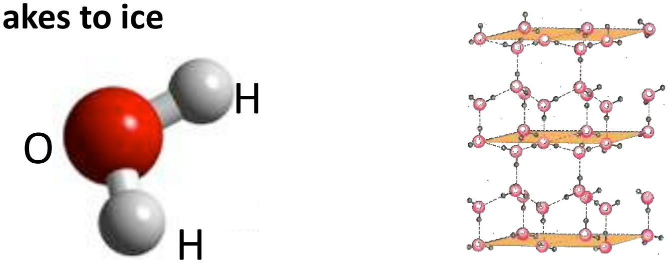
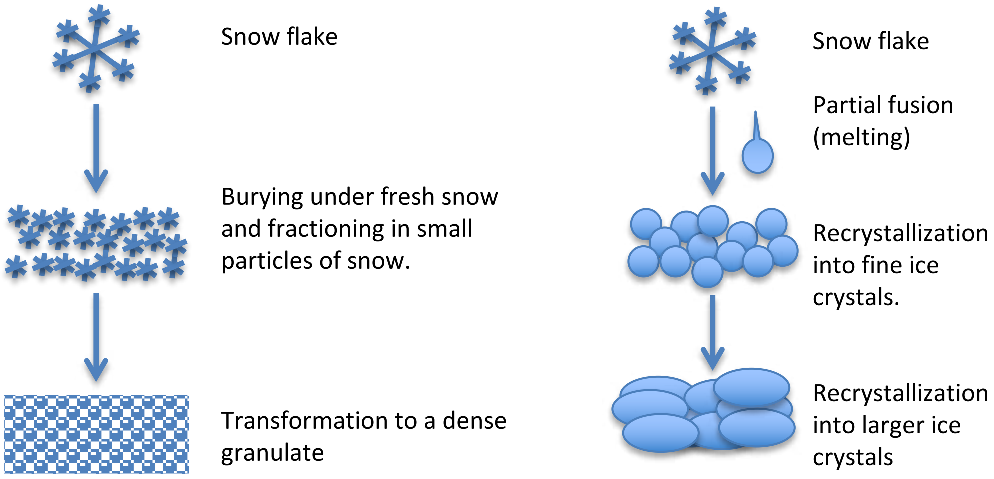


Figure 3: *structure of water and ice.*
http://www.ressources.cfadf.com/pensee/chimie6.htm

Ice forms at a temperature below 0°C from water molecules and forms a crystalline lattice (Fig. 3): every oxygen atom (in red on the figure) is surrounded by four similar atoms, with the intercalation of a hydrogen atom. As shown in figure 3 (right) oxygen and hydrogen groups are arranged in layers. Within these layers, the distance between atoms is smaller than the distance between two layers. Similar layered crystalline lattices are known from phylosilicates, such as clay minerals and mica.

Figure 4: *main processes of ice formation in a mountain glacier:*



Burying and compaction of snow (cold glaciers)

Snow flake

Burying under fresh snow and fractioning in small particles of snow.

Transformation to a dense granulate

Fusion (melting) - recrystallization of snow (temperate glaciers)

Snow flake

Partial fusion (melting)

Recrystallization into fine ice crystals.

Recrystallization into larger ice crystals

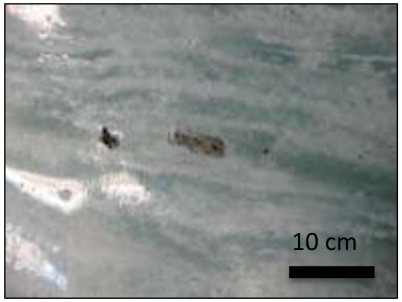


Figure 5: *artificial ice tunnel at the Mer de Glace, Chamonix (France): laminated ice with white layers of air bubbles and rock debris.*

1.2 Ice balance of a mountain glacier

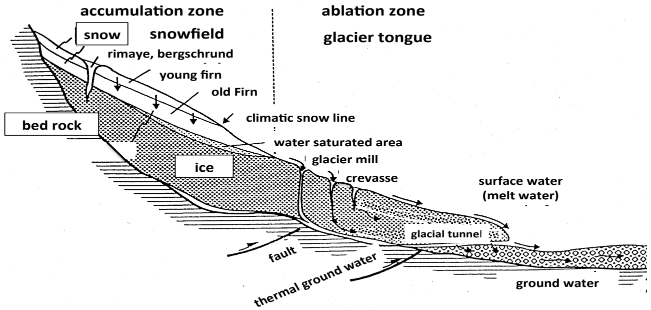


Figure 6: *section of an Alpine glacier: fresh snow accumulates on the glacier surface during the cold season (autumn – spring) and melts away at low altitudes during summer. In elevated positions snow transforms to firn and consolidates into «old firn» and ice through melting and freezing processes.*

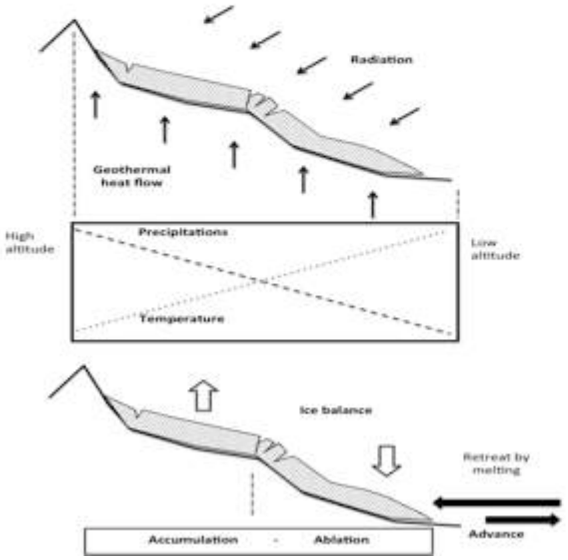


Figure 7*: main parameters of the ice balance and glacier front position: temperature, precipitation and geothermal heat flow*

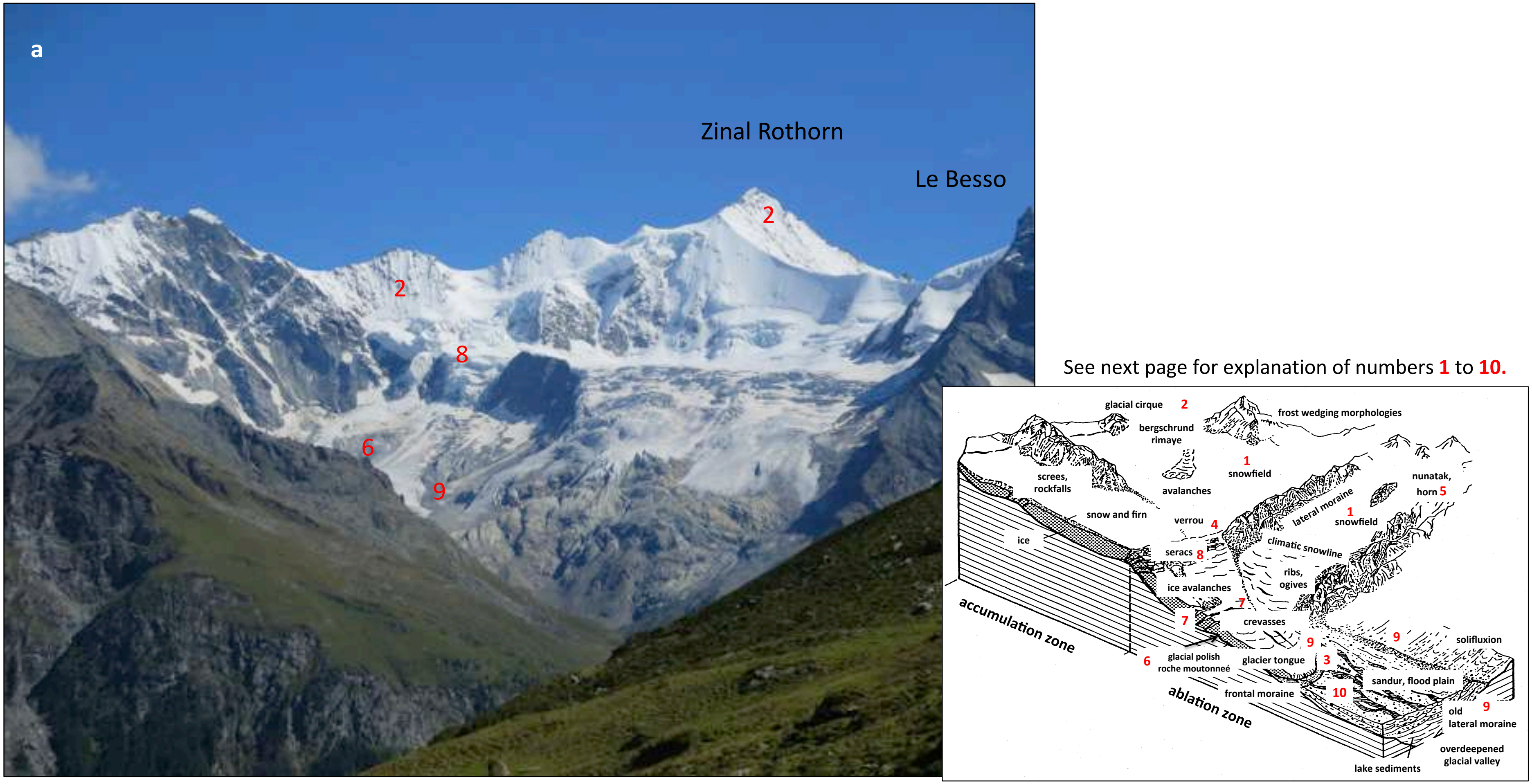
The «accumulation zone» of a glacier is the area where the ice balance is positive during a hydrological year (October 1st till September 30th). This zone is limited with respect to the «ablation zone» by the «equilibrium line». The ice balance corresponds to the difference between accumulation and ablation (ice melting) expressed in the equivalent volume of water over a hydrological year. When the ice balance is negative, the glacier «retreats» (figs. 6 and 7), which means that its tongue is shortening. The mass balance has also to consider the glacier movement: glacial ice is moving through viscous flow and sliding from the snowfield to the valley, i.e., from the accumulation to the ablation zone.

Figure 8: *glacial tunnel at the front of the Mont Miné Glacier, October 2012, on a cold day*

The water of a glacier originates from precipitations, and eventually from avalanches. The loss of water may be due to sublimation (direct evaporation from solid snow), or to ice melting and water runoff on the glacier, within the glacier or at its base through the glacier stream.

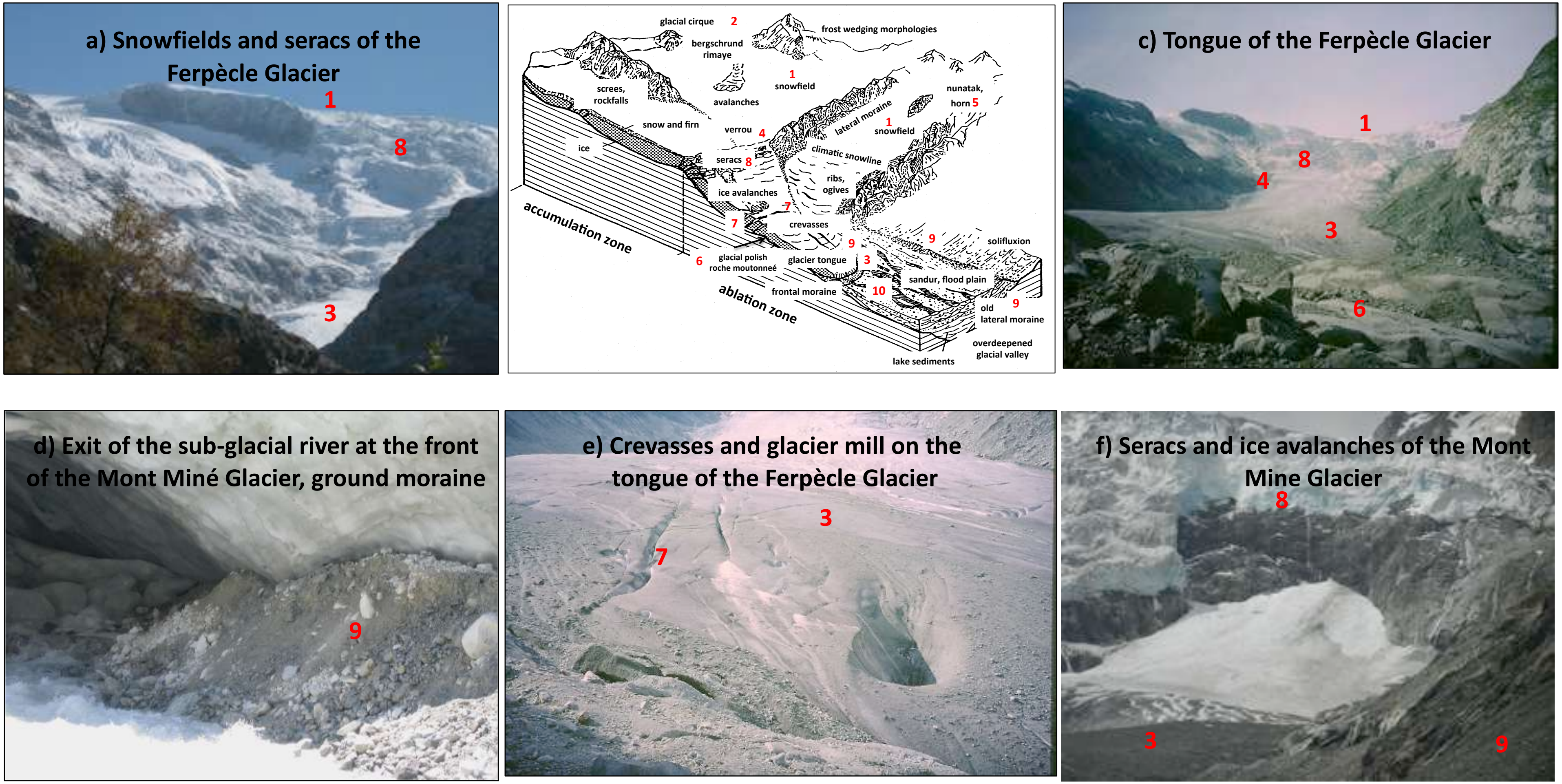
1.3. The glacial system

Figure 9a-b: *glacial system of the Zinal Rothorn (view from the Sorebois Alp– Zinal, Val d'Anniviers)*



