Sedimentology and wine, a cross road

From early evaporite to carbonate platform and foreland basin terroirs of the best Swiss wines – a Rhone Valley to Lavaux (UNESCO Site) taste transect

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From Lavaux to Rhone Valley with the main stops in white. Lac Léman "Lake Geneva" on the right. The snow-capped "Grand Combin" (4314m. high) in the background and the Morcles thrust sheet Crest ("Hautes Alpes calcaires", Helvetic domain) in the back

Field trip FTB 2 guidebook

August 23, 2014

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1-Introduction

Part of the Alps and the foreland basin will be crossed by our field trip. Limestone, gypsum, landslide siliceous carbonate pebbles and clay, marls carbonates and sandstone are composing the main terroirs of the tasted wines.

1.1- Western Switzerland geological setting

According to Trümpy (1980): "Alpine rocks fall into two categories: a pre-Triassic or pre-Pennsylvanian basement complex, affected by the Variscan (Hercynian) and older orogenies, and Triassic to Lower Oligocene sediments which were only deformed by the Alpine (mid-Cretaceous to Pliocene) movements. The Pennsylvanian and Permian continental sediments occupy an intermediate position. At higher and intermediate structural levels, basement and cover complex show quite different tectonic behavior; in many instances, the cover-rocks have been stripped away from their basement substratum, to form detachment nappes of their own. At deeper structural levels, Alpine deformation and metamorphism have largely obliterated the original differences of competence and of structure, so that the basement and cover complex were deformed conformably. Mesozoic subsidence, rifting and spreading produced the Piemont ocean with an intra-oceanic platform, of which the Briançonnais rise is the most prominent one. At the same time, the northern (Helvetic) and southern (Austro-alpine-South Alpine) margins were shaped. New oceanic crust was produced from mid-Jurassic to end-Cretaceous time (Fig. 1).

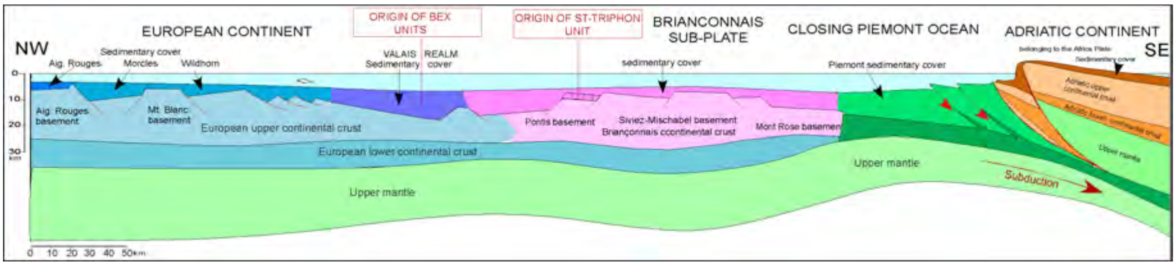

Figure 1: Middle Cretaceous (100 Ma) geological section with original position of visited outcrops in the Prealps. The European units are getting closer of the Adriatic micro-plate of African origin and, with the subduction, the Piemont oceanic belt is closing. There were no Alps at that time! (adapted from A. Escher, in Baud et al., poster 2012).

Crustal shortening, producing folds and nappes (Fig. 2), began at the end of the Lower Cretaceous and went on until the Pliocene, with an interruption during the Paleocene. The orogenic phases were accompanied and followed by metamorphism, which reached high amphibolite grade in the deepest exposed parts of the Alpine edifice. Synorogenic plutonism and volcanism remained rather modest"

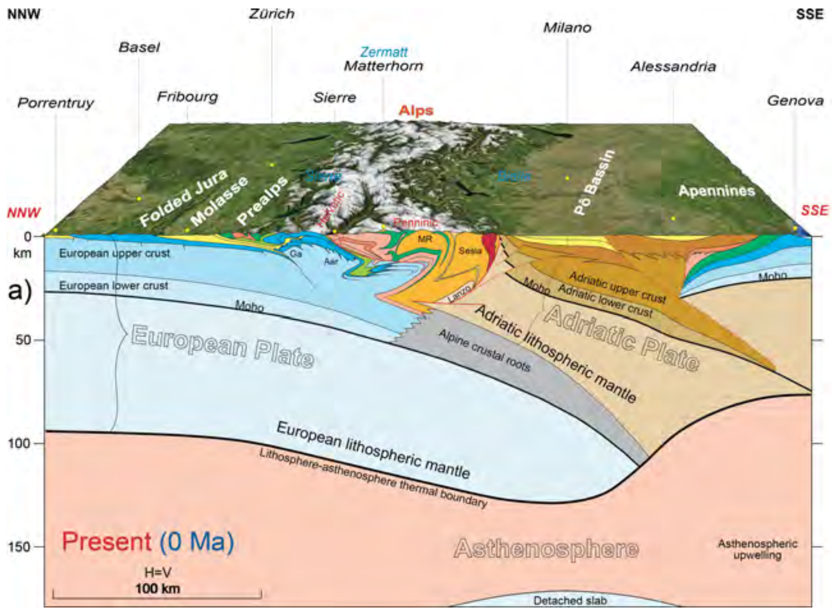

Figure 2: Block diagram of Western Switzerland from Apennines to folded Jura through the Alps. (R. Marchant, unpublished).

1.2 -The Triassic carbonate and evaporite of Western Switzerland Prealps (A. Baud)

The shallow Triassic seas are related to two domains. From the north, the Germanic Muschelkalk basin encroached on the Helvetic realm; from the Southeast, the transgression of the Paleotethys, which had been restricted in Late Paleozoic times to the southeastern most part of the future Alps, covered the Austroalpine and most of the Briançonnais realms.

Lower Triassic formations are invariably terrigenous, rich in quartz grains and poorly fossiliferous. Middle Triassic carbonates reach their maximum thickness in the Briançonnais belt (Fig. 3). A change in paleogeographical pattern occurs in the Late Ladinian. During Late Triassic times, two broad facies belts can be distinguished: the "Zone des Cols" (Ultrahelvetic and "Sub-Mediane" Mélange, Figs. 3 and 4) with a great amount of evaporites (with salt cement, area of Bex) and the intertidal to supratidal carbonate platform of the Blond Dolomite followed by well developed Rhaetian limestone to the southeast (Fig. 5).

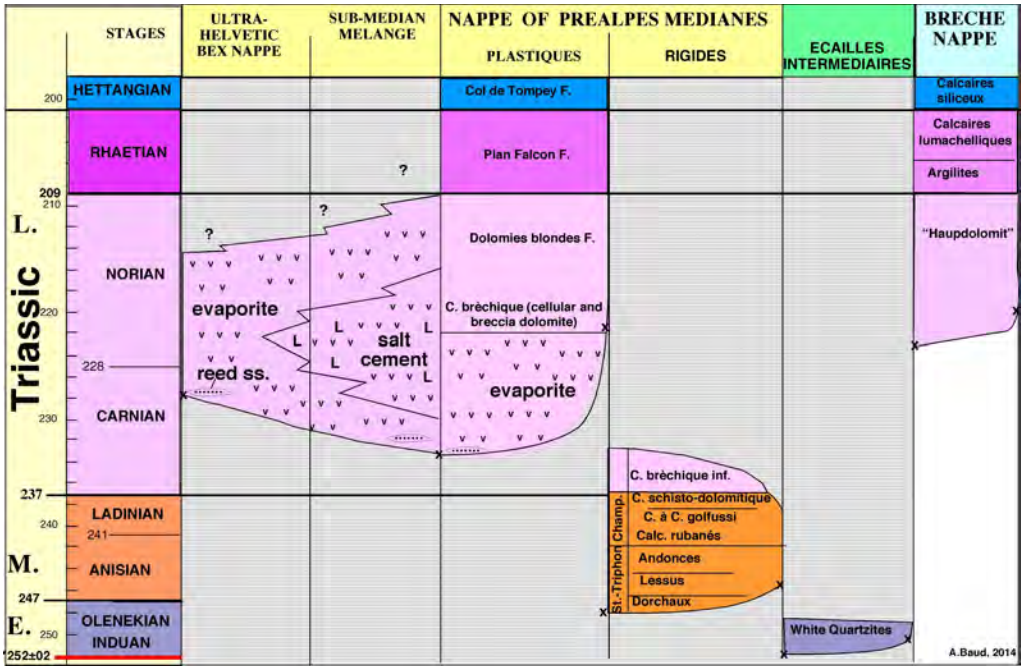

Figure 3: Sketch of the Triassic Units within the Western Switzerland Prealps (adapted from Baud in Mégard-Galli & Baud,1978). During the fieldtrip, we will look at the Anisian limestone of the Saint-Triphon Formation (Prealpes Medianes Rigides tectonic unit, Baud, 1972) and at the Late Triassic Evaporite of the "Sub-Mediane" Mélange (Salt mine of Bex).

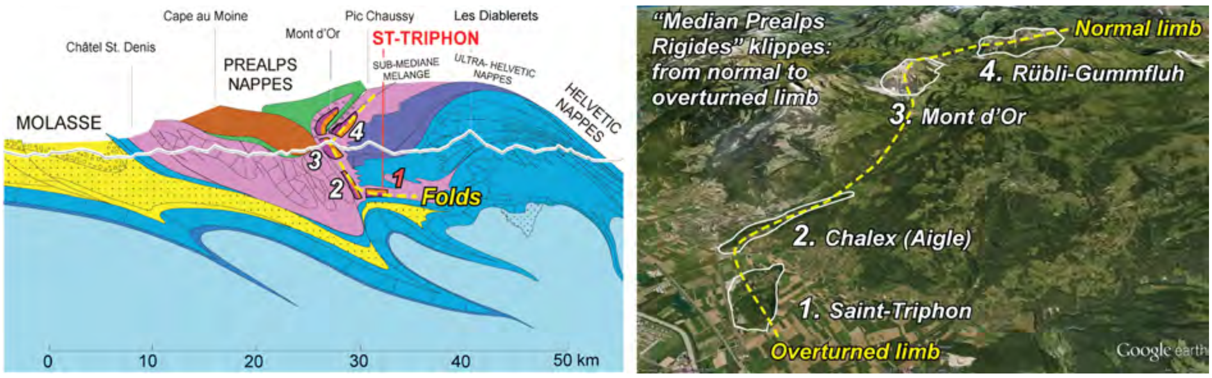

Figure 4 left: Geological cross-section from Molasse to Helvetic nappes. The Saint-Triphon hills are lying in the overturned part of the large Sub-Mediane Melange fold; right, "Google Earth" view with the position of the Mediane klippes from normal to overturned limb (adapted from A. Escher, in Baud et al., poster, 2012).

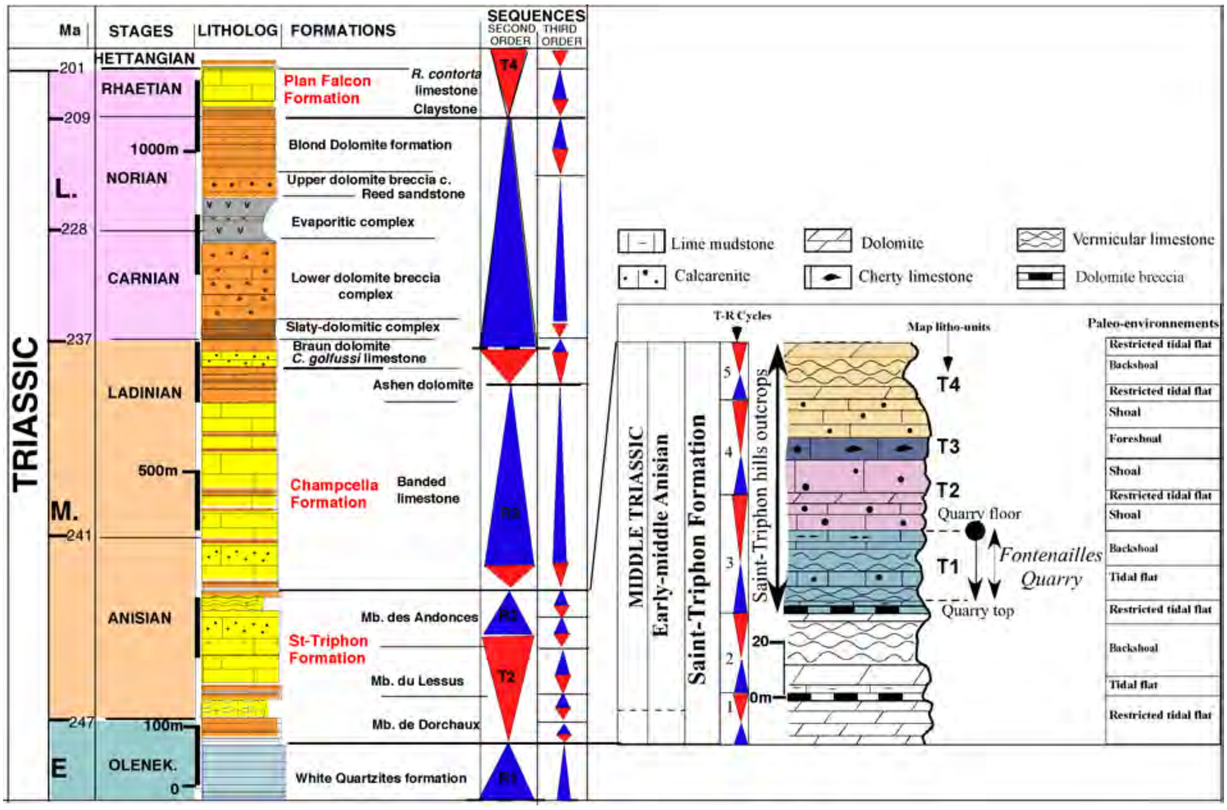

Figure 5 left: Composite Triassic section of the "Préalpes Medianes" Nappe with second and third order sequences (Baud, 1972 and 1987); right, composite Saint-Triphon Formation section from the type locality area (after Baud in Baud et al., 2012).