See next page for explanation of numbers **1** to **10.**

Figure 10: *the glacial system and its components*



a) Snowfields and seracs of the Ferpècle Glacier

c) Tongue of the Ferpècle Glacier

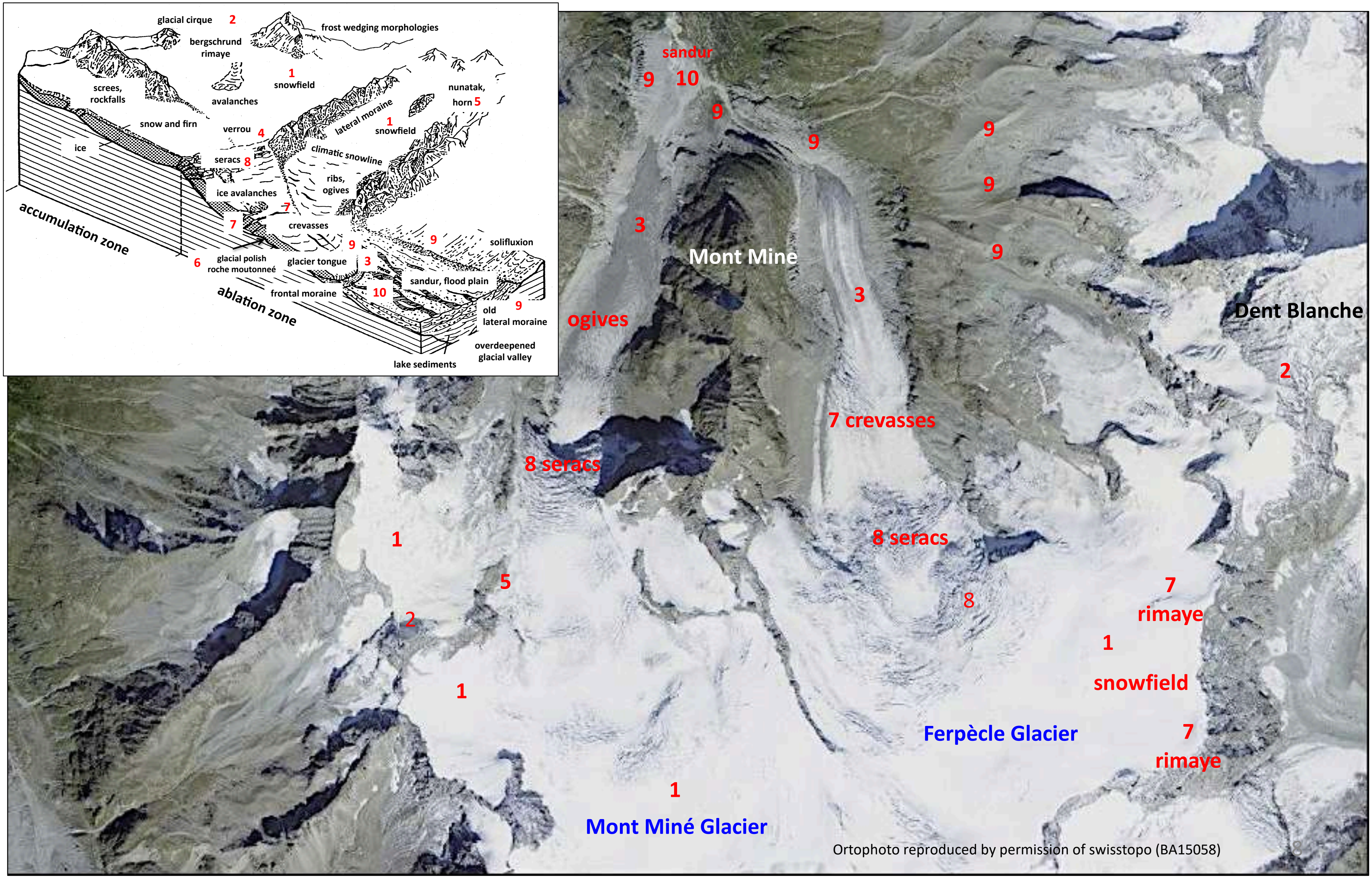
d) Exit of the sub-glacial river at the front of the Mont Miné Glacier, ground moraine

e) Crevasses and glacier mill on the tongue of the Ferpècle Glacier

f) Seracs and ice avalanches of the Mont Mine Glacier

Snowfields 1 are located in the **glacial cirques 2** covered with snow down to the **climatic snowline**. The **glacier tongue 3** drains the ice formed on the snowfields. A **verrou 4** corresponds to a restricting of the glacier tongue through a threshold and other rocky obstacles. **Nunataks** (horns) **5** can emerge from the ice in places where the rock has withheld erosion. The rock beneath the glacier is often moulded in **«roches moutonnées» 6**, made of rock morphologies rounded by abrasion, ending with an abrupt fault and a depression. The **crevasses 7** are ice fissures due to internal stress (tensions) linked to glacier movements and bedrock topography, **«bergschrund»** or **«rimaye»** is the uppermost crevasse of the snowfield; the internal folds of the ice are known as **ribs or «ogives»**, the vertical water conduits are named **mills**. The **seracs 8** correspond to ice towers due to the rupture of the glacier on rocky thresholds. The rocky material eroded by frost, water, avalanches and wind at the base and on the slopes overlooking the glacier, is accumulated at the base of the glacier along the glacier tongue and at the glacier front as **ground moraines, side and front moraines 9**. After reworking and fluvial transport, gravel and sand are deposited on the **sandur 10** (proglacial flood plain) and on deltas of proglacial lakes.

Figure 11: *the glacial system of the Mont Miné- and Ferpècle glaciers*



Ortophoto reproduced by permission of swisstopo (BA15058)

1.4. Melt water

The flow regime of glacial streams depends of the season (glacial and nivo-glacial regime):

- Flow is reduced in winter, when landscapes are frozen and snow is accumulating on the glaciers.
- The snow cover is melting from spring (mostly April) till summer, when the flow of glacial streams reaches maximum values.
- In summer, quite often at the end of July, snow has disappeared from the lower part of the ice tongue. This is the beginning of intense ice melting, mainly during daytime. Glacial stream flow increases during the day and decreases during the night. The maximum flow occurs during the afternoon, but its precise time depends on the retention of water in the glacier itself.
- In autumn, solar radiation decreases and the flow becomes more regular during the day and between day and night time.

The contribution of thunderstorms to glacial flow is generally limited. The first millimetres of rain are retained by the glacial system and appear only after a certain time in flow diagrams of glacial streams.

At the outflow of the glacier, the glacial stream has a temperature close to 0°C. The Rhône River is the main collector of glacier water from the lateral valleys in Valais. In January, its water temperature varies between 4 and 5°C. In summer, its temperature may reach 10 to 11°C when it enters Lake Geneva, where surface waters reach temperatures of 20 to 22 °C. Bottom waters in the lake have temperatures of between 4 and 5°C in cold winters and 5 to 6°C in summer.

Glacier streams transport sediments produced by glacial erosion from the interface between glacier and bedrock. The white coloured runoff, also called "glacial milk", contains mainly sand and silt.

Nowadays, most of the glacier runoff flows to reservoir lakes built for the production of hydro-electricity. The sand transported by the glacial streams may cavitate turbines through abrasion and accumulate in the lakes.

Therefore, glacial streams first flow through sand traps. These are small artificial basins from which the water flows or is pumped into reservoir lakes. Such a facility may be observed in Ferpècle, when climbing to the Ferpècle- and Mont Miné Glaciers (Fig. 14f, g).

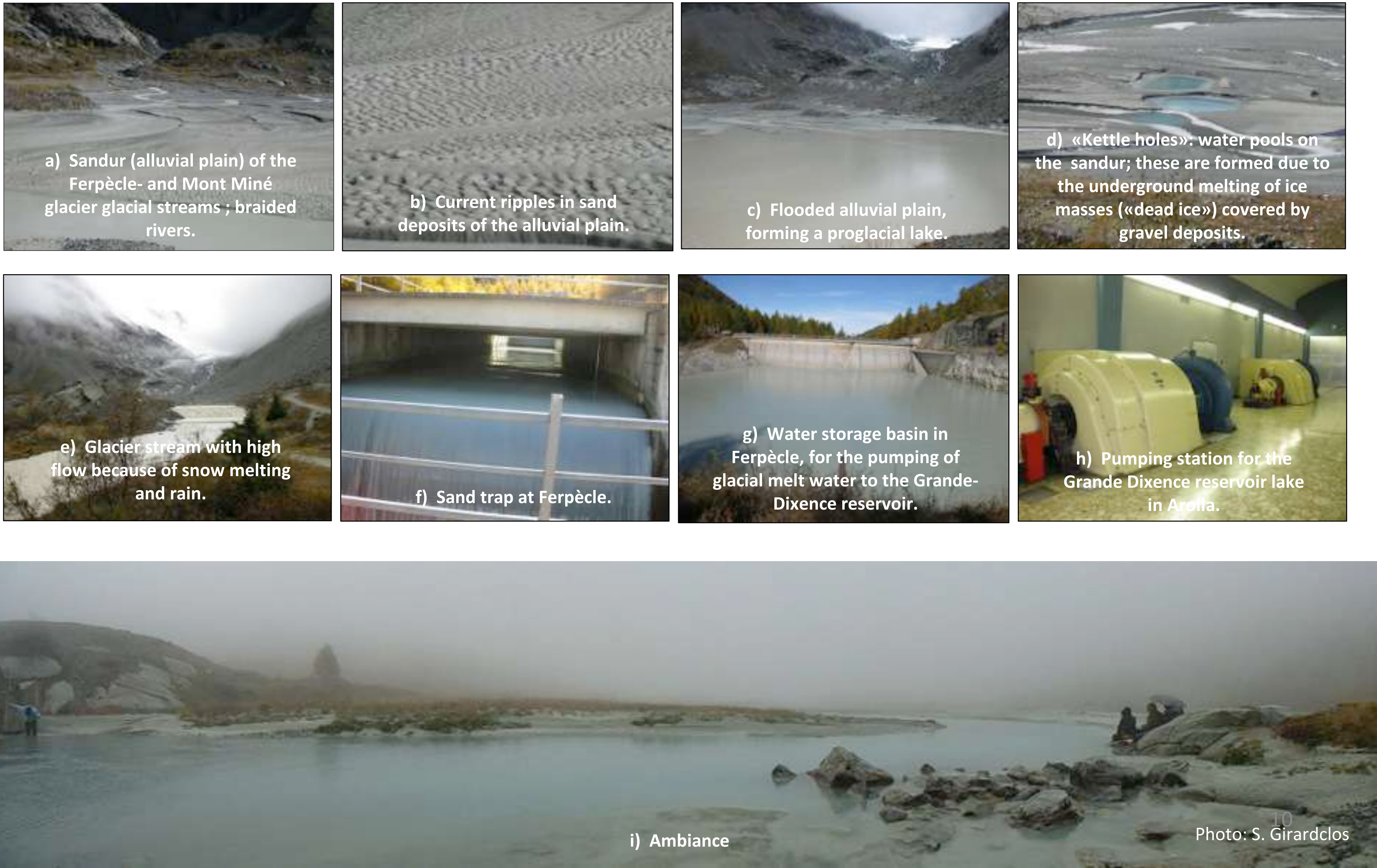
Despite the traps, part of the sediments still gets into the reservoirs where it accumulate. On a long term, they fill up the basins and have to be subsequently evacuated from time to time. However, reservoir flushing is not possible in all cases, mainly for ecological reasons, and reservoir flushing is generally not complete. The life time of reservoirs is therefore limited.

Downstream of reservoir lakes and water intakes, the river flow is strongly modified. Flow maxima are generally reduced, particularly during daytime and in summer. On the contrary, flow minima are less pronounced, particularly in winter, because of electricity production by hydro-electrical plants.

***Figure 12**: flow measurement of the proglacial stream by the salt dilution method.*

***Figure13:** classical measurement method for the flow of a proglacial stream: width and depth of the channel, flow velocity.*

***Figure 14:** melt water*



a) Sandur (alluvial plain) of the Ferpècle- and Mont Miné glacier glacial streams ; braided rivers.

b) Current ripples in sand deposits of the alluvial plain.

c) Flooded alluvial plain, forming a proglacial lake.

d) «Kettle holes»: water pools on the sandur; these are formed due to the underground melting of ice masses («dead ice») covered by gravel deposits.

e) Glacier stream with high flow because of snow melting and rain.

f) Sand trap at Ferpècle.

g) Water storage basin in Ferpècle, for the pumping of glacial melt water to the Grande-Dixence reservoir.

h) Pumping station for the Grande Dixence reservoir lake in Arolla.

i) Ambiance

Photo: S. Girardclos

1.5. Glaciers in movement

Mountain glaciers flow and glide. They behave at the same time as viscous fluids (plastic behaviour) and as brittle (elastic) bodies. Glaciers «flow» slowly and glide on their bedrock.