1.2.1 -The Anisian Saint-Triphon Formation, (Baud, 1987, fig. 5).

The visited Saint-Triphon Formation is a formally established Early Middle Triassic lithological unit of the Prealps and of the Briançonnais realm of the Western Alps. The type locality occurs in the vicinity of the village of Saint-Triphon in the Rhone Valley of Western Switzerland. Subdivided in 3 Members and 19 levels, this Formation, 220 m thick in the type area, consists of 5 main shallowing upward carbonate cycles. Lying at the base of the internal part of the Prealpes Medianes Nappe ("Préalpes médianes rigides"), the Saint-Triphon Formation is also cropping out all along the Briançonnais domain of the Western Alps, from the Barrhorn area (N of the Matterhorn) to the Ligurian Alps in the S.

The palinspastic reconstruction of the Middle Triassic marine area shows that the shallow marine carbonate deposits occur in an intra-cratonic subsident half-graben of estimated 500 km length and 100 to 150 km width. Its orientation was to the NE and E in relation to the actual alpine trend. During the time of the Saint-Triphon Formation deposit, the more subsident area was emplaced in the original position of the "Préalpes médianes" and the calculated rate of sedimentation is 100m/Ma. This rate decreases from a 2/3 ratio in the direction of the Ligurian Alps with an average there of about 30m/Ma.

The dynamic aspect of the Saint-Triphon Formation carbonate deposits and the faciès models are presented through the 3 main stages of shallow water carbonate platform development:

A. the birth and initial development stage occurs during the end of the Early Triassic and the Anisian start and is characterized by a multi-phased transgression of the peritidal dolomites followed by the shallow ramp - lagoonal vermicular limestone;

B. after an important eustatic regression and emersion of the platform, the early stage (Early to Middle Anisian) is represented by a complete tidal flat succession;

C. during the mature stage of the carbonate platform (Middle to Early Late Anisian), the depositional model consists of 4 main paleoenvironnments (Fig. 6): 1-the coastal plain, 2- the tidal flat - backshoal, 3- the "barrier" consisting in lime sand shoals and patch algal-sponge mounds, 4- the foreshoal.

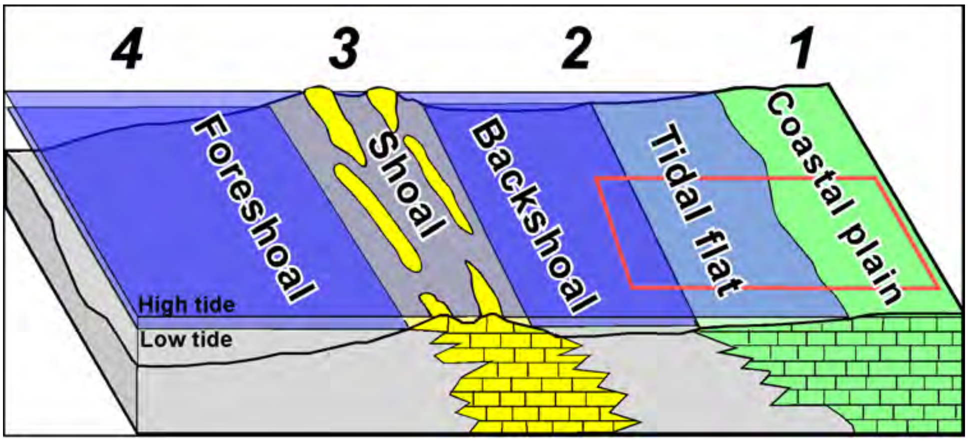

Figure 6: Paleoenvironments sketch of the mature carbonate platform stage. Explanations in the text (Baud, 1987).

1.2.2 -The Late Triassic evaporite and Salt.

The Salt mines of Bex, North of the Bex Village known since 1684, are still in activity and provide all the salt needed by the county of Vaud and the chemical industries of Monthey. The salt is included in a huge mass of Upper Triassic anhydrite, belonging to Sub-Mediane Mélange Zone (Fig. 7), which covers a large area north and northeast of Bex Village.

The anhydrite (gypsum at the surface) contains Triassic inliers of dolomite, green dolomitic shale, black shale and sandstone, and thick but discontinuous intercalations of fossiliferous Liassic limestone, of Aalenian shale and of Eocene flysch. This complex is folded in such a wild manner that, in spite of the numerous galleries, shafts and borings of the mines, the structure is only partially understood.

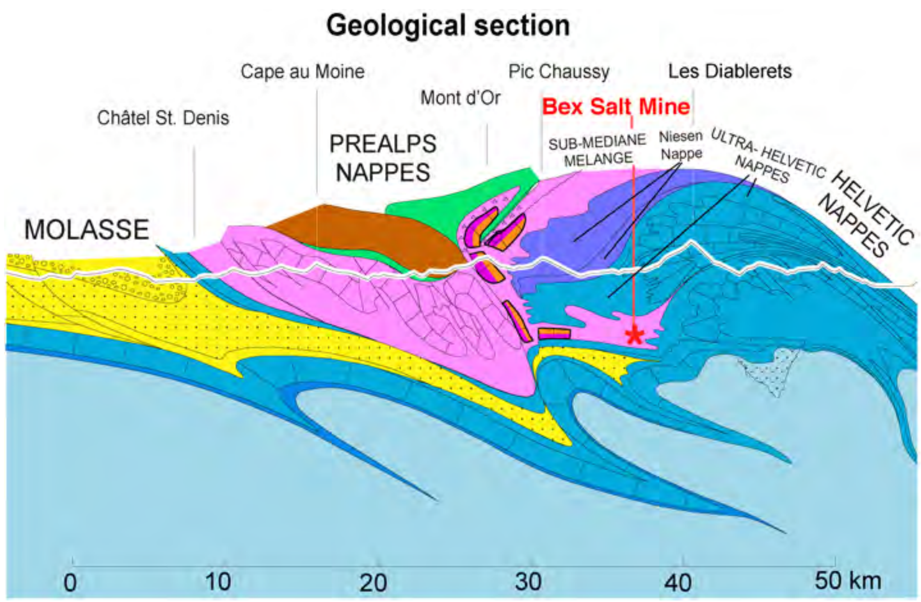

Fig. 7: Geological section (NW-SE) through the Western part of the Swiss Alps along the Rhone valley (adapted from A. Escher in Baud et al., poster, 2012).

The evaporite and salt deposits occurred during the upper Triassic time (partly Carnian) within an aborted rift, Dead Sea like, between the Briançonnais sub-plate and European plate (Fig. 8).

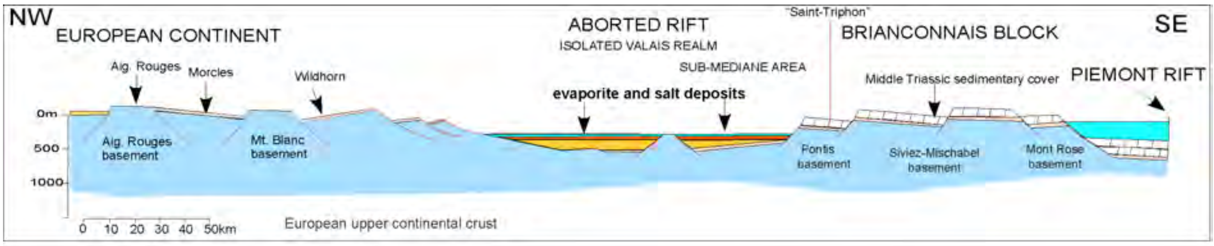

Fig. 8: Late Triassic geological sketch with the original position of the evaporite basins (A Baud).

1.3 -The Miocene Western Switzerland foreland basin (Molasse), sedimentation, deformation and erosion story (R. Marchant and Borel & Marchant, 2007).

Lavaux's geological history is closely linked to the formation of the Alpine mountain range and the last glacial periods. It may be summarized in three main phases:

1- the deposition of Molasse sediments, which now form the rocky beds that are typical of Lavaux's wine-growing landscape;

2- the formation of the Alps, which shifted and folded the layers of Molasse;

3- the major glacial periods, which carved out the Lake Leman basin.

1.3.1 -Molasse deposits

The rocks that compose the base of Lavaux are of Molasse, a huge mass of sedimentary rock deposits formed at the foreland of the Alps as the mountain chain was forming (Fig. 9). The Molasse basin stretches along the axis of the Alps from Savoy to Austria passing by way of the Swiss Plateau and Bavaria.

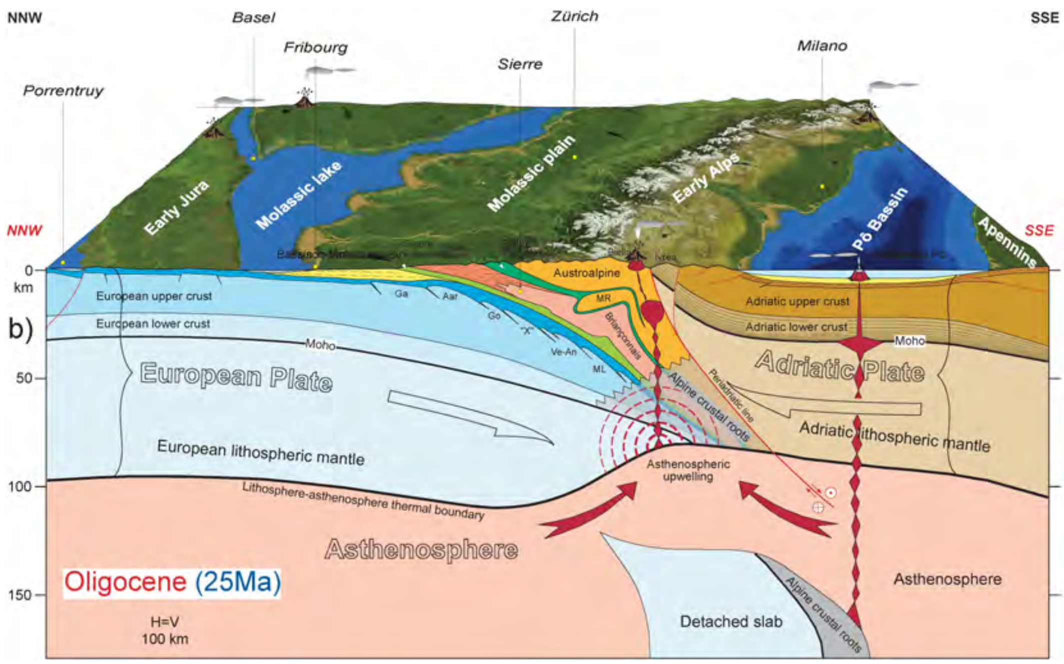

Figure 9: Block diagram of Western Switzerland area 25 millions years ago. The European plate is overthrusted by the Adriatic plate, part of the African plate. The foreland basin (left) consists of the Molasse plain and lakes (R. Marchant, unpublished).

This is a flexural-type sedimentary basin whose genesis was directly linked to plate tectonics, as illustrated in Figure 9. This sedimentary basin has gradually been filled in with material stemming from the erosion of the Alps during the formation stage : torrents, streams and rivers have transported pebbles, sand and clay to the basin. The Molasse was deposited during the Tertiary Period between 34 and 7 million years ago in four successive stages:

- the first is marine (Lower Marine Molasse);
- the second is continental (Lower Freshwater Molasse);
- the third is again marine (Upper Marine Molasse);
- and the fourth is once again continental (Upper Freshwater Molasse).

In Lavaux, only the Lower Freshwater Molasse is exposed, as shown in Figs. 10, 11 and 12. The Lower Marine Molasse is located at a deeper level, as demonstrated by an oil-drilling projects in Savigny. The Upper Marine Molasse and the Upper Freshwater Molasse were eroded in this area during the last glacial periods.

During the late Chattian stage, from 26 to 23 million years ago, there were several environments of contemporary deposits relating to the topography of that era. To the southeast, near the Alpine front, torrents flowing down the 1% gradient of the slope washed down pebbles from the uppermost thrusted units of the building mountain range (early Alps). A detailed analysis of the pebbles (Trümpy & Bersier, 1954 and Trümpy, 1976) indicates pebbles of oceanic origin (Neotethys) and reworked pebbles of the Adria-African plate basement (Baveno type Granit).

In contrast, to the northwest, in the Lausanne region, the topography must have been entirely flat so the rivers no longer had more than a weak current sufficient to carry along fine sand and clay, but not pebbles.