Viscous flow is produced by internal deformation of the crystals and by fusion/re-crystallisation. Furthermore, internal shear within the ice mass may contribute to this deformation. The main variable parameters of glacier motion are the following:

- ice temperature
- glacier thickness
- slope and roughness of the gliding surface
- presence and pressure of water at the glacier base

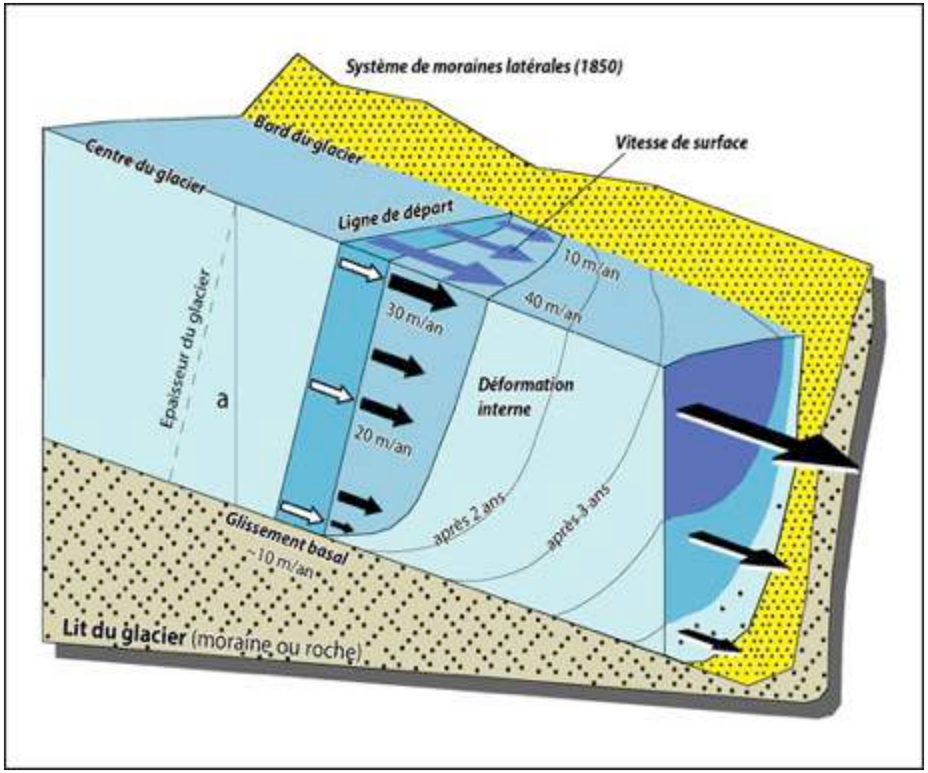
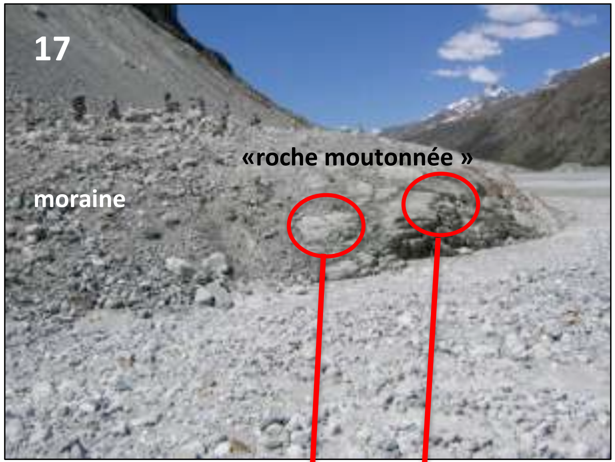
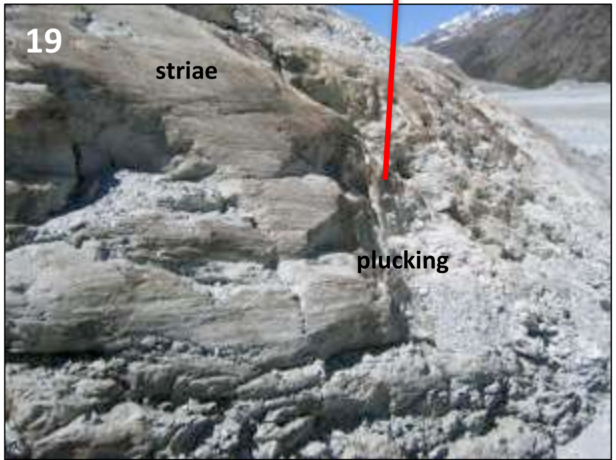


Figure 15: *the figure on the left illustrates the glacier movement: white arrows represent the glacier gliding on the substrate; black arrows represent the viscous ice flow, blue arrows correspond to the surface movement per year. In a similar way to water flow in a channel, ice velocity is at its maximum at the centre and surface of the glacier, where the effects of basal and lateral friction are minimum. The minimum velocity occurs along the areas of friction with the glacier bed. (Teaching support 2.1.2 of the Swiss geomorphological society, C. Scapozza, adapted from Maisch 1993).*

Figure 16: *overthrusts of ice layers in the frontal area of the Arolla-Glacier: overthrusting may occur when the glacier is frozen to the ground, mainly in the frontal part of the ice tongue.*

1.6 Glacial erosion





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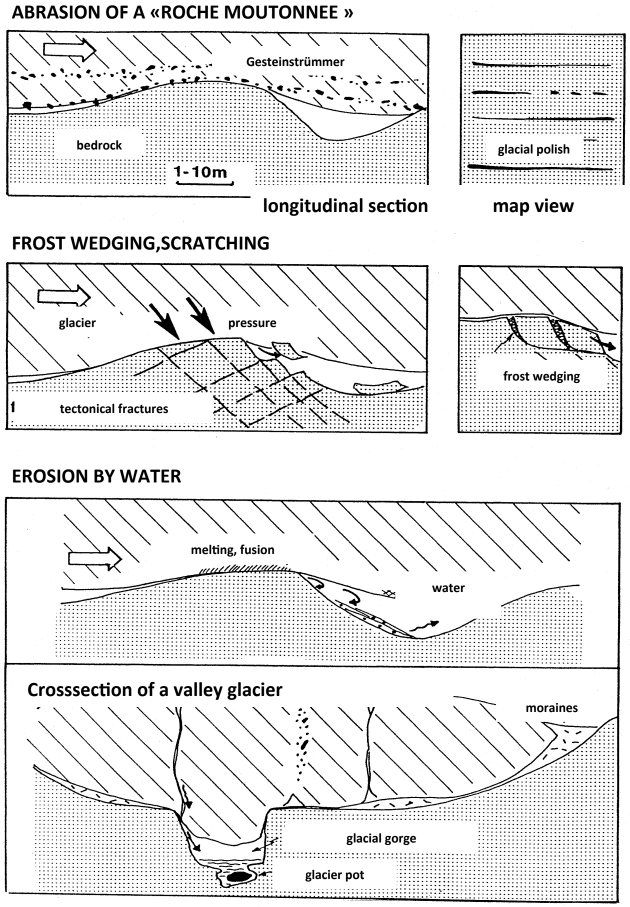


Figure 17: *"roche moutonnée" , Mont Miné Glacier*
Figure 18: *glacial striae on the surface of the "roche moutonnée" Fig. 17 .*
Figure 19: *rock plucking along tectonic fractures.*
Figure 20: *diagram of glacial erosion mechanisms.*
Figure 21: *"roche moutonnée", fluo-colored lichen (Rhizocarpon geographicum) .*
22 and 23 *: cavitation and glacier pots in the frontal part of the Ferpècle Glacier, created by water-flow .*

1.7 Sediments of the glacial landscape

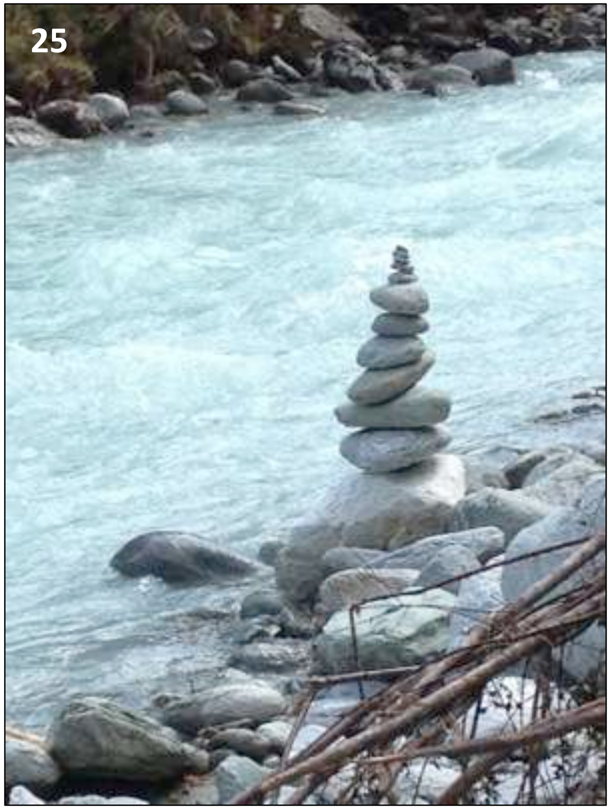


Figure 24*: glacial milk produced by bedrock abrasion; glacial stream of the Mont Miné Glacier; boulders and blocks formed by plucking and then rounded during river transport.*

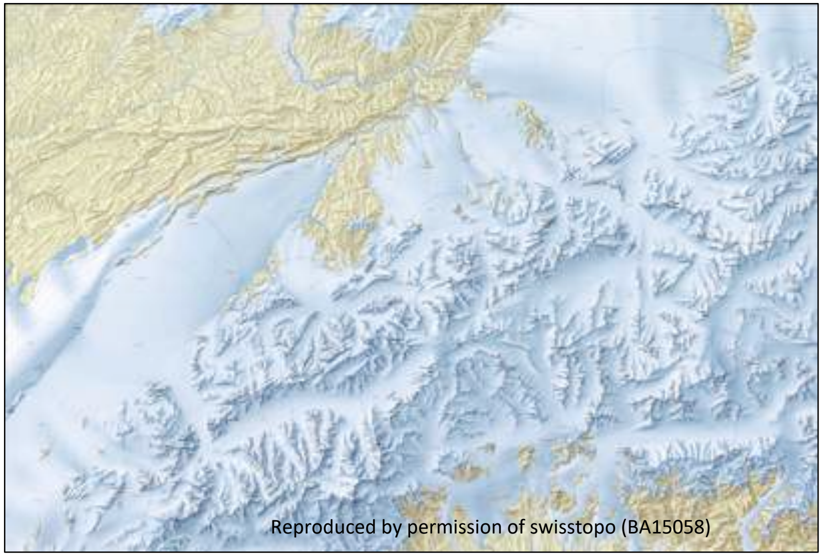
Figure 25: *"ice- milk" in Navisence River, Zinal (photo Lucie Wildi).*

Figures 26 and 27: *rocks crushed and broken by the ice pressure appear at the base of the Mont- Mine-Glacier. These images illustrate the formation of blocks by plucking, which are then transported either in the sub-glacial stream, or caught in the moraine.*

Figure 28*: the moraine (here the left lateral moraine of the Mont Miné Glacier) is formed of abrasion material (sand and silt) and blocks from plucking at the base of the glacier or slope deposits (scree, landslides) from the slopes above the glacier. Currently, erosion by runoff creates vertical gullies and very pronounced ridges. Scree from this erosion accumulates downslope.*

2. Glacial history

2.1.Major climate changes at the origin of Alpine valleys and landscapes



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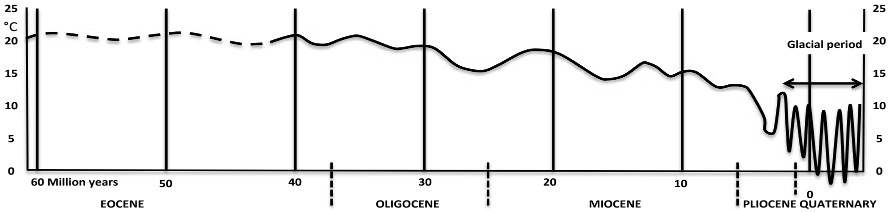
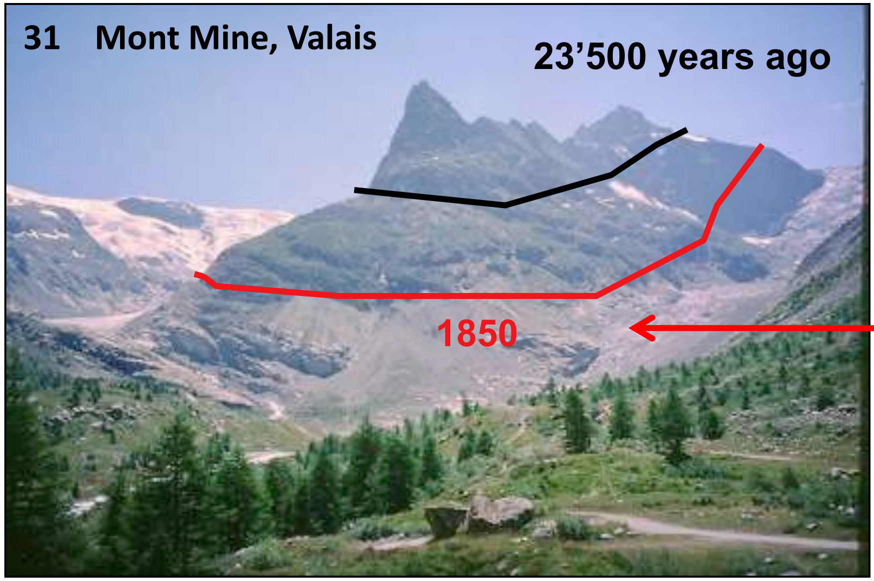


gletschergartenLuzern

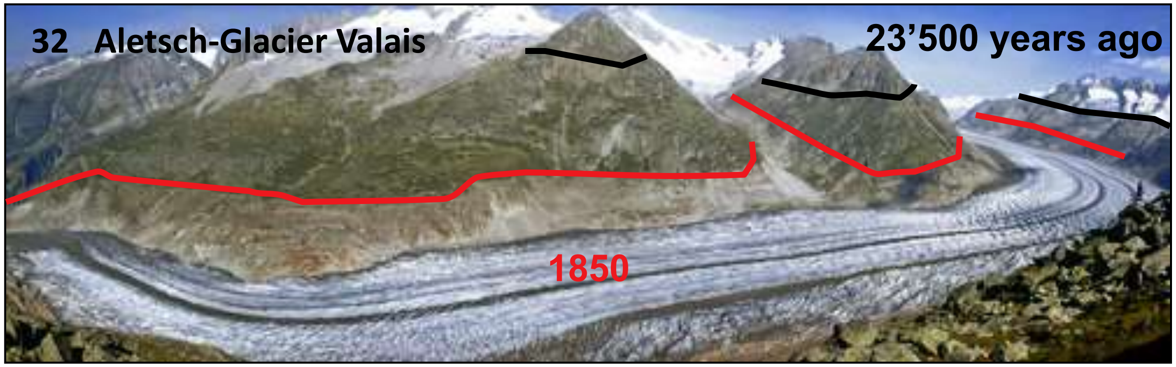
Figure 29: *this map represents Switzerland during the last ice age (Bini et al., 2009).* ***Figure 30 top:*** *changes in land temperatures from 60 million years ago till now;* ***centre****: Lucerne 20 million years ago;* ***bottom****: Lucerne during the glacial period (oil painting by Ernst Hodel, following a sketch of the geologist Albert Heim). These figures illustrate the landscape changes linked to major climate changes.*

The erosion of the Alpine valleys and Alpine foreland is mainly the work of glaciers (ice carving) during the ice ages that affected the Earth's climate during the last two million years. In the watershed of the Rhône River, the first indications of glaciations were discovered in the Lake Geneva basin 800 m above sea level. They date bact to around 800’000 years ago. This glacial period was followed by other cold periods separated by warmer interglacial periods, sometimes with a climate comparable to the present-day climate and sometimes even warmer. The last maximum extension of ice occurred globally slightly more than 20’000 years ago. The maximum extension of the Rhône Glacier occurred some 23’500 years ago.



Last glacial maximum

Little Ice Age



Figures 31 and 32*: the bedrock morphology allows the determination of the Alpine glacier extension during the last cold period, approx. 23’500 years ago. It corresponds to the upper boundary of glacial polish. Above this limit, rocks are altered and fragmented by frost (frost wedging) . The last maximum extension during the Little Ice Age around 1850 , appears to be the limit of the rocks affected by the recent erosion , where the vegetation of lichens and mosses has not yet completely covered the rocky surfaces.*

2.2. The Medieval Climate Optimum and Little Ice Age

Legends of Blüemlisalp and Manzettes

The first detailed presentation of the Blüemlisalp legends in the Val d'Hérens is from Röthlisberger (1976). Blüemlisalp is a magnificent mountain range reaching an altitude of 3664m amsl and located east of the village of Kandersteg (Bernese Oberland). Literature and oral tradition describe under the term "Blüemlisalp legends" (*Blüemlisalpsagen*) popular stories recalling climate periods milder than today.

In the Val d'Hérens, the legend is linked to that of passageways connecting the valley to the Zermatt region through high passes , especially the Col d'Hérens. In the Middle Ages, this footpath was indeed commonly used by the inhabitants of the Val d'Hérens, who went to church service on Sunday morning in Zermatt, or buried their dead in that same locality.

Note also that the footpath leading from Evolène through the village of La Sage to the Alp Bricola was probably already used by the Romans, as evidenced by silver coins found along the route and an inscription in Manzettes uphill of Bricola. There is also a legend about the presence of a former resthouse at the same time period.

We can recommend to anybody interested in the history and legends of the Val d’Hérens valley, and also in glacial and climate history, to read the book written by A. Fauchere (2014, p. 27 and below). This journalist, ethnobotanist and "rebel of the mountain" (http://www.a-fauchere.ch) presents information form official archives. Her story begins as follows: ”Once upon a time there was a king, rich and gay, whose name was Re Borah. His kingdom was located at the foot of Mount Miné, the centre of a magnificent Alpine world. . . ". The story continues with the drama of the advancing glaciers and the disappearance of the kingdom of Mount Miné with its mild climate. The author goes on with the historical analysis of glacier fluctuations in the valley compared to other glaciers and valleys in the region. He also extends the study of passages to other passes, and former connections with the Aosta Valley and Savoy. The proper interpretation to be given to these stories is obvious: during the Roman era and the Middle Ages, glaciers were strongly reduced with respect to their present-day position. Alpine valleys counted a large population, living from the exploitation of rich and fertile pastures, up to an altitude of over 2’600m amsl. This "Medieval Warm Period" lasted at least until the 13th century.

Climate Optimum and Little Ice Age

From the 10th until the 13th century, the Earth northern hemisphere enjoys a period od exceptionally mild climate, called "Medieval Warm Period". This is a time during which wineyards were grown in England and a large population settled in Greenland, the green country. And it is certainly to this period that the Blüemlisalp and Manzettes legends date back. The following climatic deterioration in stages which affected vulnerable regions, such as the Alpine valleys, Scandinavia and Greenland, led to famine and significant migrations. In the Chamonix valley (France), within 100 km from the Val d'Hérens, the advancement and fluctuations of the largest glacier in the valley, the Mer de Glace, have been reconstructed by Nussbaumer et al. (2007) for the period spanning from the 16th century till now (Fig. 33). The authors postulate a first advance of the ice tongue of more than one kilometre within about 50 years, and some variations until the last peak in 1852. The retreat then takes place in several steps: the glacier tongue first shortens of approximately 1’200 m within 30 years (40 m/year). A rather stable glacier tongue with minor fluctuations is then reported from about 1880 till 1930. The next phase of glacial retreat, from 1930 till 1970,

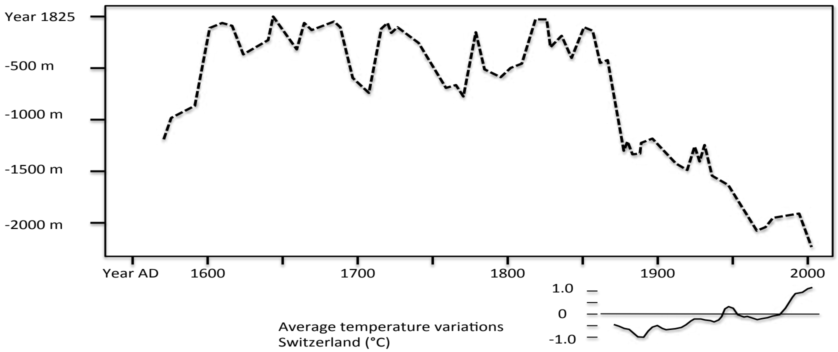


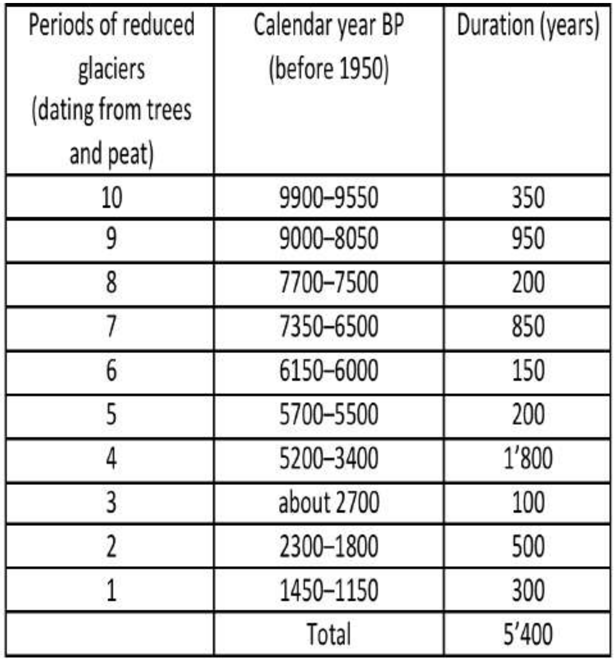
Figure 33, top: *length fluctuations of the glacier tongue of the Mer de Glace in Chamonix-Mont Blanc (France) from 1550 until 2001 AD (Nussbaumer et al. 2007); interpolated curve . The 1825 reference point corresponds to a boulder.* ***Figure 33, bottom****: Changes in average temperature (instrumental measurements; moving average over 20 years) for Switzerland from 1864 till 2012 ; reference period : 1961-1990.*

produces a reduction of the glacier tongue of some 800 m (20 m/year). The following phase of stagnation spans from about 1970 till 1995. In the present-day phase of rapid melting, the tongue of the Mer de Glace is losing some 35 m per year in average (see Fig. 33).

In the Val d'Hérens, the climatic variations since the end of the last Ice Age, about 10,800 years ago, are well documented. A recent research study describes in particular the course of the Little Ice Age (Nicolussi K., Le Roy, M., Schlüchter, Ch. et al. 2022): *"The term 'Little Ice Age' (LIA) is classically used to define a period of repeated and extensive glacier advances during the last millennium. In the meanwhile, this term is also used to address the period of relatively low temperatures between the Medieval Climate Anomaly (MCA), or Medieval Warm Period, and present-day warming. The end of the LIA is generally set to the mid or late 1800s CE, however, the published onset dates of the LIA are more variable from the mid 1200s to the late 1500s".*

Table *on the right handside: periods of reduced Alpine glacier extension, inferred from the age of trees and peat which appear under the glacier tongues (adapted from Schlüchter & Jorin 2004). This table shows the climatic variations , expressed by the extension of the glacier tongues in the Central Alps since the end of the last ice age some 10'800 years ago .*

Figure 34*: tree trunks, more than 8200 years old, which appeared in the moraine under the Mont Miné Glacier at an elevation of 2000 m (photo 2010).*



Periods of reduced glaciers (dating from trees and peat)	Calendar year BP (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	about 2700	100
2	2300–1800	500
1	1450–1150	300
	Total	5'400

"At Mont Miné and Morteratsch glaciers, Swiss Alps, we sampled and subsequently analysed detrital as well as in situ tree remnants from the early LIA period. At both glaciers, trees with lifespans of up to about 400 years were buried at various lateral moraine sites. The corresponding advance of both glaciers can be traced from the 1280s until the 1310s. At Morteratsch glacier, this early LIA advance phase culminated likely around 1375 CE. Evidence collected at both glaciers indicates that the ice surfaces were at least c. 12–15 m from the lateral moraine crests deposited during the maximum extent of the LIA. This suggests a similar (though very slightly weaker) magnitude than later LIA advances at our sites. The advances of Mont Miné and Morteratsch glaciers coincide with relatively cool summer temperatures from the late 1200s to the late 1300s. Taken together, the onset of the Little Ice Age in the Alps can be considered to be c. 1260 CE.

The Little Ice Age was not a uniform period, but had several phases as can be derived from the records of Alpine glaciers and summer temperatures (from lichenometry). *We propose a subdivision of the LIA in the European Alps into an early (1260–1380 CE), an intermediate (1380–1575 CE) and a main (1575–1860 CE) phase."*

3. The glaciers of the Val d'Hérens

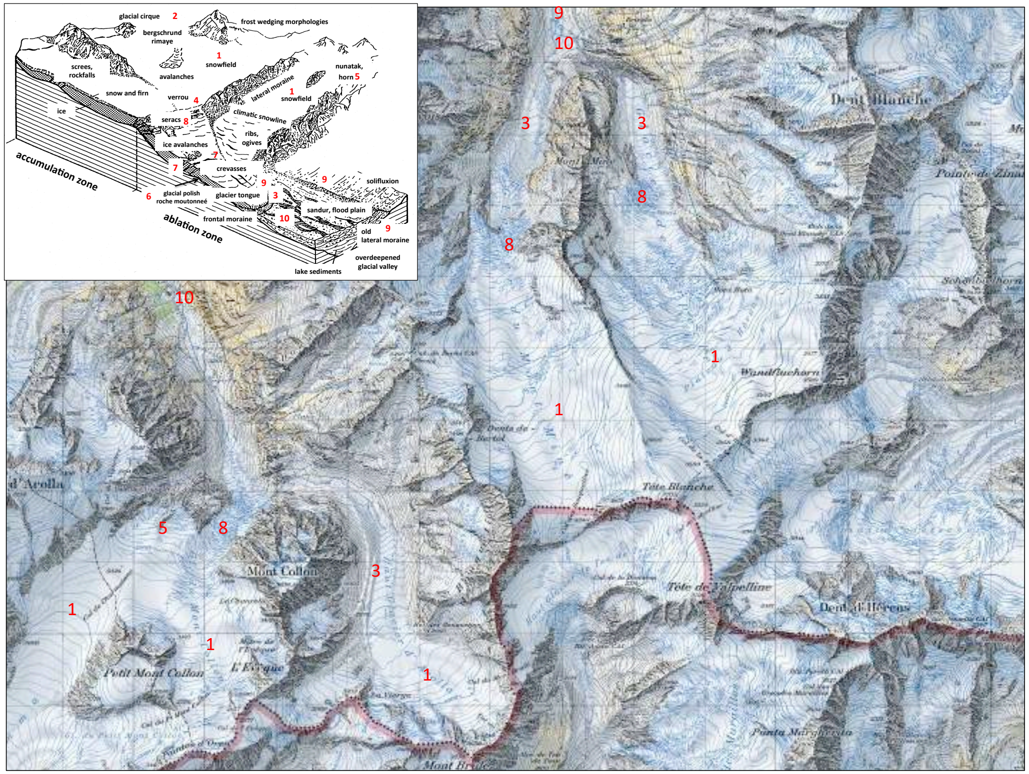


Figure 35: *topographic map of the glaciers of Val d'Hérens,* reproduced by permission of swisstopo (BA15058)