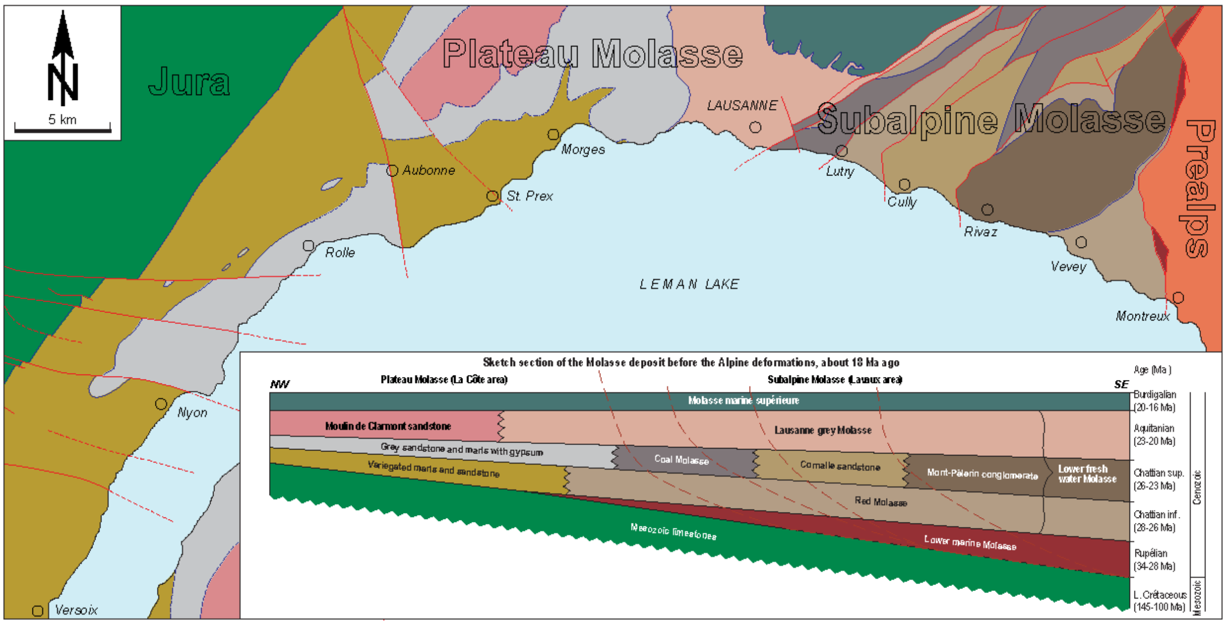

Figure 10: Geological map of the Western Pateau Molasse and below the different types of Molasse according their ages and position (proximal – distal), (R. Marchant, in Borel & Marchant, 2007).

1.3.2 –Molasse and Alpine deformations

The Alpine mountain chain is the result of the collision of the African and European plates, during which an ancient ocean called Piemont (Neotethys) separating the two plates disappeared (Figs. 1 and 9). The rock deformation associated with this collision began approximately 100 million years ago, when Africa started to shift towards Europe. The front of this deformation has gradually moved northwest and reached the Lavaux region approximately 10 million years ago.

In Lavaux, this deformation basically resulted in a sliding and superpositioning of different rock segments, separated by thrust faults, as Fig. 11 shows. These fault systems have thus juxtaposed rocks that were originally several kilometers away from each other. The last of these faults, between the Aquitanian Molasse and the coal Molasse, marks the front of the Alpine range. For this reason, the Molasse in the Lavaux region bears the tectonic designation of subalpine Molasse. The tectonics here are, in fact, very complex, with many secondary fault lines thus fracturing the region's rocks.

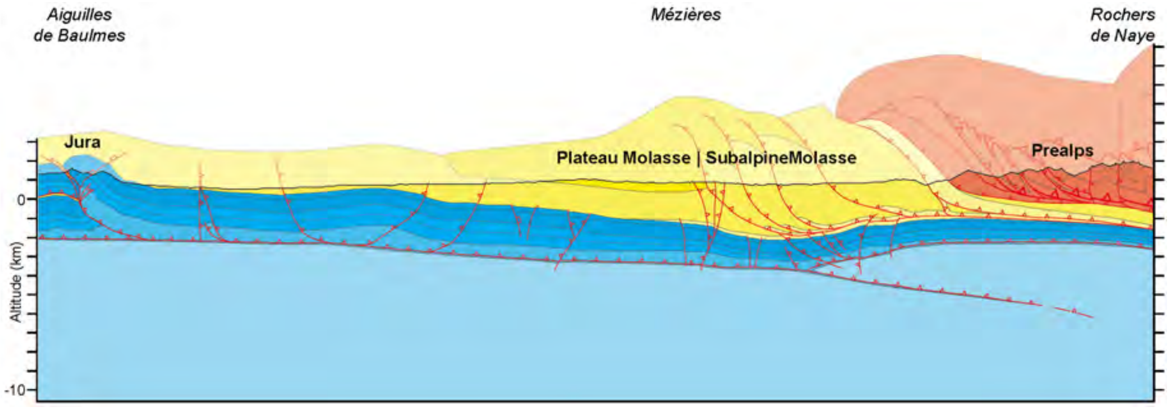

Figure 11: Cross section through the Molasse basin. In light blue, the European basement; above the more dark blue represent the Mesozoic succession: in yellow are the Tertiary Molasse sediments; in Orange-red, the folded Prealps; red lines: faults and thrusts (R. Marchant, unpublished).

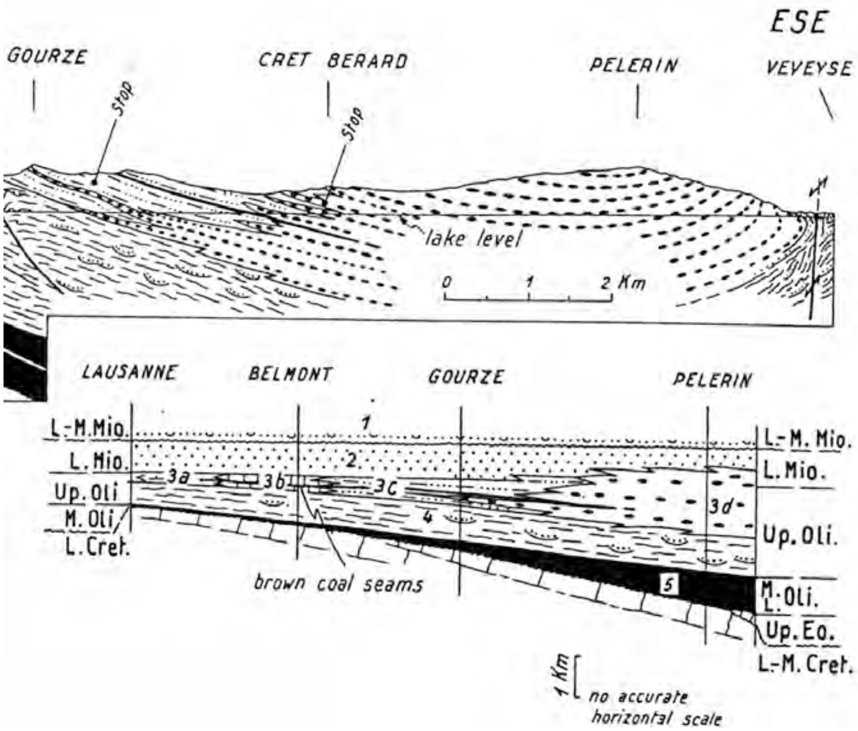

Figure 12: Simplified cross section through the Molasse basin in the Lavaux area; 1- upper marine Molasse; 2- fluvio-terrestrial sandy Molasse; 3a to 3d, from distal (brackish) to proximal (deltaic conglomerate) fluviatile Molasse; 4- continental red Molasse; 5- lower marine Molasse (adapted from Trümpy, 1980).

1.4 –Quaternary deposits (R. Marchant) (Figs. 13 and 14).
Except for the Molasse of the Lower Tertiary Period, other geological formations in Lavaux date back to the Early Quaternary Period (from 1.75 million years ago until today). Over the last several millions of years, our planet has been affected by a succession of glacial periods, punctuated by warmer interglacial periods.

In Lavaux, only deposits dating back to the Last Glacial Period (Würm, 100,000-15,000 years ago) are present, as the last glacier swept away nearly all deposits from previous glacial periods.

1.4.1 - The great glacial periods.
Moreover, these great glacial periods have shaped the landscape that we know today. In the past, the Rhone flowed from Martigny towards Chamonix, and the Lake Leman basin did not exist. The Rhone valley and the Lake Leman basin were carved out by the Rhodanian Glacier, which went in direction of the city of Lyon during the Last Glacial Maximum, approximately 25,000 years ago (S. Coutterand, 2010, Fig. 14).

Some moraine deposits, such as those of Savuit and Châtelard and, locally, the striaes left by rocks caught in the ice serve as evidence of the passage of the glacier. In the past, there must have been many erratic blocks, but many have slid into the lake, as it is the case West of Villette village, and most have likely been used as construction stones.

Figure 13: Sketch of landscape about 18'000 years ago; part of the area and the lake are covered by a large glacier and on the side a Mammoth herd is feeding on (© Geological Museum Lausanne).

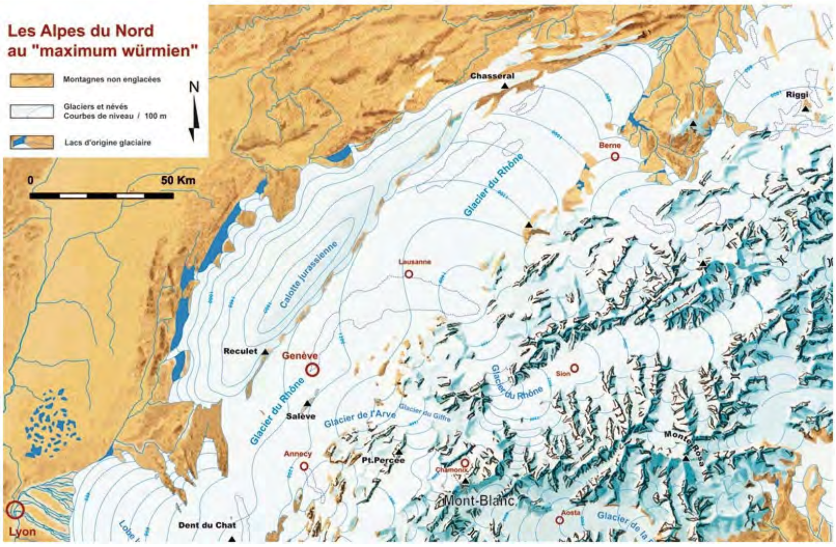

Figure 14: Maximum glacier expansion during the Würm time, about 25'000 years ago (© Sylvain Coutterand 2010, Fig. 2.2).

1.4.2 Recent events: Lavaux landslides

The thawing of the rhodanian Glacier destabilized some of the mountainsides in Lavaux, especially in the western region. Because the mountain was no longer supported by the glacier, there were numerous landslides into the lake. Today most of these landslides are stabilised but they remain active near Epesses village: “At some period that we cannot pinpoint, but certainly a very long time ago, in the area now known as La Cornallaz, a long fissure and a subsidence occurred. The entire village of Epesses slid down several hundred paces below its original location, but what is strange is that there was no damage to the residents or their homes,” testified Louis Levade, physician and historian, in 1823.

1.4.3 Recent events: “Ovaille”, an historical landslide in the Rhone Valley (Fig. 15)**.**

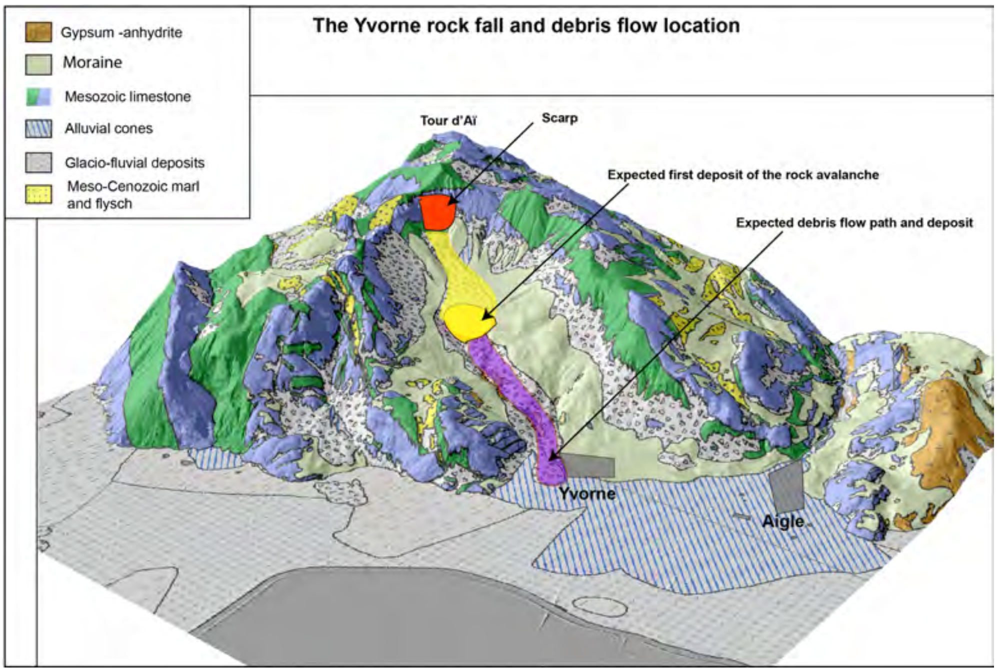

Figure 15: *Geological map on 3D relief topography of the "Ovaille" landslide area (adapted from David Giorgis maps, 2012 and from Michel Jaboyedov, 2011)*

"Tour d 'Ai (2331 m) east of Lake Geneva is the highest point of a northeast-trending anticlinal ridge composed mainly of limestone of the intensely deformed Pennine klippen belt of the Swiss Prealpes (Fig. 102). The south-facing scarp slope of Tour d' Ai exposes northward-dipping recessive argillaceous limestones grading upwards into thick-bedded limestone which forms the castellate summit ridge. Below the scarp face a bench of Pleistocene surficial deposits forms the bowl-shaped terrace of Luan (1200 m) from which the Torrent d'Yvorne flows to the Rhone Valley (400 m).
The communities of Yvorne (445 m) and Corbeyrier (920 m) were well established agricultural villages when, on 1 March 1584, a severe earthquake jolted the area. A carbonate ledge on the south-facing scarp slope of the western summit ridge of Tour d' Ai collapsed, and blocky debris ran out over the terrace of Luan. From 2 to 3 March (?) it rained and snowed almost without interruption. The Luan terrace, now overloaded by the rock avalanche lobe, soaked up large amounts of water from the rain and meting snow. On 4 March the weather improved and people again worked the fields below Luan. However, deep fissures opened at the terrace rim and slabs of surficial deposits began to skid and slump downhill. Near Corbeyrier cracks in the soil ejected mud and the earth trembled. Noisy toppling of trees should have suggested to the inhabitants of the village that much of the terrace was now in motion. However, most people remained in the fields. On the afternoon of 4 March incipient creep and ground subsidence changed into a well-defined stream 600 m wide, involving Pleistocene surficial deposits and superincumbent rock avalanche material. Along its western flank the slide mass tore away the main section of Corbeyrier. As it accelerated along its downward tapering track, the debris stream attained a volume of 10 x 106 m3. Its velocity was so great that the front locally became airborne as it cleared slight elevations in the track. As the chronicler describes it, the debris 'jumped over several plots and grape stands without doing any damage (Heim, 1932, p. 155). The slide mass overwhelmed the entire village of Yvorne and claimed the lives of 328 people (Heim, 1932, p. 155 and 186; Jeannet, 1918, p. 690-694).
The breakaway scar of the rock avalanche is still recognizable below the crags of Tour d' Ai. The steep grassy slopes below the cliffs are the starting zone of snow avalanches whose run out zones extend onto the terrace of Luan. The terrace itself is mantled by a thick protective forest, broken by a few clearings for summer chalets. The conical debris deposits of 1584 on the north side of the Rhone Valley host the enchanting village of Yvorne and its vineyards". (text from Eisbacher and Clague, 1984)

2 - Described vineyards during the fieldtrip.

The vineyards of western Switzerland are growing in impressive landscape and on various substratum (Fig. 16). With the visited outcrops, we selected four main terroirs: soil on limestone ground (Saint-Triphon), soil on gypsum ground (Montet hill, Bex), soil on landslide ground (Ovaille, Yvorne) and soil on sandstone and marls ground (Molasse, Lavaux) .
"The king of Western Switzerland, the Chasselas, is a typically Swiss white grape variety, even though it is also used in the production of wine in Alsace, Savoy and Burgundy. The Chasselas grape originates most probably from Lavaux, where its oldest traces can be found. It was originally named Fendant or Luzannois (taken from the name of the city of Lausanne). With a subtle aroma, the Chasselas permeates the soil in a unique way, wherever it is planted. Wines can, therefore, vary considerably, depending on which region they are from. Generally, it is a sparkling and fruity wine, with nice mineral overtones and a pleasant freshness. It is ideal as an aperitif, as well as with dishes such as fish or cheeses" (Text from Lavaux – UNESCO website, slightly modified).

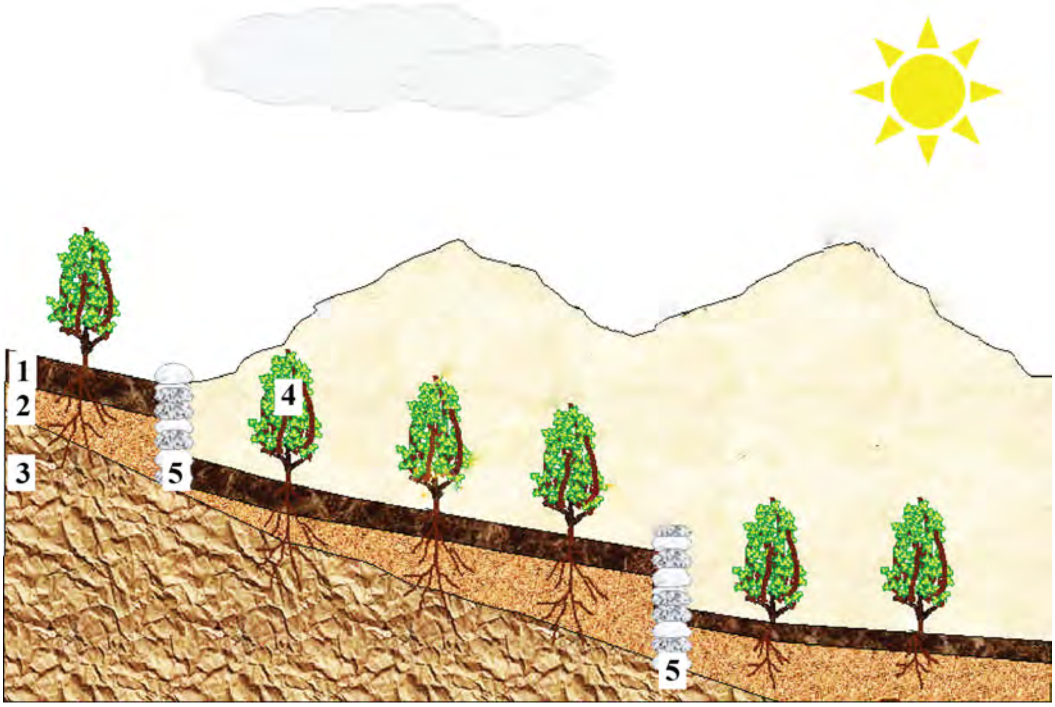

Figure 16: Vineyard section on a slope. 1- soil on underlying moraine (2); 3- substratum (ground); 4- vine stock; 5- vineyard wall (sketch after Pythoud & Caloz, 2004)

2.1 -The Saint-Triphon terroir (Fig 17)**.**
A small vineyard is growing between the Saint-Triphon hills on the South-West side of the village. With a limestone ground, the Saint-Triphon vineyard terroir is quiet different from the surrounding one's growing on gypsum. A local winemaker restored succesfully old grape type as the red "Mondeuse" and also white grape assemblage, and is producing a very fine type Chasselas.

Figure 17 left: White (Chasselas) and red (Mondeuse) wine bottle label from the Saint-Triphon vineyard; right: the Saint-Triphon village and the Fontenaille limestone quarry (up right).

2.2 -The Bex vineyards growing on gypsum
Just North of Bex village is a hill named "Le Montet" entirely built by anhydrite in the ground and gypsum at the surface (Figs. 18 and 19). At the top of the hill is a large gypsum quarry providing the calcium sulfate for surrounding plaster factories.
The South oriented vineyards benefit from fine climatic condition (earliest flowering from all

the area) with the "Foehn" a dry and warm wind coming from the South and from the gypsum substratum (Fig. 20) which brought a specific fine minerality . The main grape is Chasselas among the white, Gamay and Pinot for the red.

Figure 18 left: The Montet vineyard in Autumn; right: the Bex village and the Montet hill toped by the gypsum quarry and the vineyard in the middle, the rectangle correspond to the left photo. (photos from Bex vineyards web site)

Figure 19: The Montet hill from the South (from Bex vineyards web site).

Figure 20 left: Natural section of Montet vineyard (1), 2- 20cm of brown soil, 3- gypsum substratum with a doline section; middle: vine root in banded gypsum; right: white wine bottle label from the Montet vineyard. (photos from Bex vineyards web site)

2.3 -The Yvorne "Ovaille" vineyards and terroir (Fig. 21)**.**

Growing on the historical landslide, the "Ovaille" vineyards have a thick (more than 10m thick) soft substratum made of debris flow with siliceous limestone pebbles in a silty-clay matrix. This distinctive terroir is giving to the white Chasselas grape a brillant and complex taste and offer the benefit from being kept.

Figure 21 left: Red wine bottle label of the Mondeuse noire grape; in the middle, the "Ovaille" vineyards in autumn; middle: the Ovaille vineyard in autumn; right: white wine bottle label, Chasselas grapes from the 425th. anniversary of the landslide (2009). (photos from Yvorne vineyards web site and label from G. Testaz)

2.4 -The Lavaux World Heritage, vineyards and terroirs (Figs. 22 and 23)**.**

"Patrimony is the legacy of the past, which we enjoy today and pass on to future generations. UNESCO divides its listed World Heritage sites into 3 main categories: natural sites, constructed sites and cultural landscapes. Lavaux constitutes a cultural landscape, where human actions have contributed to shaping an exceptional area.

In the 11th Century, monks already grew vines on the narrow terraces, supported by stone walls. Since then, generations of winemakers have been respectful of traditions and have helped to foster this magnificent mosaic, which covers some 40 km of slopes stretching along the shores of Lake Geneva. This cultural landscape constitutes Switzerland's largest vineyards and includes 14 well-preserved villages. It displays its evolution and development over almost 1'000 years in a striking way, thanks to a balanced interaction between the inhabitants and their environment.

Figure 22: View on the Lavaux vineyards, with "Lac Léman" and Mesozoic Prealps in the ground (Photo R. Marchant)

The vineyards of Lavaux are one of the most impressive in the world. They comprise of 400 kilometres of walls and 10,000 terraces spread over 40 levels. All of this creates a strong impact, together with the elegance enhanced by the mountain setting. The quality of the wines that are cultivated from this land is the logical reflection of the beauty and richness of their environment.

These vineyard terraces of 830 hectares cover the vertiginous shores of Lake Geneva between Montreux and Lausanne, offering one of the most beautiful panoramas in the world.

The vineyards terrain, with its steep slopes, gives it a characteristic identity and makes the wines of Lavaux unique: with a very typical character, discernible to the taster through their persistence, strength and harmony of aromas and flavours.

The soil comes from a natural moraine, with a varied content of clay, limestone and a variety of minerals contributing to its diversity. The vine is the gold of Lavaux, where tradition, the love of wine and the soil, combined with an exceptional exposure to sunshine, ensure its reputation for successful vintages, year after year.

Figure 23: Wine harvest in Lavaux, F. A. L. Dumoulin 1808 colored engraving (reproduced from Lavaux and the Arts – UNESCO website).

The beauty of the Lavaux region is entirely linked to the existence of the vines. The future of the vineyards is protected by ensuring that of the winemakers who cultivate the vines. A bottle of wine bought at the correct price contributes directly to the upkeep of this area.

Strengthened by its ideal climate and optimal hours of sunshine, Lavaux has a particularly interesting flora and fauna.

Several waterways feed the land making it ideal for successfully growing vines. Dazzling with splendour, thanks to their scenic vineyard terraces, Lavaux displays a true balance radiating a profound beauty, down to the finest natural detail.

To resume, Lavaux counts 200 winemakers, 830 hectares, 400 kilometres of walls, 10,000 terraces planted on 40 levels" (Text from Lavaux – UNESCO website).

3 -Geological itinerary and stops (Figs. 24 and 25).

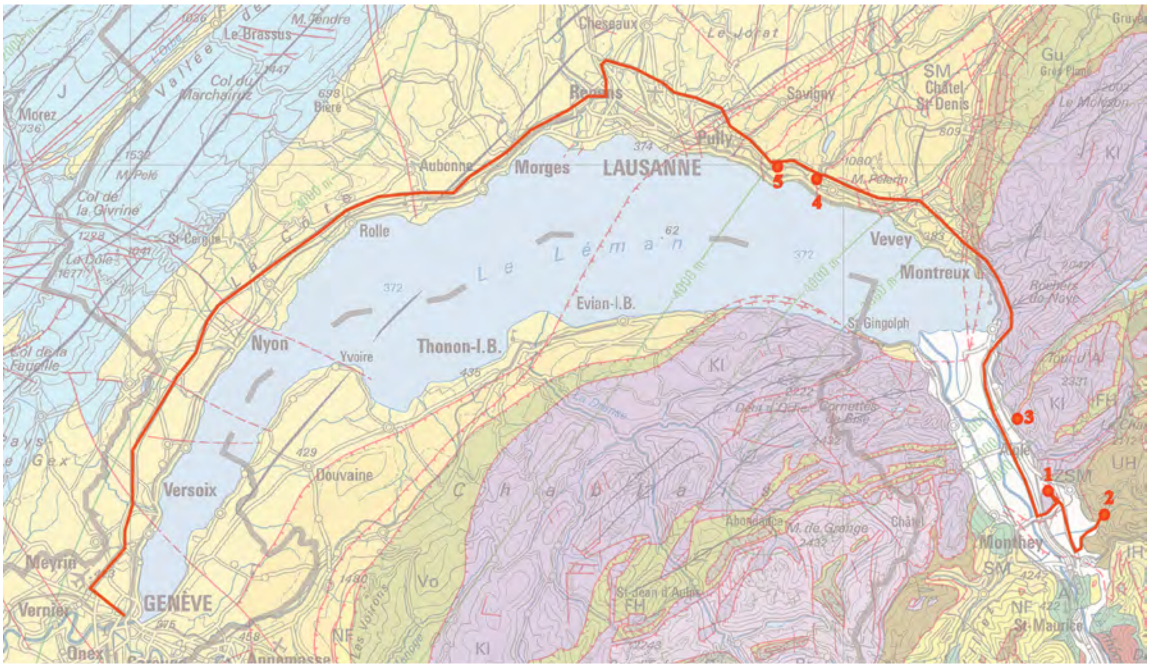

Figure 24: Tectonic map of Western Switzerland with , in red, the itinerary and the five stop places; stop1, Saint-Triphon, Fontenaille quarry; stop 2, visit of the Salt mine of Bex; stop 3, the vineyard growing on the historical "Ovaille" landslide; stop 4, La Corniche and the vineyard of Lavaux; stop 5, wine tasting in the Chollet winemaker house.