Figures 36 – 40: *most important glaciers in the Val d'Hérens under observation by the Swiss glacier monitoring network; situation 2015. (http://glaciology.ethz.ch/messnetz/?locale=en)*

36

Mont Miné Glacier

37

Photo: P. Kunz

Mont-Collon-Glacier

38

Photo: P. Kunz

39

Bas-glacier d'Arolla

40

Ferpècle Glacier

Glaciers	Length (km)	Surface (km^2)
Mont Collon	4.8	13.2
Mont Miné	8.4	11
Ferpècle	6.6	9.8

4. From the last glaciation till modern times and from Geneva to Ferpècle: the retreat of Alpine glaciers

The Earth is undergoing an ice age since two million years ago. Following a radical climate change, notably linked to the parameters of the Earth's orbit around the sun, glaciations characterized by the significant growth of ice sheets and mountain glaciers alternated during this period with interglacial intervals with a temporary decline of ice volumes. This story is accurately known thanks to changes in the isotope composition in marine sediments and cores from the ice sheets of Antarctica and Greenland. It is also documented in the Alpine regions through landscape morphologies and glacial sediments, but only for approximately the last 800’000 years. During this period, four to five major glaciations have left their imprint in the Alpine foreland (Fig. 41). However, the erosion in the Alps was so intense during the successive glaciations that only the morphologies of the last glaciation are still clearly recognizable. During this period, called “Würm" (126’000 till 11’700 years before present), glaciers in the Alps experienced two maximum phases of extension: the first one about 60’000 years ago and the second one approximately 23’500 years ago (in the Lake Geneva Basin). There are important differences between the two periods, depending on the region : whereas glaciers in the Eastern Alps had approximately the same extension during the two maxima, those in the Western Alps, including the Rhône Glacier, were less developed during the second maximum.

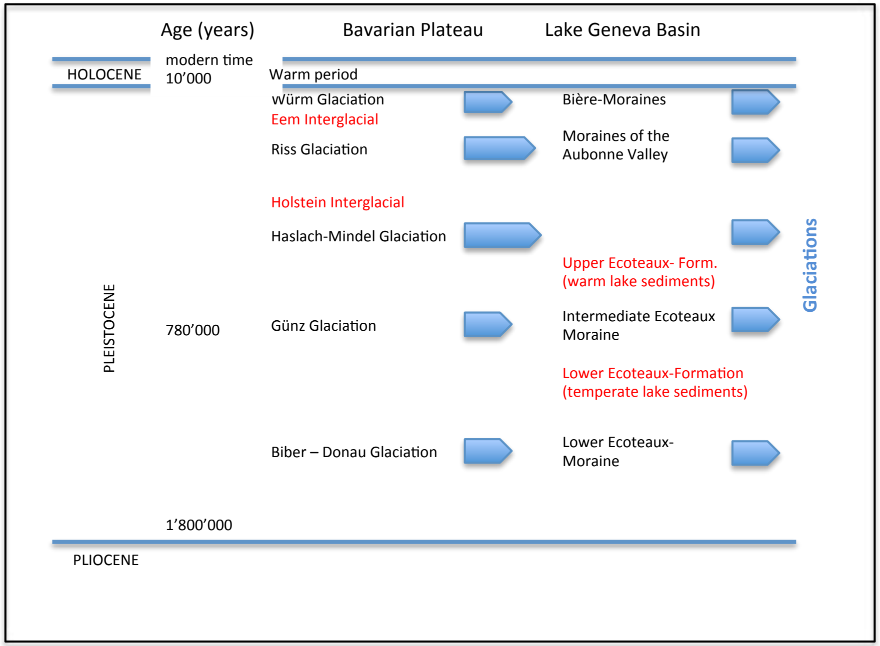


Figure 41: *glaciations in the Lake Geneva area: comparison with the Bavarian Plateau in the Eastern Alp foreland (Lih et al. 2002, simplified; Lake Geneva: Pugin et al. 1993)*

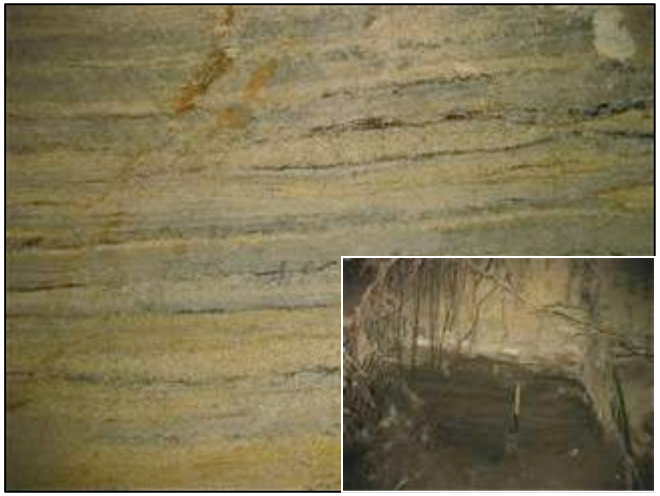


Figure 42: Lake Geneva region, lake sediments of the Upper Ecoteaux Formation. Remains of plants (pollen, leaves, branches, pine cones) indicate the presence of a lake with warm climate conditions, shortly before 780,000 years ago (magnetic field inversion). These sediments overlie the Lower Ecoteaux Moraine, the lake sediments of the Lower Ecoteaux Formation and the Intermediate Moraine (Pugin et al. 1993).

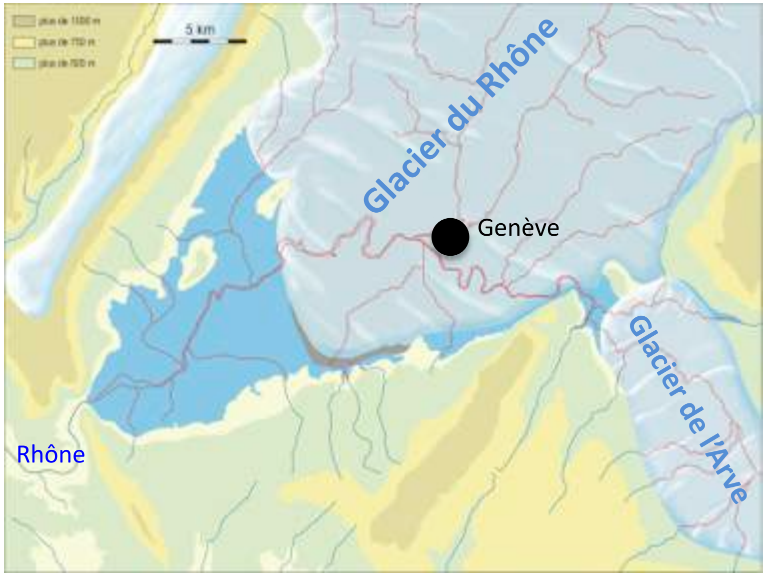
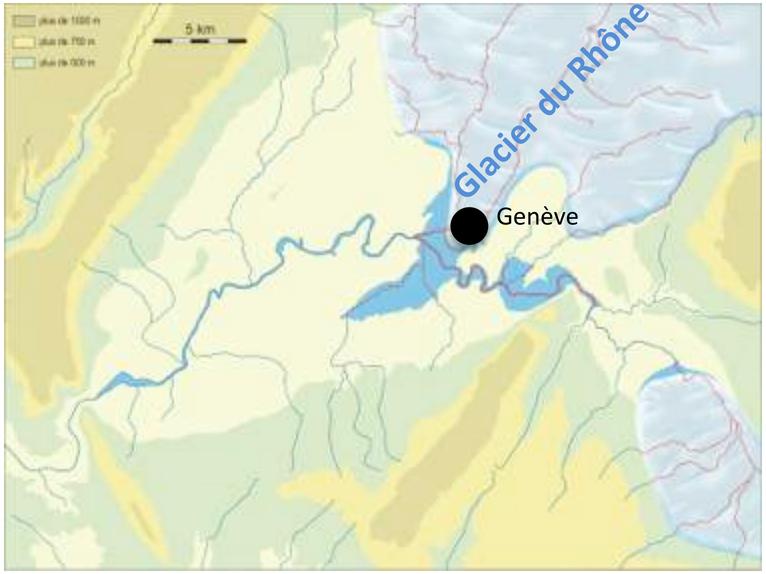


***Figure 44**: ca. 23’500 ago, last glacial maximum in the Geneva Basin, position of the Rhône Glacier close to Laconnex, 8 km west of the city of Geneva. The lake level was at 450 m amsl (Wildi et al. 2014).*



During the first part of the so-called Würm Glaciation, the Rhône Glacier was in contact with the glacier of the Durance upstream of Lyon. This was clearly no longer the case during the last glacial maximum of the Rhône Glacier about 23’500 years ago. At that time, moraines were formed in the Laconnex region, some 8 km west of Geneva, marking the most advanced position of the glacier (Fig. 44). The glacier front then advanced into a lake, with a level at about 450 m amsl (currently 372 m).

Some 22,500 years ago, the front of the Rhône Glacier had melted back to the present Geneva Bay (Fig. 45), and the lake level was located at 400 m amsl. Icebergs floated on the water and dropped blocks at the lake bottom, called dropstones (Fig. 46). This explains the presence of the Pierres du Niton in the Geneva Bay (Fig. 47).

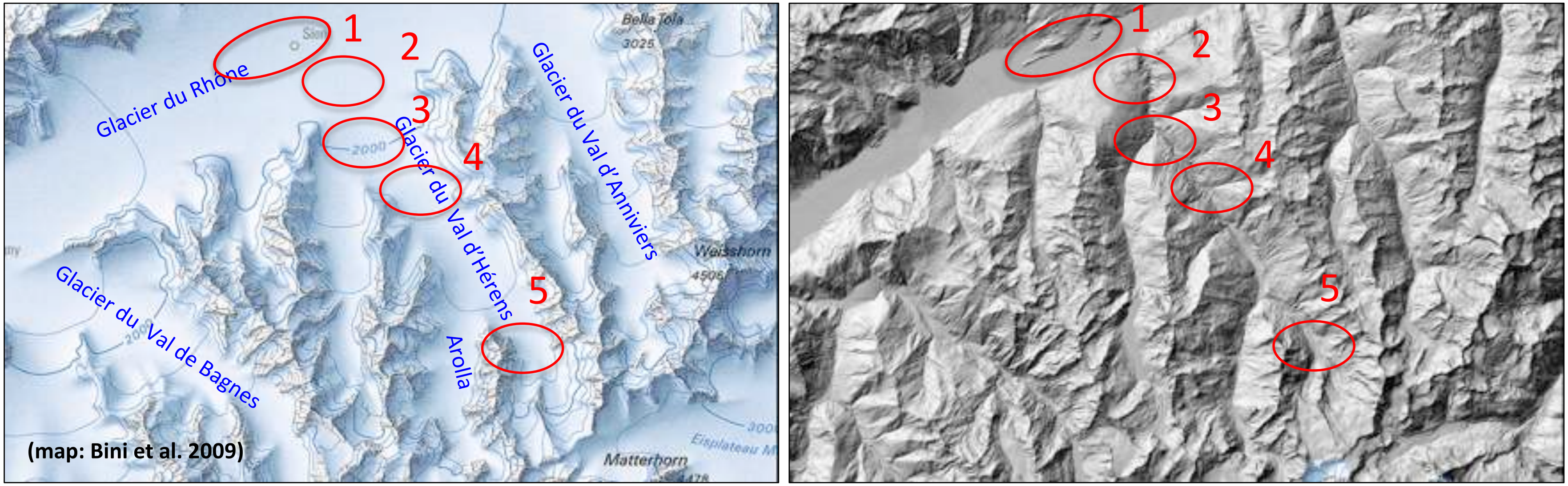
Upstream of Geneva one can follow the melting glacier tongue to Coppet and Nyon, where large moraines were deposited in Lake Geneva. When continuing upstream towards the Alps, only the moraine crests of Chexbres and Puidoux (southeast of the city of Lausanne) reflect another temporary halt of the Rhône Glacier in the Lake Geneva basin. Further upstream in the Rhône Valley, it is only in the lateral valleys of the Valais that one can find other landmarks in the deglaciation history.