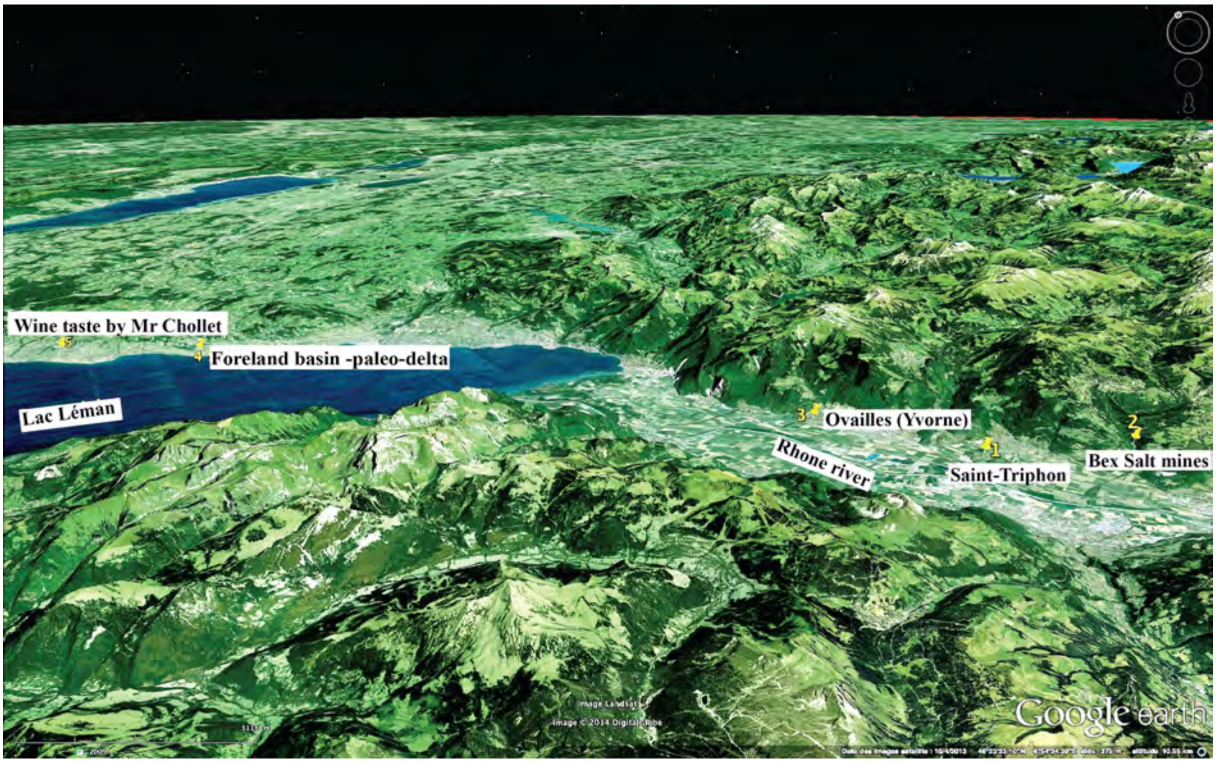

Figure 25: Google Earth oblique view with the five main stops of the day as presented in the map above.

3.1 -Stop 1: Saint-Triphon, Fontenaille quarry (A.Baud, Figs. 26 to 29)

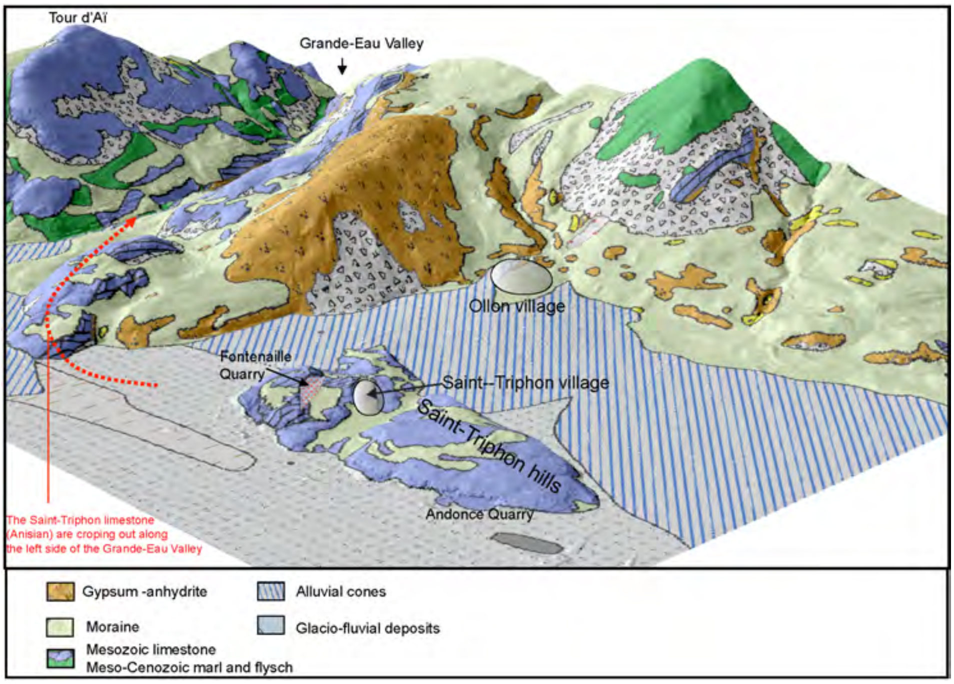

Figure 26: Geological map of the Saint-Triphon area on a 3D relief (adapted from Giorgis. 2012)

The first stop of our Fieldtrip is the lower Anisian limestone of the Fontenaille quarry in the Saint-Triphon hills. The main geological settings are given in the introduction. The geology of this overturned limestone klippe is shown on hills map (Fig. 29) and detailed geological sections have been worked in each quarries along the hills. A composite section of the hills compared to the main Prealps Triassic composite section is given at the Fig. 28 .

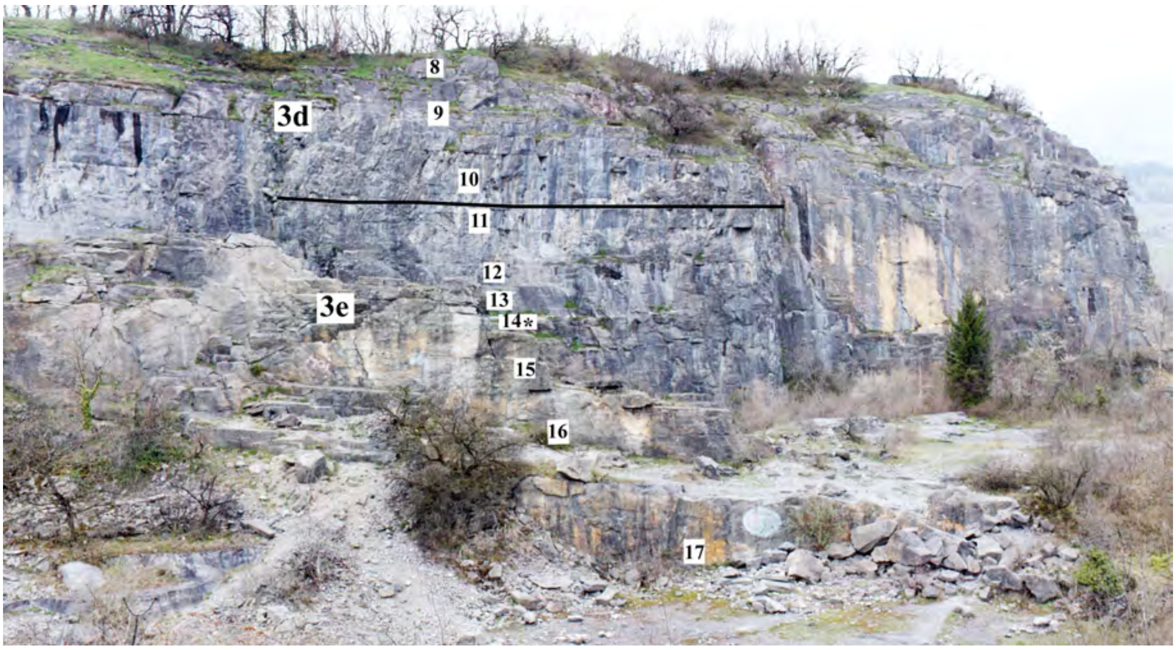

Figure 27: Stop 1, the Fontenaille quarry with overturned middle Anisian limestone; the units 3d and 3e and the bed nombers8 to 17 refers to the lithological section shown at the Fig. 28.

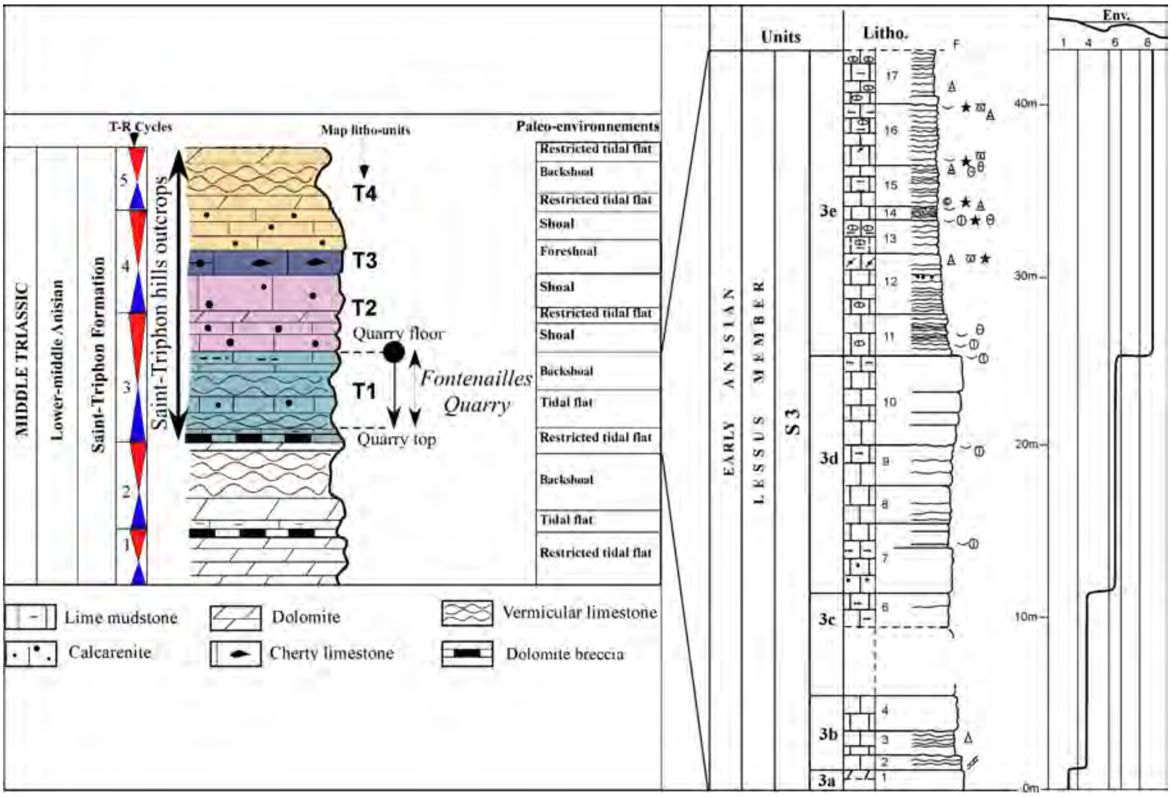

Figure 28: Composite Saint-Triphon Formation section from type locality area on the left (adapted from Baud et al., 2012). The color of the lithological units T1 to T4 are the same as in the geological map below (Fig. 29); on the right is the lithological section of the Fontenaille quarry (Baud, 1987); the bed numbers are reported on the quarry wall picture Fig. 27.

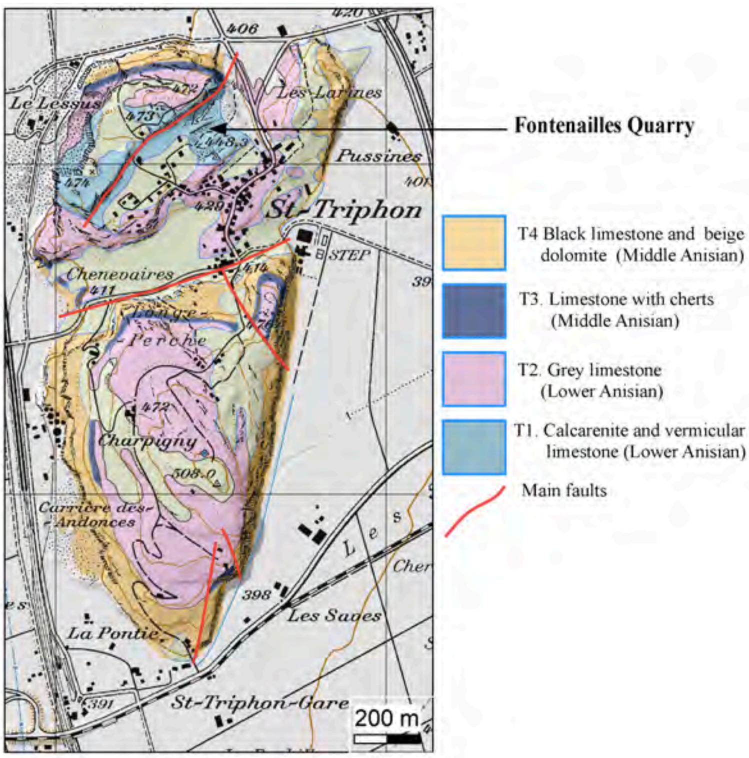

Figure 29: Detailed Geological map of the Saint-Triphon hills, from Badoux, 1962, colored in Baud et al., 2012)

After looking at the geological explanation panel in the quarry (Poster of Baud et al., 2012), we will move to a typical "calcaires vermiculés" surface (Fig. 30). These shallow water facies have a wide distribution in the lower and middle Triassic epeiric seas west of the Neotethys (Baud, 1976). The burrowing activity is here due to *Spongeliomorpha* types of burrows. The organisms which produced these burrows are Decapods (Crustacea). Their presence is confirmed by *Palaxius* and *Favreina* types of coprolites in the surrounding rocks. Decapods were very sparse at the end of the Paleozoic, but at the beginning of the Mesozoic, they apparently underwent explosive development due to favorable ecological conditions in these shallow water seas. In this way, they strongly influenced the early diagenetic environment and consequently the rock facies.

A detailed description of this facies and of the trace fossils are given in Baud, 1976 (in french). Below, the Figure is showing burrowed overturned bed surface as we can see in the NW part of the quarry (bed 12, Figs. 27 and 28).

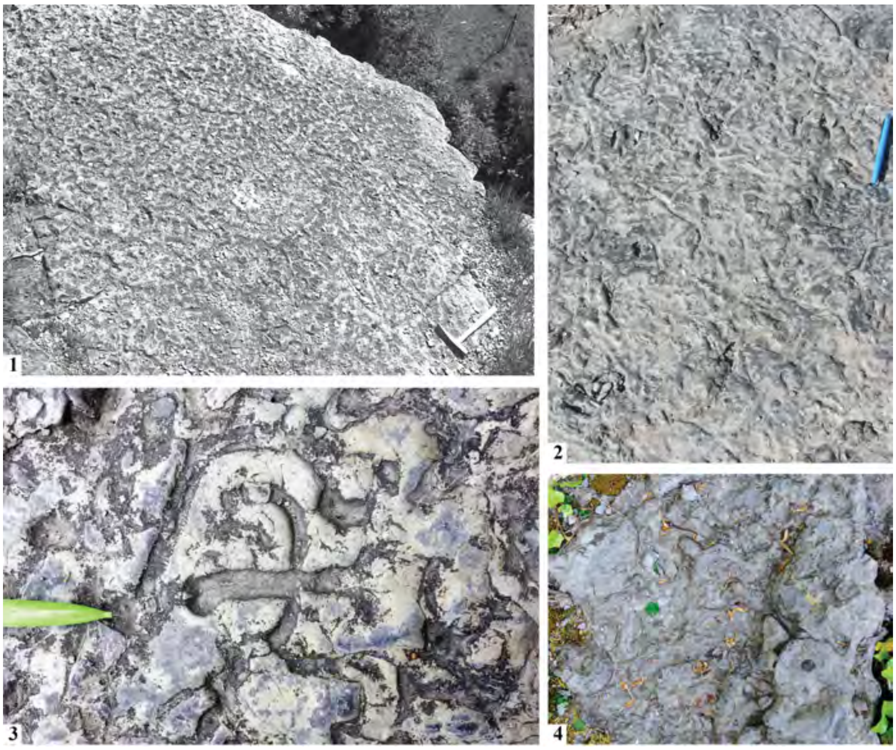

Figure 30: The vermicular limestones; 1- vermicular surface near the top of the Fontenaille quarry with Spongeliomorpha suevica trace fossil; 2- surface in the middle part of the quarry with thiner Spongeliomorpha network; 3- detail of the branching burrows; 4- Rhizocoralium jenense burrows from the younger unit 5 in the Andonce quarry (photos A. Baud).

After examining the "calcaires vermiculés" surface, we will move and discuss the deformational structures due to overpressure on unstable soft and partly cemented lime deposits (Baud, 1987).
These deformational structures (Figs. 31 and 32) appear in the shallow ramp to lagoonal rythmicaly layered lime-mud sediments. Vertical, "en chevron" and sigmoidal slab joints, pseudo-folding, crumpled beds and pseudo-breccia or conglomerate are illustrated, and 2 processes of the synsedimentary deformations are analysed. These processes are influenced by reversed viscosity gradients and by the "soft" and "hard" layers thickness ratio. My first interpretation (Baud, 1987) was the overpressure by fair weather giant waves but now I think that the earthquake shaken is a better hypothesis.

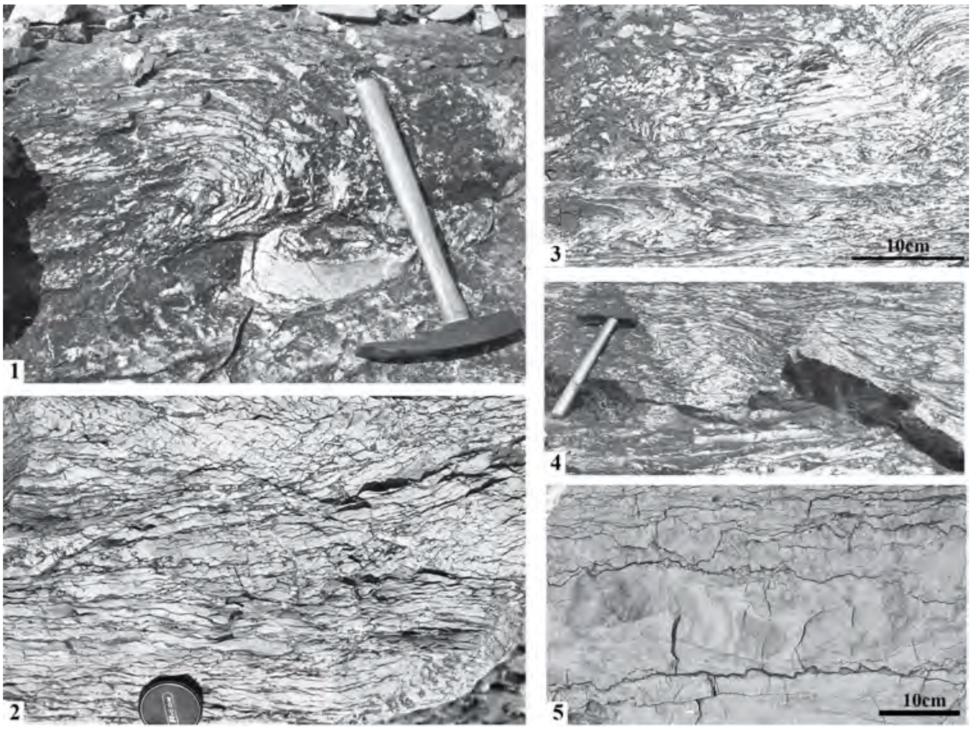

Figure 31: Seismite soft-sediment deformations; 1- Recumbent fold, horizontal micro-fault and disrupted lime mud layers; 2- disrupted and pinch-and-swell layers; 3- gentle fold inclined over disrupted layers and recumbent fold; 4-disrupted and brecciated layers; 5- Soft lime mud injected and folded by disrupted layers (photos A. Baud).

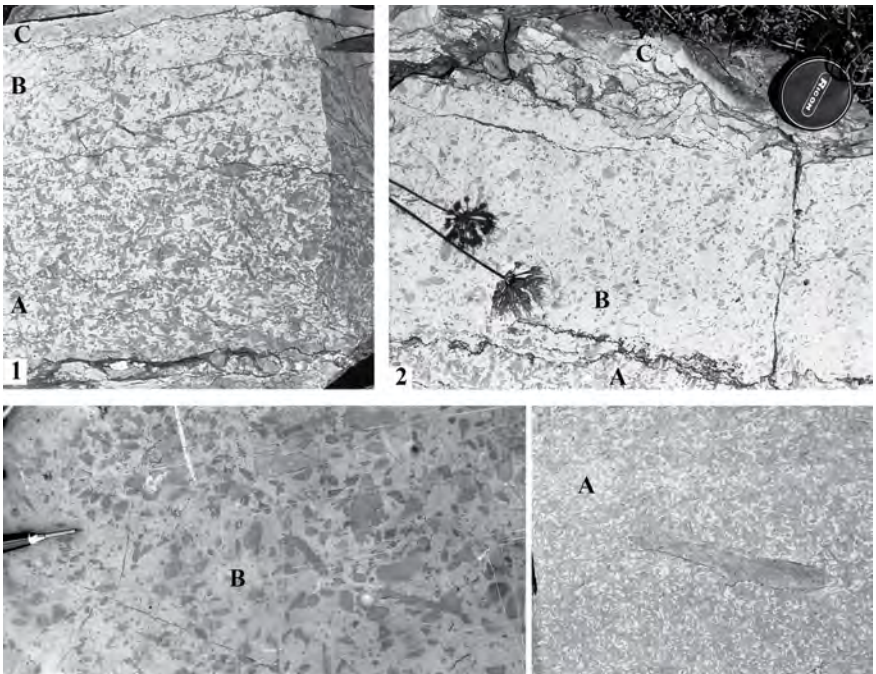

Figure 32: Seismites, liquefaction of the vermicular limestone matrix; 1- graded deposition (A, B) of the semi-solid burrow clasts in the quasi-liquid lime-mud matrix (thixotropic shock); 2- detailed view of the upper part with high matrix ratio (B), the top level C is showing an erosive base with re-deposit of large lime clasts (tsunamite?); 3 and 4: detail view of the burrow and lime clasts, less packed in 3 and more densly packed in 4 (photos A. Baud).

3.2 -Stop 2 (12h00-14h00): Bex: visit of the Salt Mine (Figs. 33 to 37)

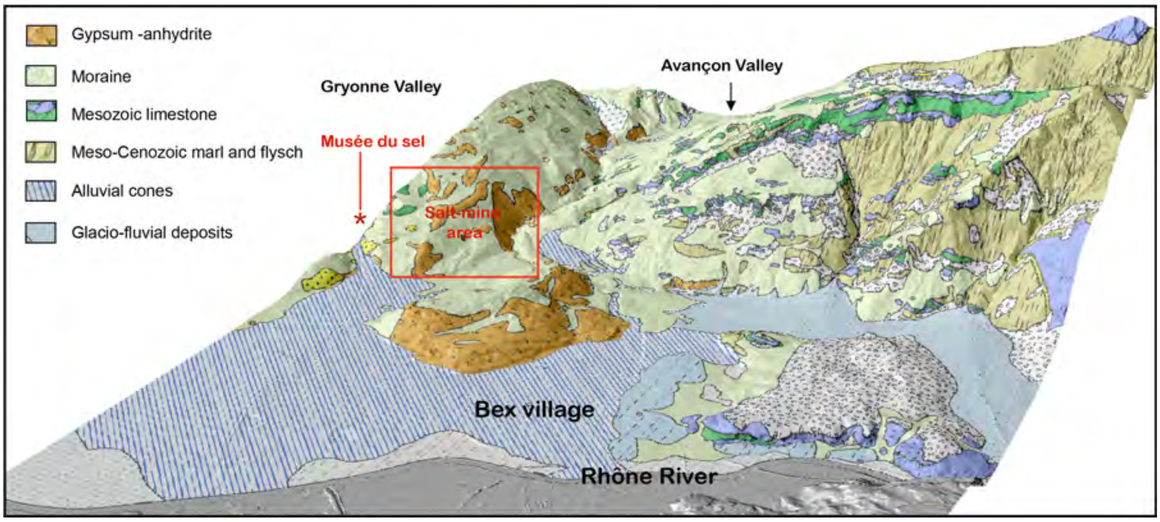

Figure 33: Geological map on 3D relief topography (adapted from David Giorgis maps, 2012)

The main geological setting is given in the introduction. The salt is included in a huge mass of Upper Triassic anhydrite, belonging to Sub-Mediane Melange Zone, which covers a large area north and northeast of Bex Village (Fig. 34).