***Figure 46:** Iceberg with erratic blocs (http://serc.carleton.edu/NAGTWorkshops/sedimentary/images/dropstones.html*

***Figure 47:** the Pierres du Niton, Geneva Bay; they are dropstones transported through icebergs in the proglacial Lake Geneva.*

***Figure 45:** 22’500 years ago: position of the Rhône Glacier in the Geneva Bay; lake level is at about 400 m amsl.*

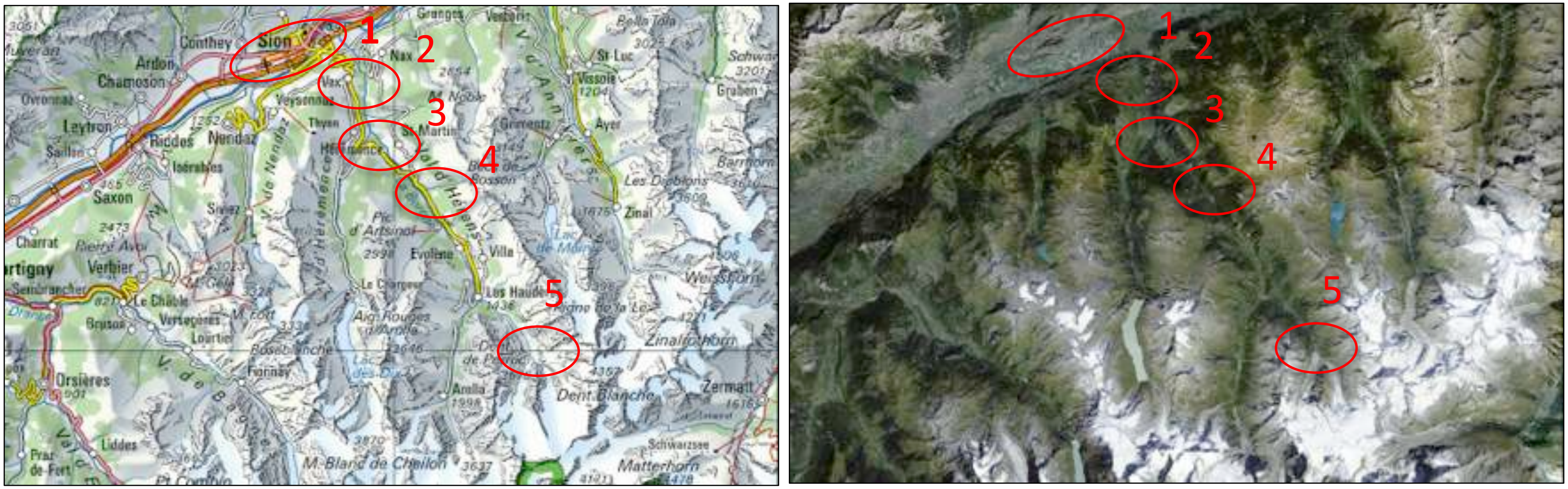
Figure 48a - d: *location of the glacial landscapes between Sion and Ferpècle described below*
(all maps reproduced by permission of swisstopo (BA15058))



a: *extension of the Rhône Glacier in the Sion area, ca. 23'500 years ago*

b: *DEM (digital elevation model)*

(map: Bini et al. 2009)



c: *topography*

d: *orthophoto*

1 The drumlins around the city of Sion

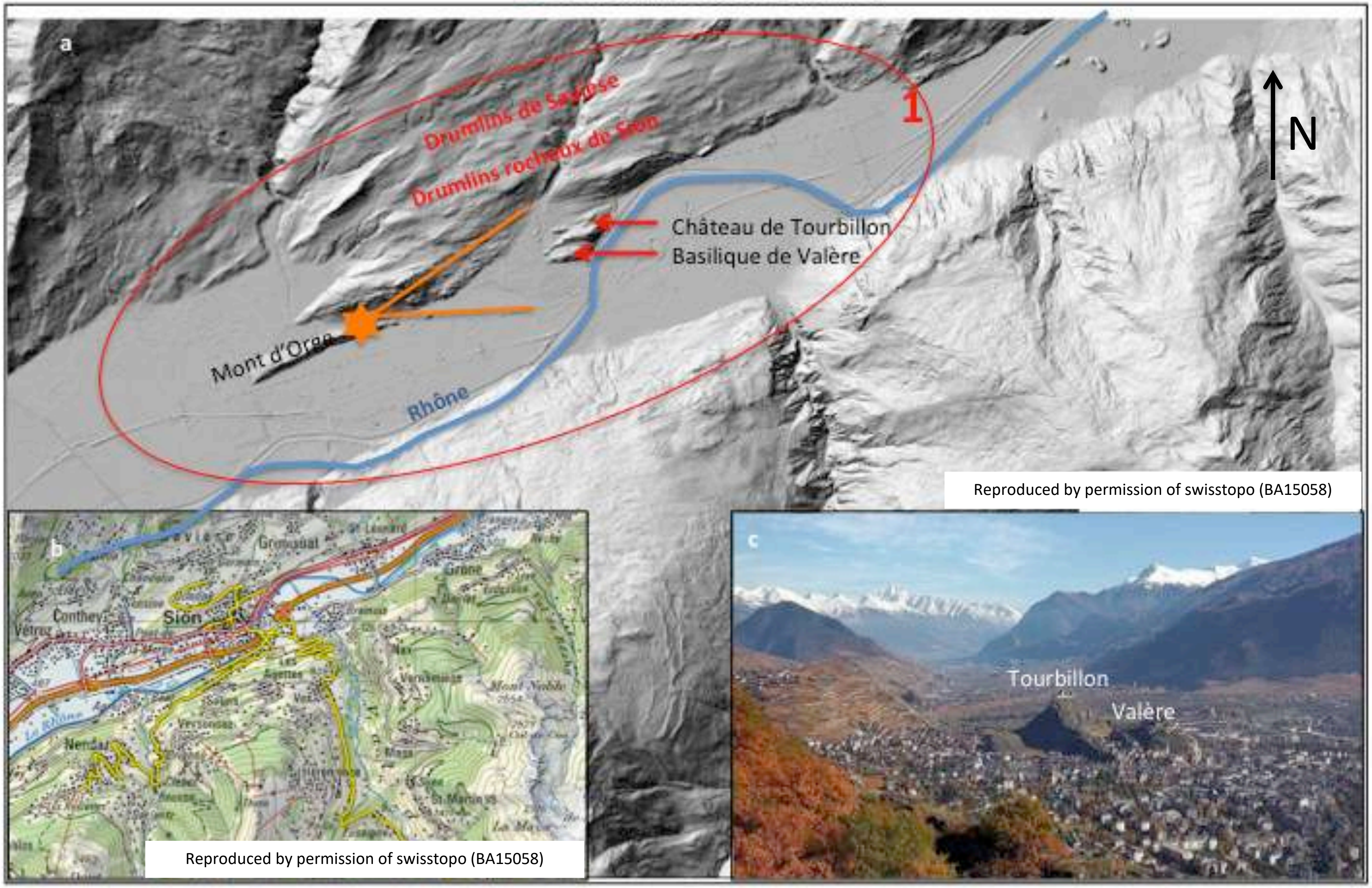


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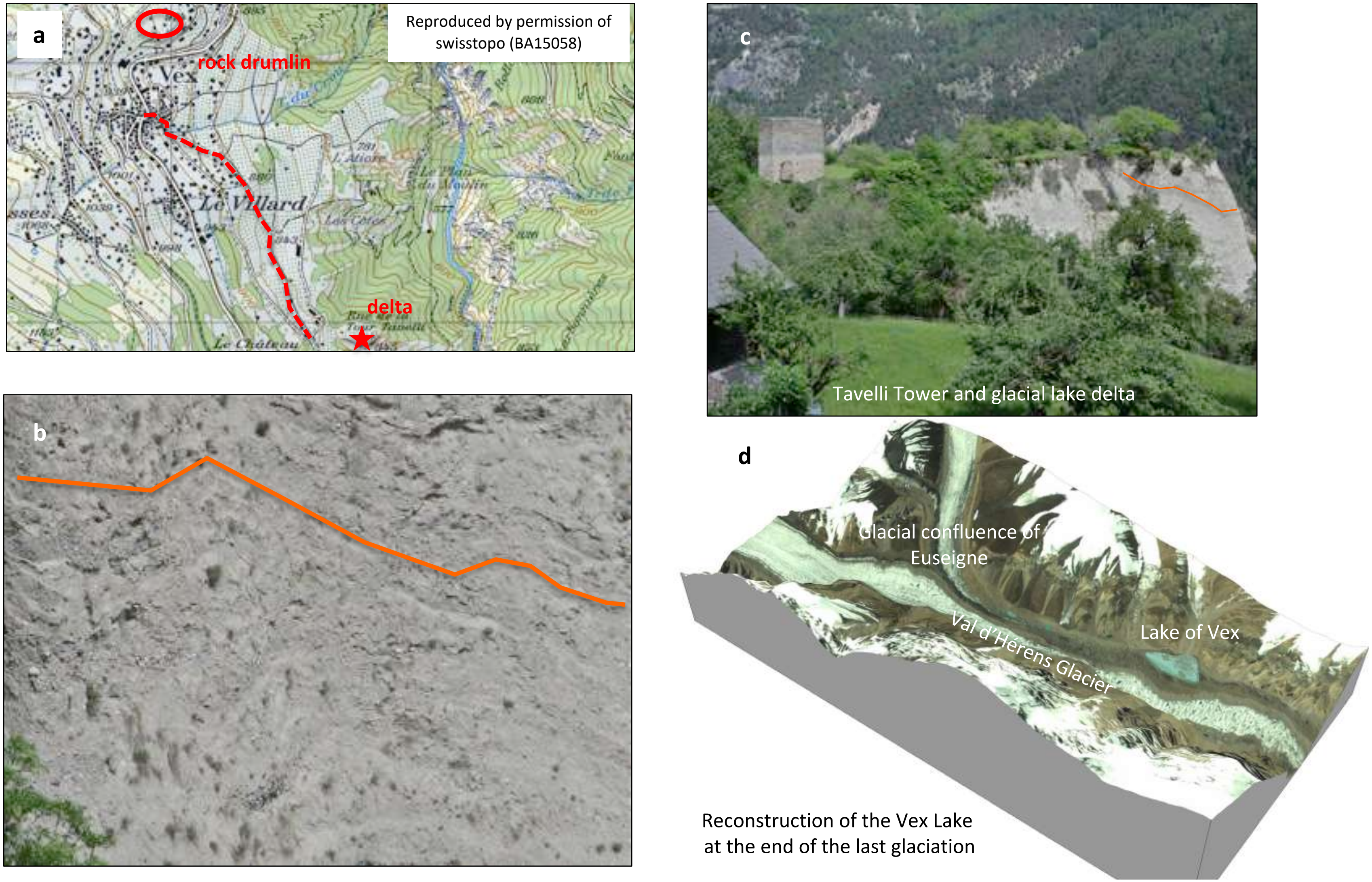
Figure 49a – c: *Mont d'Orge, Tourbillon and Valère are rock drumlins (or large "roches moutonnées") which whithstood glacial erosion. They stand out of the flood plain of the Rhône River which infill a more than 100 m deep valley carved through the glacier and sub-glacial water circulation. The infill of this valley consists of glacial sediments (moraines), lake (silts and sands) and fluvial sediments (gravels and sands the Rhône tributaries). The slope north of the Rhône Valley (red circle, Fig. 49a) is characterized through a series of drumlins ("elephant backs") which are the signature of the former gliding surface of the Rhône Glacier. The southern flank of the Rhône Valley is steeper and often marked through slope instabilities, resulting in glacial morphologies less preserved than on the valley northern flank.*

2 The glacial Lake of Vex



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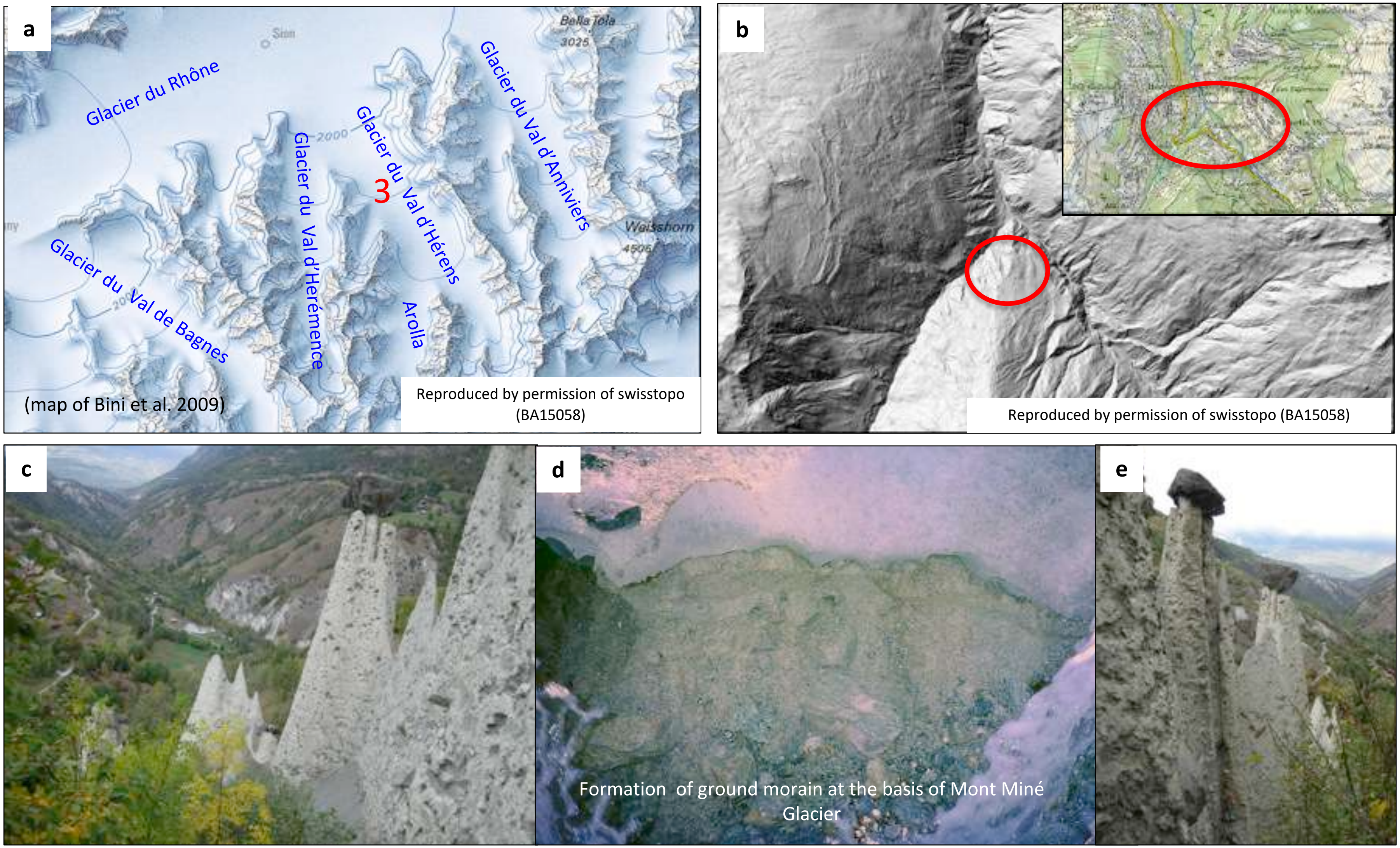
Reconstruction of the Vex Lake at the end of the last glaciation