3.2.1 Resumed approach to the geology of the mines

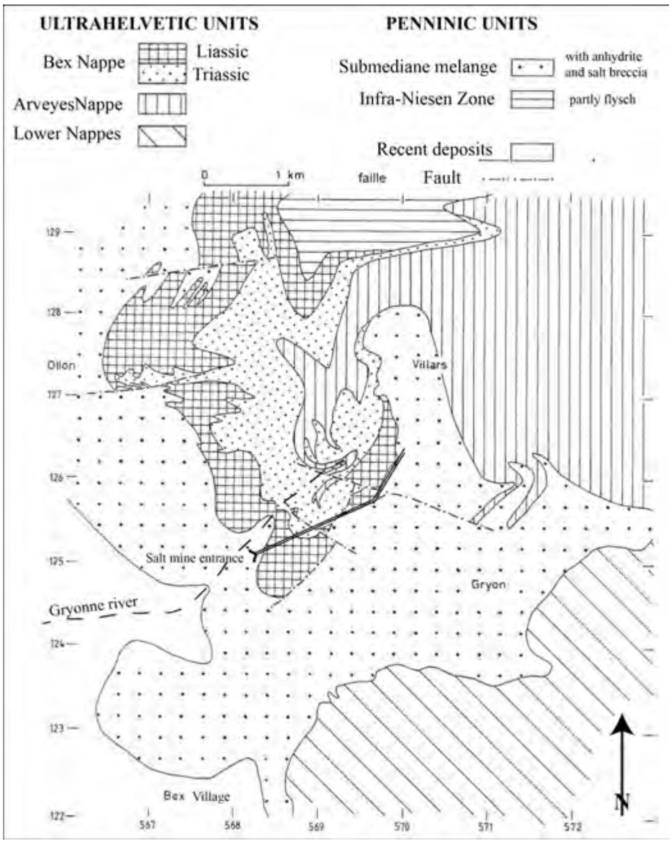

Figure 34: Tectonic map of the Salt mines area adapted from Graf, 1993; the trace of the visited gallery is shown in the middle of the map.

This stop 2, during the lunch time will be given to the underground visit of the Bex salt mine. Below (Fig. 35) is a picture of the main panel near the entrance of the mine, with the gallery topography and the main underground rooms.

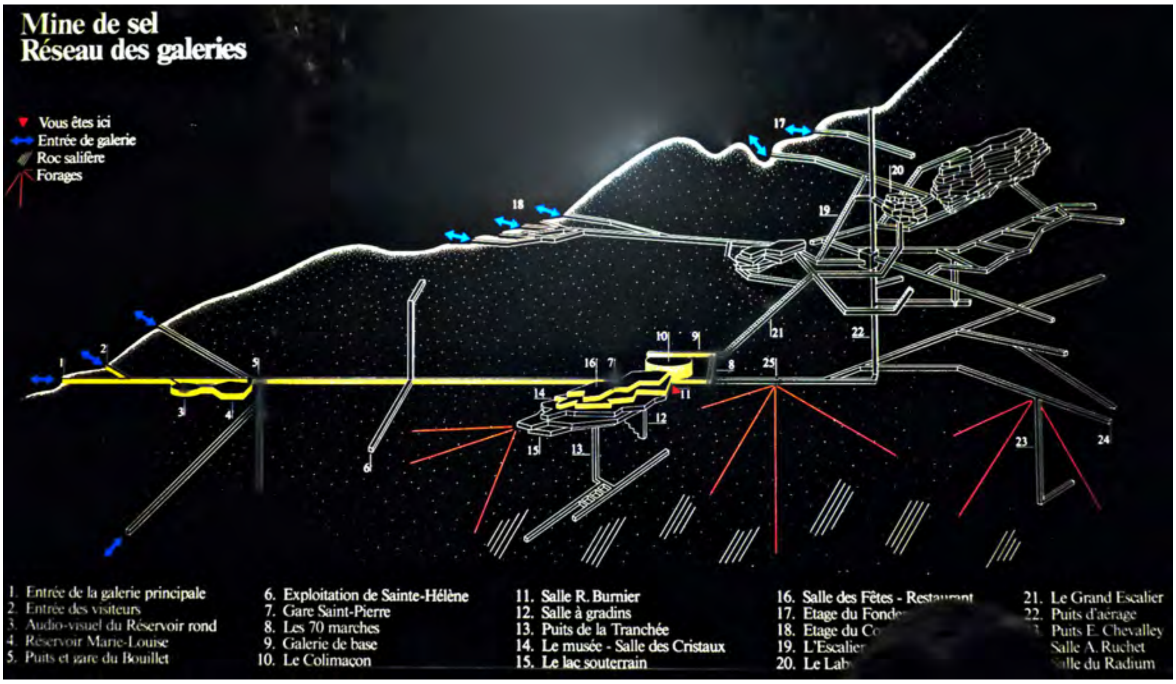

Figure 35: The gallery network of the Bex salt mines (the visited gallery is in yellow)

A geological cross section of the visited gallery is given below (Fig. 36)

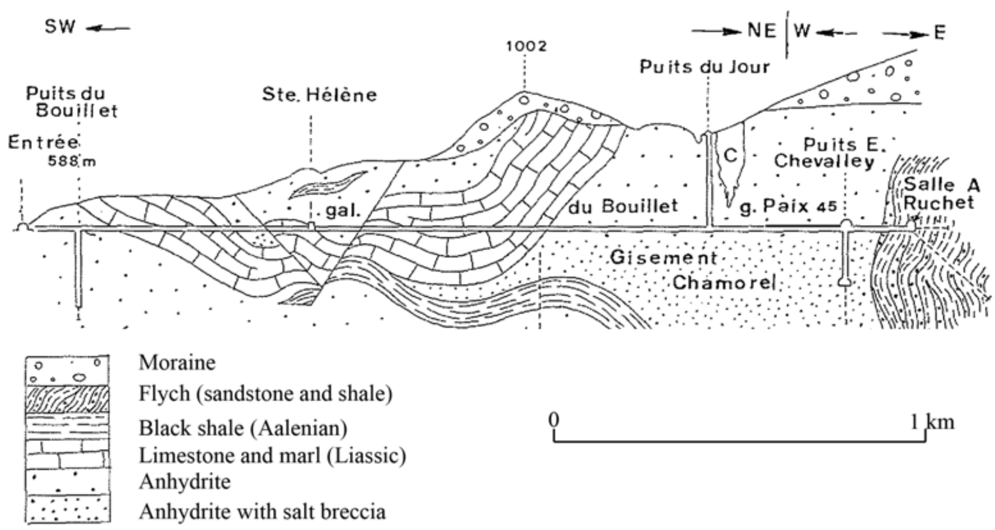

Figure 36: General cross section through the mine area (adapted from Badoux, 1982).

This complexity of the regional geology is also shown on the tectonic map (Fig. 34): the main tectonic units, Ultrahelvetic and Penninic are belonging to the distal European continental margin and the Briançonnais sub-plate (Fig. 7).

The salt does not form solid lenses surrounded by anhydrite, but appears as "cement" in a tectonic breccia where it fills the voids (25 % in volume) between the bits of anhydrite, shale and dolomite. The salt is extracted by water injections through borings drilled from inside the old mines. Annual production for the last years: 40'000 to 50'000 tons.

Acccording to Weidmann, 2006, the following evaporite facies are founded in the salt mine galeries:
a- ribbon anhydrite; b- brecciated anhydrite; c- grained gypsum with large grain; d- saccharoidal gypsum; e- ribbon gypsum; f- saliferous breccia.
The lithological sketch below is showing a section across a 500 m thick evaporite melange (Fig. 37).

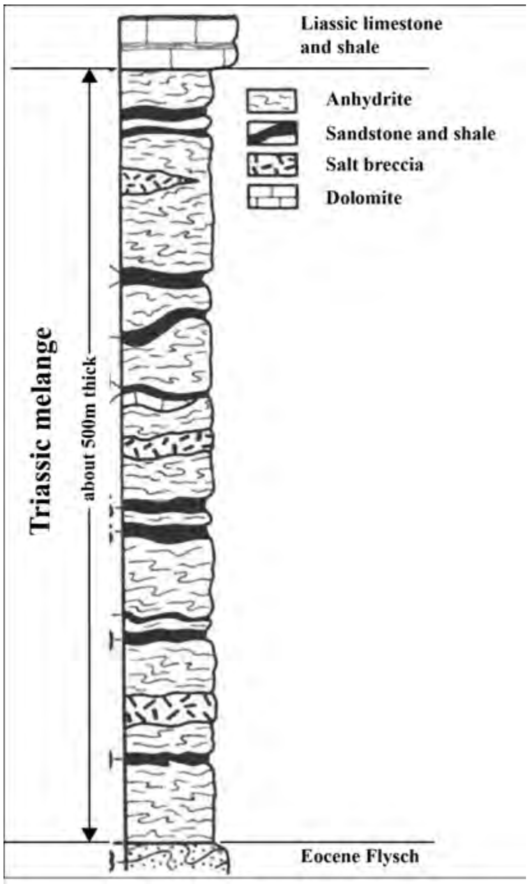

Figure 37: Lithological sketch across the evaporite (anhydrite –salt breccia) of the salt mine according to Badoux and Weidmann, 1964

Due to the highly complicate tectonic processes, it is not possible to give a precise depositional model (Angeloz, 2014), but with this salt deposit type, now as cement of an anhydrite breccia with strong diagenetic changes followed by a low metamorphism influence, it is interesting to note the appearance of new minerals.

3.2.2 Mineralogy and sulfur isotopes (Nicolas Meisser, Figs. 38 to 40).
Fine studies of mineralogical assemblages in the Triassic evaporitic facies show a rich and complex mineral paragenesis (Meisser & Ansermet, 1993). Most of rare minerals are related to alpine low grade metamorphism event or neoformation after mining activities. Sulfur isotope study shows clear genetical trends (Meisser, 2012). One can definite eight different paragenesis:
1- Primary evaporitic minerals, often completely recrystallized during diagenesis and alpine tectonic (halite, anhydrite, massive and platy crystallized gypsum, dolomite, calcite, celestine, barite, pyrite, quartz, native sulphur, sodium carbonates). Sulfur isotopes data for Ultrahelvetic anhydrite have value of +13.1‰, and for Penninic anhydrite, up to +16.7‰. These values are in accordance with oceanic values of this period, but this notable variation have to been studied according paleogeographical and/or age aspects.

2- Late stage alpine veins (< 10 m.y.) crosscutting dolomite, sandstones and black shale with epithermal mineralisations (calcite, pink anhydrite, gemmy gypsum, magnesite, Fe-dolomite, strontianite, celestine, Ba-celestine, native sulfur, chalcopyrite, sphalerite, galena, quartz, hematite, albite, etc.).
Sulfur isotopes data of celestine associated with sulfides have high value (+20.2‰ to +25.6‰) and sulfides with lower values (+11.5‰ to +14.5‰). This discrepancy is interpreted as epithermal partial bacterial reduction of Triassic evaporitic sulfate into sulfides species and precipitation as galena and sphalerite. Residual ^{32}S enriched-sulfate precipitate as celestine.
Large gemmy gypsum crystals embedded in clay, mostly discovered in 1790 and 1817, are world-wide widespread in old mineralogical collections. Most of them are considered as crystallographical morphological types for gypsum (Soret, 1817; Dufrénoy, 1848, Meisser, 2014).

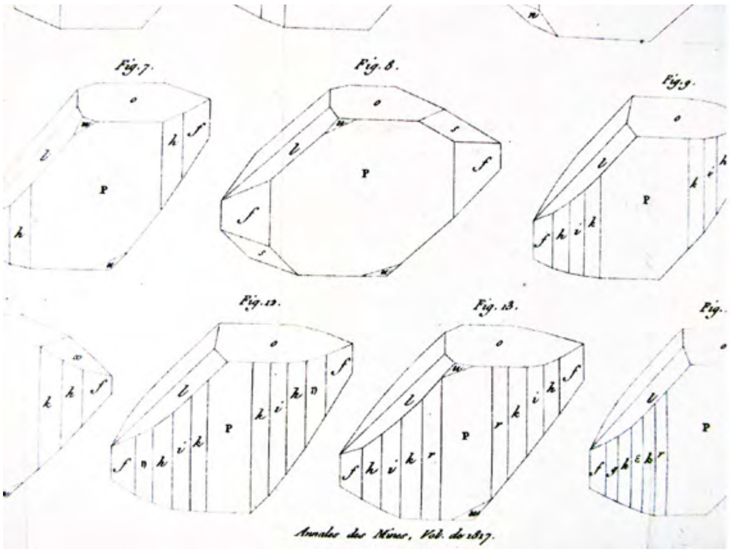


Figure 38 left: Soret (1817) Gypsum plate right, Gypsum cristal (paragenesis 2)

3- Quaternary-aged alteration of former mineral assemblages. Mostly dissolution of halite, sulfates and carbonates, massive hydratation of anhydrite into gypsum and clay mineral formation.
4- Post-mining (< 300 years) neoformation or exudations (Fig. 40) of partially water-soluble caliche and efflorescences from evaporites or black shales (gypsum, aragonite, mirabilite, thenardite, epsomite, nahcolite, trona, thermonatrite, natron, eugsterite, hydroglauberite, gaylussite, hydromagnesite, etc.).
The local abundance of sodium carbonates- bearing mineral species as exudates on anhydrite is interpreted as typical influence of continental ± lacustrine brine. Medium sulfur isotopes data of soluble sodium and magnesium sulfates mirabilite (+ 9.5‰) and epsomite (+11.2‰) co-crystallized with these alkaline carbonates corroborate this genetical hypothesis.
5 - Post-mining (< 300 years) neoformation by oxidation of primary iron and copper sulfides dispersed in black shales or epithermal alpine veins (jarosite, natrojarosite, metasideronatrite, tamarugite, melanterite, paratacamite, atacamite, botallackite and several new mineral species under investigation).
6 - Sub-actual (< 200 years) alteration of anthropogenic metallic objects or wastes (chaconatronite, posnjakite, devilline, cuprite, simonkolleite, salmiac, etc.).
7 - Actual reduction of gypsum by thiobacillum sp. into native sulfur and calcite.
8 - Actual crystallization of prismatic crystal of gypsum or cubic halite in underground brine reservoirs (Fig. 39).