Figure 50a - d: *The village of Vex is located in a landscape where the geomorphology is mainly related to the presence of moraines dating back to the last glaciation. To the north, a rock drumlin is overlooking the agglomeration. The Vex Delta is located downstream of the village, where stand the ruins of the Tavelli Tower, a small fortress from the 13th century: follow the hiking trail, a 20 mn walk from the village centre. The delta (Figs. b and c) dates back to the last retreat of the glacier (ca. 14'500 B.C.). A small lake basin was left on the eastern flank of the ice stream, into which a local river brought gravel and sand sediments dipping towards the glacier.*

3 The Pyramids of Euseigne



(map of Bini et al. 2009)

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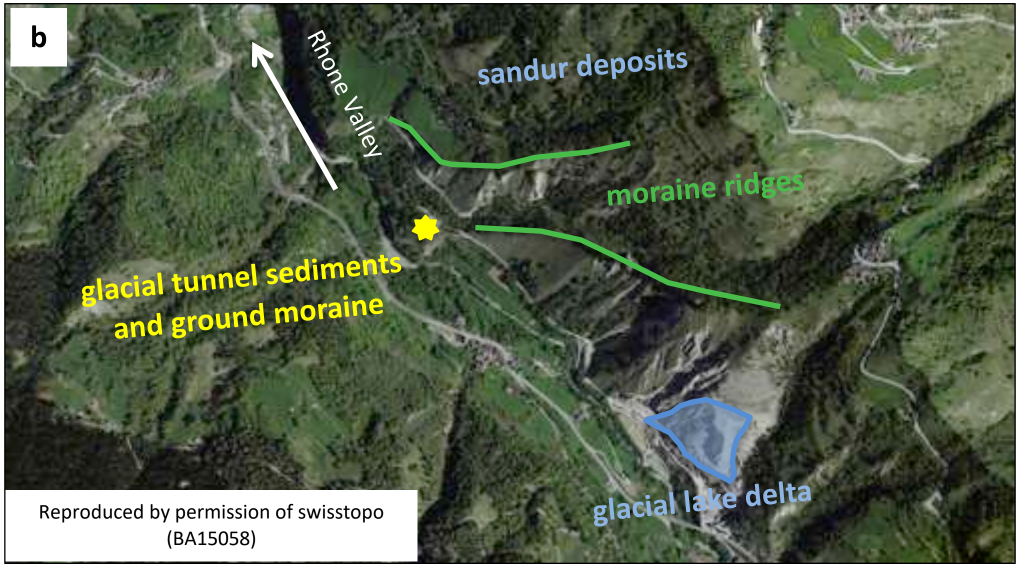
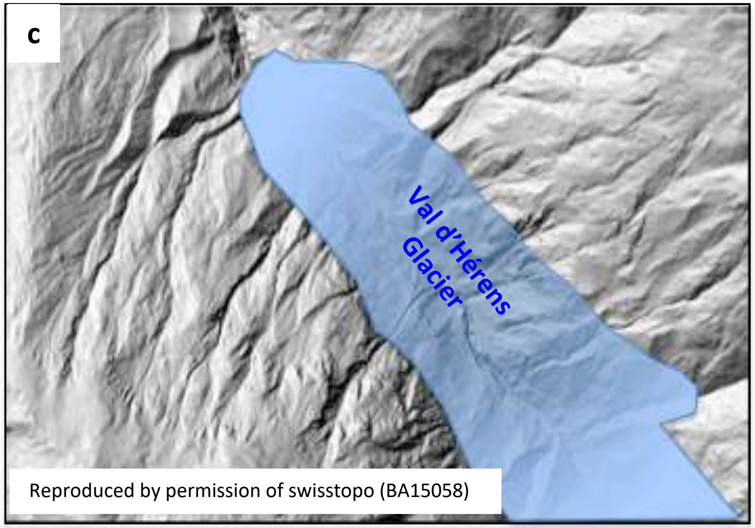
Formation of ground morain at the basis of Mont Miné Glacier

Figure 51 a - e: *during the last glaciation, the Val d' Hérémence and Val d' Hérens glaciers merged at Euseigne (Fig. a, b) to form a single valley glacier (confluence of Euseigne). A ground moraine made of silt, sand and blocks from the two glaciers was deposited on the ridge separating the two valleys. This moraine was compacted through the ice weight and cemented through water flowing in the fine pores of the deposit. Following the retreat of the glaciers, erosion shaped the moraine crest, preserving the pyramids (or "demoiselles" = " ladies "), with their hats (the latter are blocks preserving the underlying finer-grained moraine from pluvial erosion).*

4 The glacial stadium of La Luette



Reproduced by permission of swisstopo (BA15058)



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At the end of the last glaciation the melting trend of mountain glaciers was interrupted by short cold periods, with a duration of tens to hundreds of years. Subsequently, Alpine glaciers re-advanced, although modestly, leaving moraine ridges presently visible in the landscape. These cold periods are due to the “Heinrich events" (named after their discoverer): in North America, huge glacial lakes in the Great Lakes region emptied suddenly into the North Atlantic, bringing down the temperature at a global scale. The corresponding periods are called “Dryas " referring to the white flower close to the glacier front, *Dryas octopetala.*

Figure 52 a – c: *the moraine ridges of La Luette and other glacial sediments of subglacial streams and glacial lakes are evidences of a temporary temperature drop and halt of glacial meltdown. During this period, the Val d' Hérens Glacier re-advanced, re-occupying the valley for several centuries (ca. 14’200 – 13’000 before J.C. . ?), and left a lake when it retreated. The latter was rapidly filled up through sand and gravel. The site visit starts with a panoramic view from the main road and a walk on the small road that passes by the gravel pit.*

4 The glacial stadium of La Luette

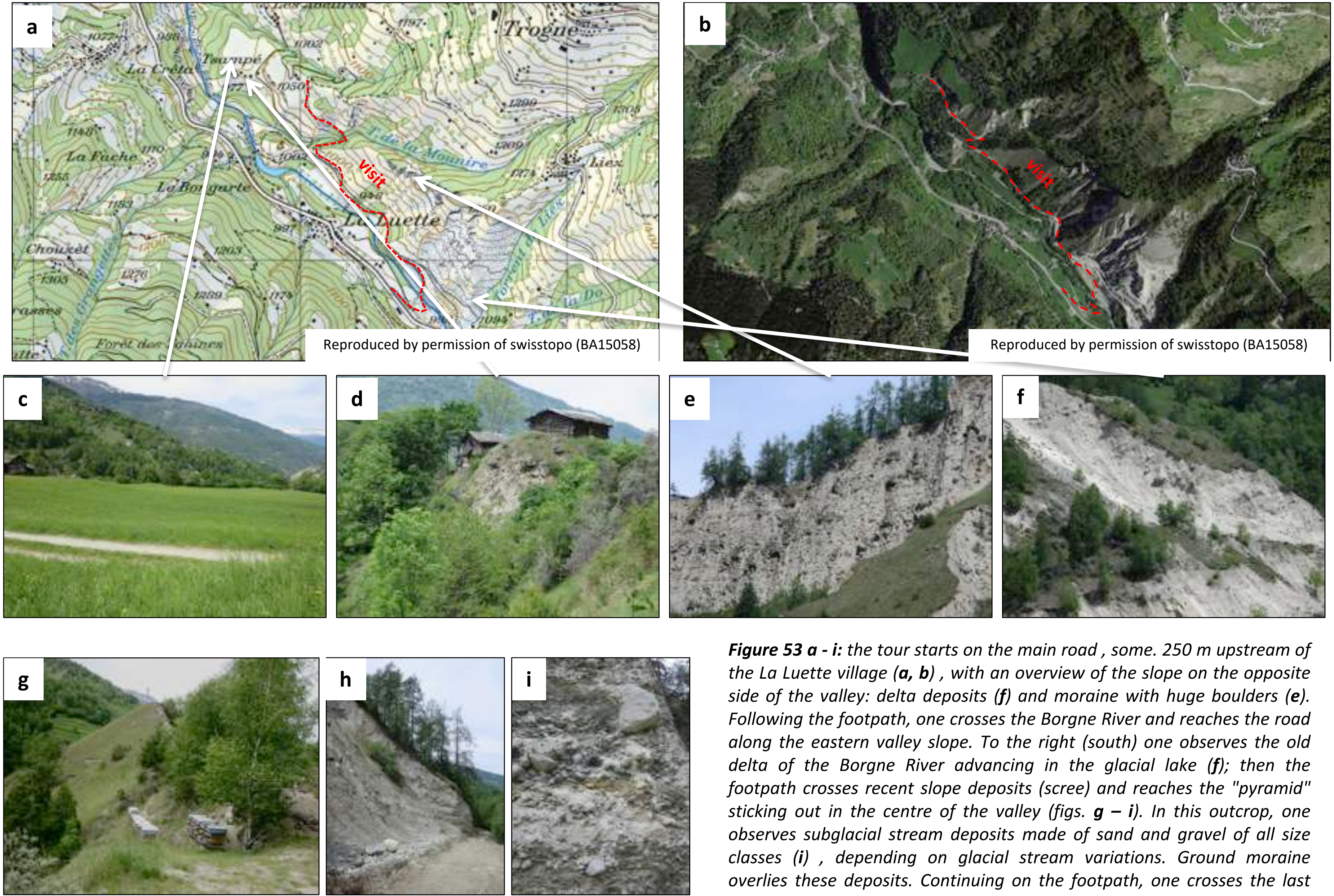

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***Figure 53 a - i:** the tour starts on the main road , some. 250 m upstream of the La Luette village (**a, b**) , with an overview of the slope on the opposite side of the valley: delta deposits (**f**) and moraine with huge boulders (**e**). Following the footpath, one crosses the Borgne River and reaches the road along the eastern valley slope. To the right (south) one observes the old delta of the Borgne River advancing in the glacial lake (**f**); then the footpath crosses recent slope deposits (scree) and reaches the "pyramid" sticking out in the centre of the valley (figs. **g – i**). In this outcrop, one observes subglacial stream deposits made of sand and gravel of all size classes (**i**) , depending on glacial stream variations. Ground moraine overlies these deposits. Continuing on the footpath, one crosses the last moraine ridge with boulders (**d, e**) and gets to the former proglacial floodplain, the sandur (**c**).*

5. From Ferpècle to the Mont Miné Glacier: a travel to the Little Ice Age 5

Compilation: P. Masset (2012)

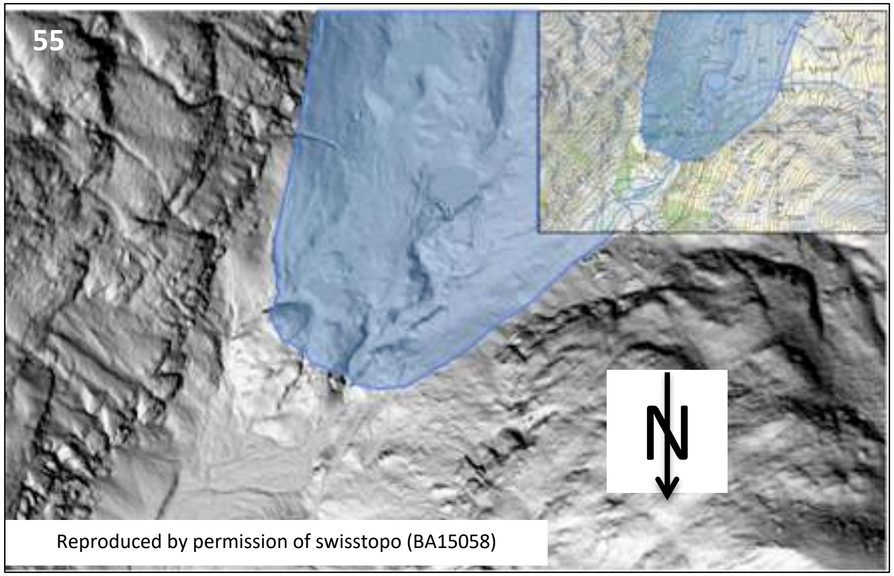

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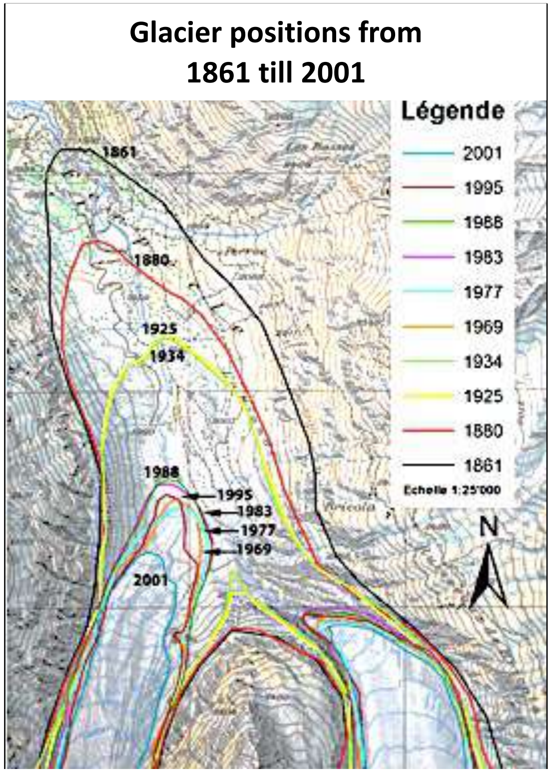
Figure 56 (->): *reconstruction of the Ferpècle and Mont Miné glacier position since the last maximum of the Little Ice Age. This map was compiled by P. Masset (2012) using topographic maps, paintings and photographs. After separation of the two glacier tongues around 1960, the tongue of the Ferpècle Glacier declined rapidly, while the Mont Miné Glacier remained in the same position until the 1990s .*


Glacier positions from 1861 till 2001

Reproduced by permission of swisstopo (BA15058)

Figure 54: *maximum extension of the Ferpècle and Mont Miné glaciers during the Little Ice Age (Bühlmann 1835, Graphic Colletion ETHZ). Please note: the main glacier tongue is that of the Mont Miné Glacier, whereas the Ferpècle Glacier remains clearly in a higher position.*

Figure 55: *frontal area of the glacier tongues shown in Fig. 54; digital elevation model and topographic map.*

***Figure 57:** engraving by Bühlmann 1835, Graphic Collection ETHZ. Please note: the tongue of the Mont Miné Glacier extends clearly lower down than that of the Ferpècle Glacier.*

***Figure 58**: the Mont Miné Glacier in 1900, Dumoulin et al. (2010).*

***Figure 59:** the Ferpècle and Dent Blanche glaciers in 1910, Dumoulin et al. (2010)*

***Figure 60:** Ferpècle Glacier, changes in the length of the glacier tongue 1891 – 2013**

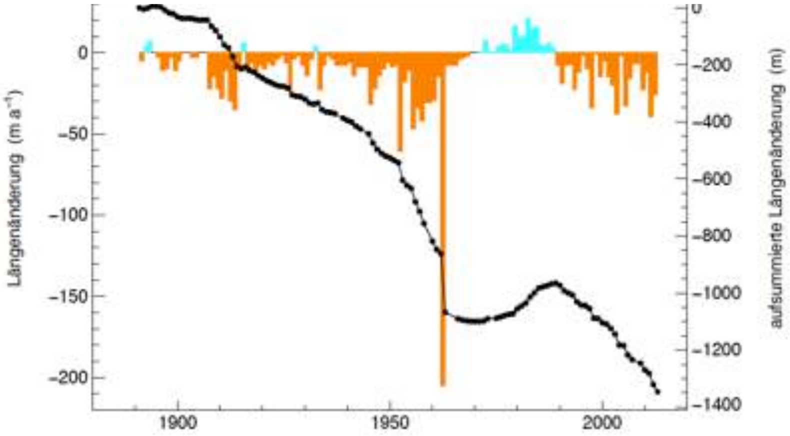
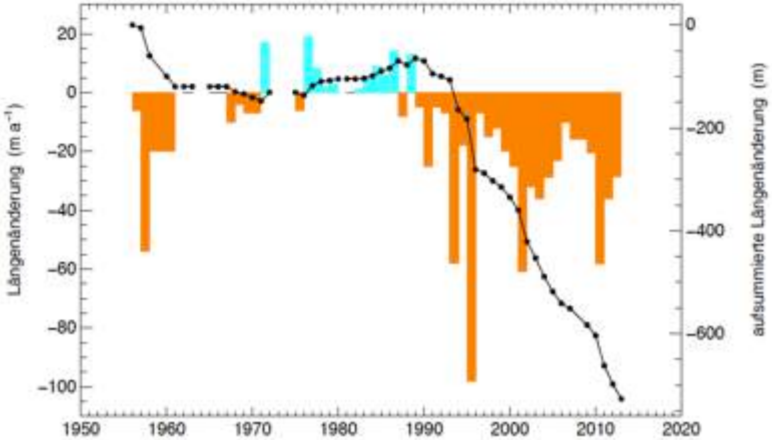


***Figure 61:** Mont Miné Glacier, changes in the length of the glacier tongue 1956 – 2013**



* On these figures the Swiss Glacier Monitoring Network (http://glaciology.ethz.ch/swiss-glaciers/) mixed until 1956 the glacier tongues of the Ferpècle and Mont Miné glaciers. The dominant glacier tongue is in fact that of the Mont Miné.

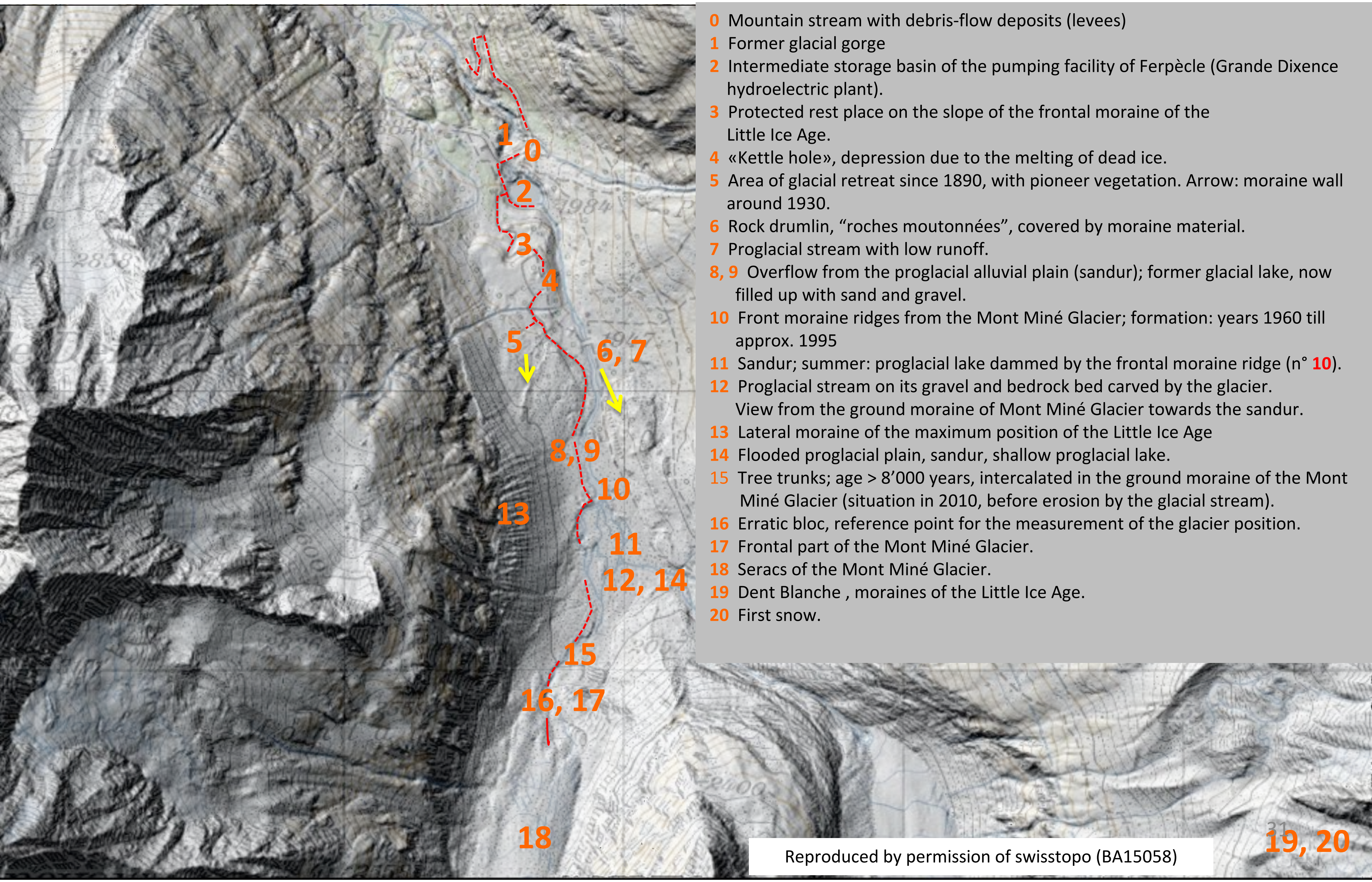
***Figure 62**: the Mont Miné Glacier in 1931, © Collection Gesellschaft für ökologische Forschung, München*

***Figure 63: the** Mont Miné Glacier in 2003, © Collection Gesellschaft für ökologische Forschung, München*

***Figure 64: the** Mont Miné Glacier in 1990, photo E. Reynard*

***Figure 65: the** Mont Miné Glacier in 2015, Photo J.L. Loizeau*

6. Field trip: the Mont Miné Glacier from the Little Ice Age until modern times



0 Mountain stream with debris-flow deposits (levees)

1 Former glacial gorge

2 Intermediate storage basin of the pumping facility of Ferpècle (Grande Dixence hydroelectric plant).

3 Protected rest place on the slope of the frontal moraine of the Little Ice Age.

4 «Kettle hole», depression due to the melting of dead ice.

5 Area of glacial retreat since 1890, with pioneer vegetation. Arrow: moraine wall around 1930.

6 Rock drumlin, “roches moutonnées”, covered by moraine material.

7 Proglacial stream with low runoff.

8, 9 Overflow from the proglacial alluvial plain (sandur); former glacial lake, now filled up with sand and gravel.

10 Front moraine ridges from the Mont Miné Glacier; formation: years 1960 till approx. 1995

11 Sandur; summer: proglacial lake dammed by the frontal moraine ridge (n° **10**).

12 Proglacial stream on its gravel and bedrock bed carved by the glacier. View from the ground moraine of Mont Miné Glacier towards the sandur.

13 Lateral moraine of the maximum position of the Little Ice Age

14 Flooded proglacial plain, sandur, shallow proglacial lake.

15 Tree trunks; age > 8’000 years, intercalated in the ground moraine of the Mont Miné Glacier (situation in 2010, before erosion by the glacial stream).

16 Erratic bloc, reference point for the measurement of the glacier position.

17 Frontal part of the Mont Miné Glacier.

18 Seracs of the Mont Miné Glacier.

19 Dent Blanche , moraines of the Little Ice Age.

20 First snow.

Reproduced by permission of swisstopo (BA15058)

For this trip, follow the small road from the Ferpècle Alp (**GPS point, Swiss coordinates:** 608 460/101 140). **0:** view from 608 670 /100 880; **1:** view from 608 580/100 820; **2:** view from 608 595/100 270; **3:** protected rest place 608 600/100 580*; **4**: fry pond 608 700/100 355*; **5:** moraine of the 1930's: 608 755/100 150; **6:** overview of the rock drumlin on the (orographically) right side of the valley (top: 609 09/ 99 830) seen from the bridge 608 860/100 163; **7**: glacial stream with low flow regime 608 900/100 000 seen from the bridge; **8**: spillway of the sandur plain 608 850/99 840; **9**: proglacial lakes in summer 2006, 608 800/99 850, view towards the south; **10**: front of the Mont Miné Glacier 1960 till 1990, area shown: 608 950/99 600 – 608 860/ 99600; **11**: sandur; in summer: proglacial lake dammed by moraine ridge (n° 10); **12**: glacial stream and sandur, view from the frontal area of the Mont Miné Glacier; **13**: lateral moraine in the area of coordinates 608 600/99 700; **14**: proglacial lake, same area as Fig. 12 (flooded); **15**: tree trunks > 8'200 years old (eroded after 2010) 608 810/99 090; **16**:reference point for the measurement of glacial retreat, 2008; **17**: frontal zone of the Mont Miné Glacier in 2011; **18**: seracs of the Mont Miné Glacier in 2009; **19**: peak of the Dent Blanche; **20:** first snow in autumn. * Photos Anh Dao Le Thi

Be careful: Access to the Mont Miné Glacier looks easy. One would almost try the adventure in small sandals. But beware: one is in an Alpine environment, at nearly 2000 m above sea level and accident risks have to be seriously considered. A few tips:

- **Adequate clothes and robust shoes are recommended. Indeed, thunderstorms travel fast in this area and paths between the weir in point 7 (see map) and the glacier front is rocky and often slippery.**
- **It is not recommended to cross the glacial streams elsewhere than over bridges. The water is very cold, sometimes with ice blocks, and the bottom is unstable.**
- **Do not stop near the slopes along the lateral moraine on the left (western) side! Landslides and rock falls are especially common during rain periods and under intense mid-day and afternoon sun!**
- **Caution when approaching the glacier front: blocks of rocks of all sizes are placed on the glacier and can slide.**
- **Do not visit the glacier frontal zone; danger of collapse.**

Accident: Stay with the injured people and call. . . . (The entire area is covered by the SWISSCOM network and partly by other mobile networks).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2010


4
2010


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2011


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2009


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2009


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2010


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2006


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2010


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2010

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2012

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2009

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2009

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2010

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2011

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2011

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2009

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2011

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2013

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Links

Tourist information
http://www.evolene-region.ch/

Historical glacier views:
www.gletscherarchiv.de

Glacier monitoring:
http://glaciology.ethz.ch/swiss-glaciers/

Geology of Val d’Hérens:
http://www.evolene-geologie.ch/

gletschergarten Luzern
http://gletschergarten.ch

Topographic maps

- Carte nationale de la Suisse 1:25’000, 1307 Vissoie
- Carte nationale de la Suisse 1:25’000, 1327 Evolène

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