Figure 39: surface of dry underground brine reservoirs with prismatic crystals of gypsum (left) and cubic halite cristals (right)- S. Ansermet slides

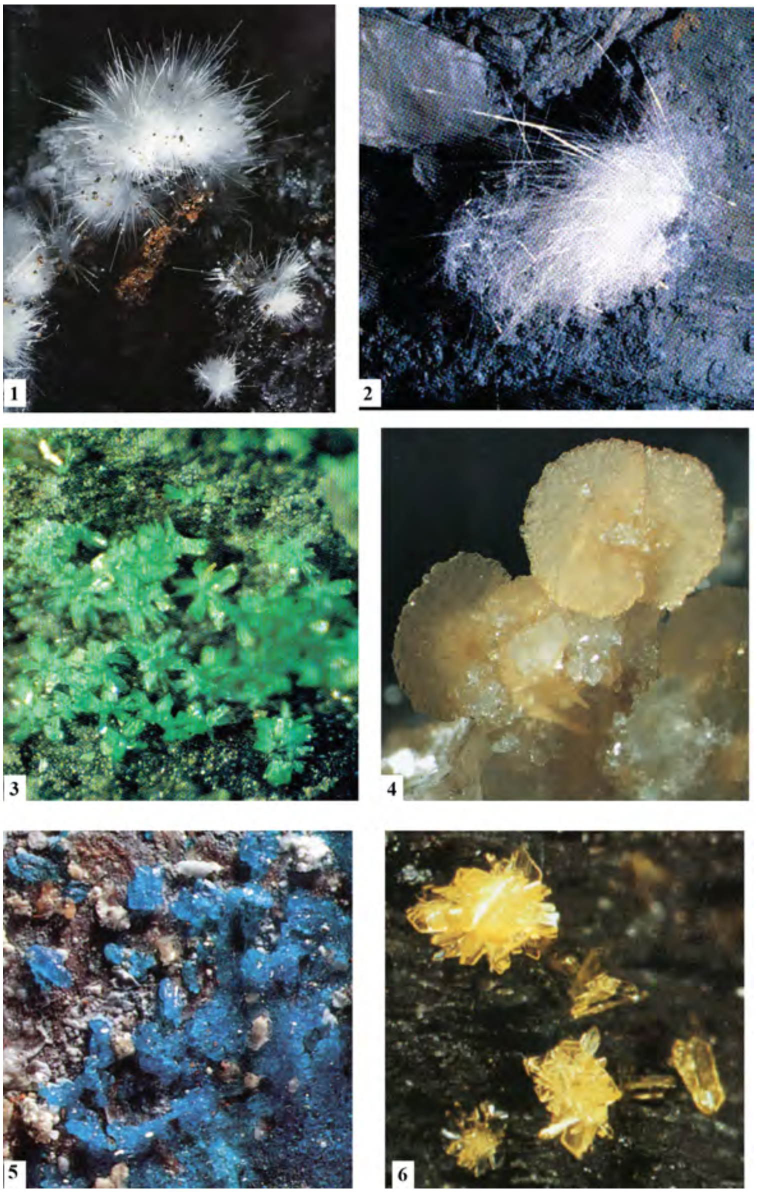

Figure 40:Post-mining, neoformation minerals 1- Nahcolite ($NaHCO_3$); 2- Epsomite ($MgSO_4$ • $7H_2O$); 3- Atacamite and para-atacamite ($Cu_2Cl(OH)_3$); 4- Magnesite ($MgCO_3$) *5- Chalconatronite $Na._2Cu(C0_3)_2$ • $3H_2O$; 6 - Métasidéronatrite $Na_2Fe^{+3}(SO_4)_2(OH)$ • H_20 (Photos from Stefan Ansermet in Meisser & Ansermet, 1993).*

Stop 3 (14h30-15h00): Yvorne village, vineyard on the historical landslide "Ovaille" (Figs. 41 to 43).

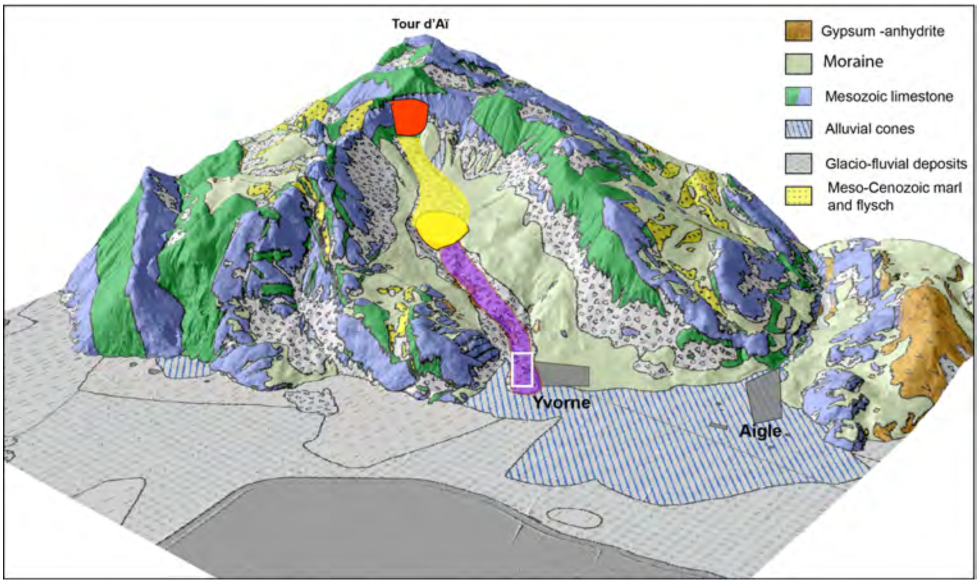

Figure 41: *Geological map on 3D relief topography of the Yvorne landslide area; the white rectangle is the wine appellation "Ovaille" (adapted from David Giorgis maps, 2012).*

We will make a short geomorphological and landscape stop along the road crossing the historical landslide "Ovaille", close to the beautifull "Maison Blanche" Castle (Figs 42-43).

Figure 42 left: The "Maison Blanche" Castle in early spring; middle: white wine bottle label; right: the "Ovaille" vineyard growing on the historical landslide (pictures from Yvorne, Maison Blanche vineyard website).

Figure 43: Stop 3, close to the "Maison Blanche" Castle (picture from winechablais website).

Stop 4 (16h00-16h30): "La Corniche" with scenic view on Lac Léman and Mesozoic Pre-Alps. Terraces of Dezaley vineyard in the Miocene Paleo-Rhone delta (Mont Pélerin conglomerates and Figs. 44 to 48).

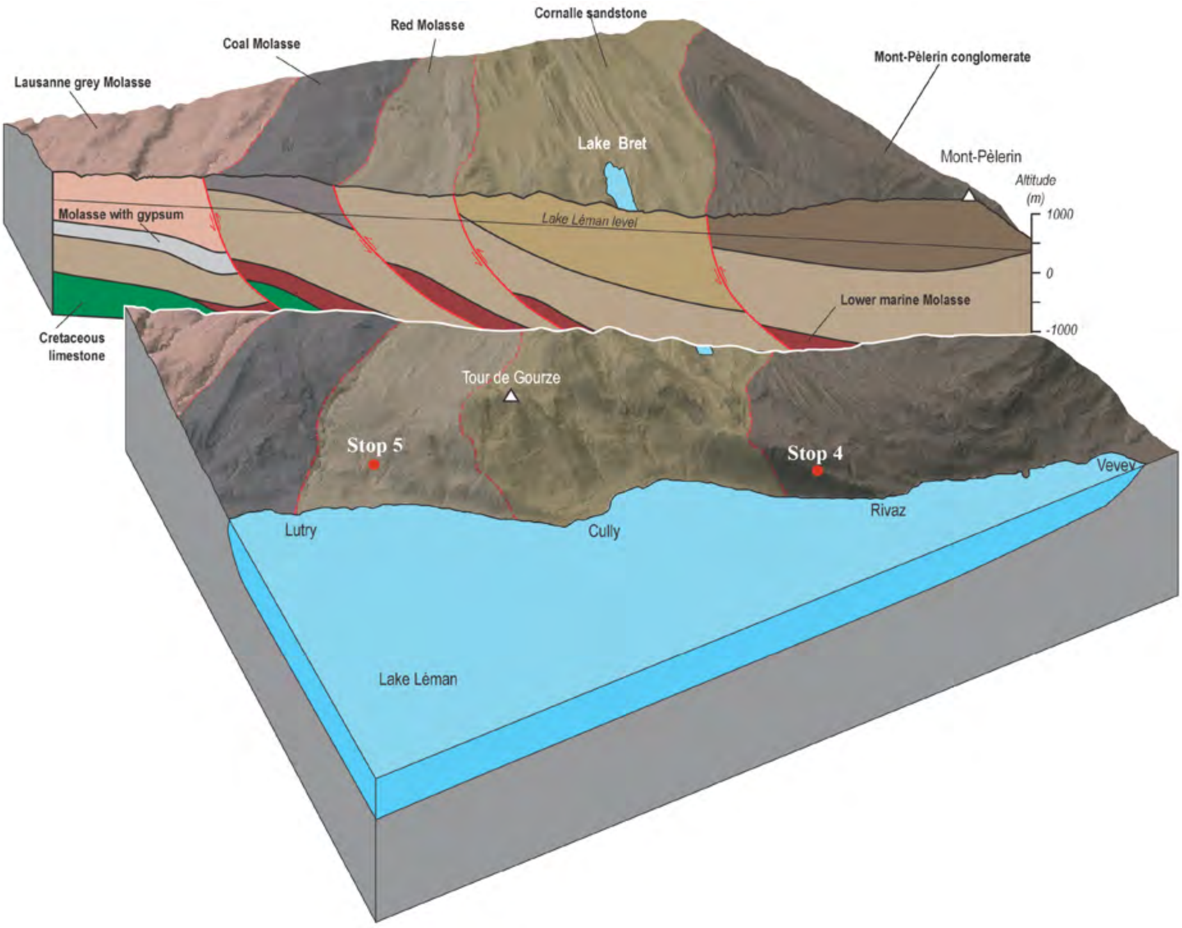

Figure 44: Block diagram of the Lavaux area showing the different type of Molasse gently folded with a set of overthrusts. Stop 4 and 5 places are given on the lower relief map (after R. Marchant, in Borel & Marchant, 2007).

Today, the shape of the landscape is the result of glacial erosion (Fig. 45) and of mechanical erosion caused by runoff water, chemical erosion due to the dissolving of the limestone and rock-binding clay, and the freeze/thaw phenomena fracturing the rocks. These processes specifically affect the layers of "poudingues" that consequently tend to collapse. This is why these rocks are frequently the focus of geotechnical work to strengthen them (Fig. 46).

As shown in Fig. 45, the Rhodanian Glacier attained an altitude of approximately 1400 metres in the Lavaux region. The Tower of Gourze was under some 500 metres of ice. The abrupt slope of Dézaley, which extends under the lake level, presents a type of morphology that is typical of glacial erosion.

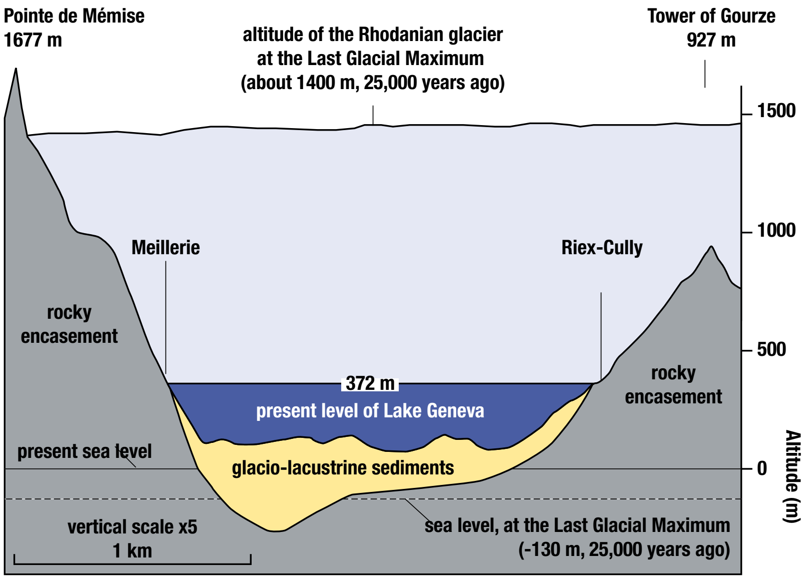

Figure 45: SW-NE section across Lake Léman. The abrupt slope of Dézaley (Riex-Cully), which extends under the lake level, presents a type of morphology that is typical of glacial erosion. (from R. Marchant, in Borel & Marchant, 2007).

Our stop 4 is close to the upper entrance of the sightseen "La Corniche" road and we will look both at the typical Lavaux vineyard spectacular landscape and view on the Miocene Paleo-Rhone delta with the Mont Pélerin conglomerates (Figs. 46-47).
These conglomerates correspond to a vast fluvial spread fanning out its interlacing rivers where conglomerates made up of rounded pebbles were deposited. These conglomerates were called “poudingues” due to their resemblance to the large currants in the paste of English puddings.
It is these deposits of conglomerate, which make up the rocky ridges of the landscape between Dézaley and Vevey. The vineyards were planted between these rocky ridges on much softer rock, such as marl or clay (Fig. 46) and sometimes even coal. Coal deposits correspond to marshy environments, whereas marl and clay correspond to areas that flood when the water level rises and which were sometimes wooded. A 25 million years ago subtropical forest on deltaic landscape is shown at fig. 48.

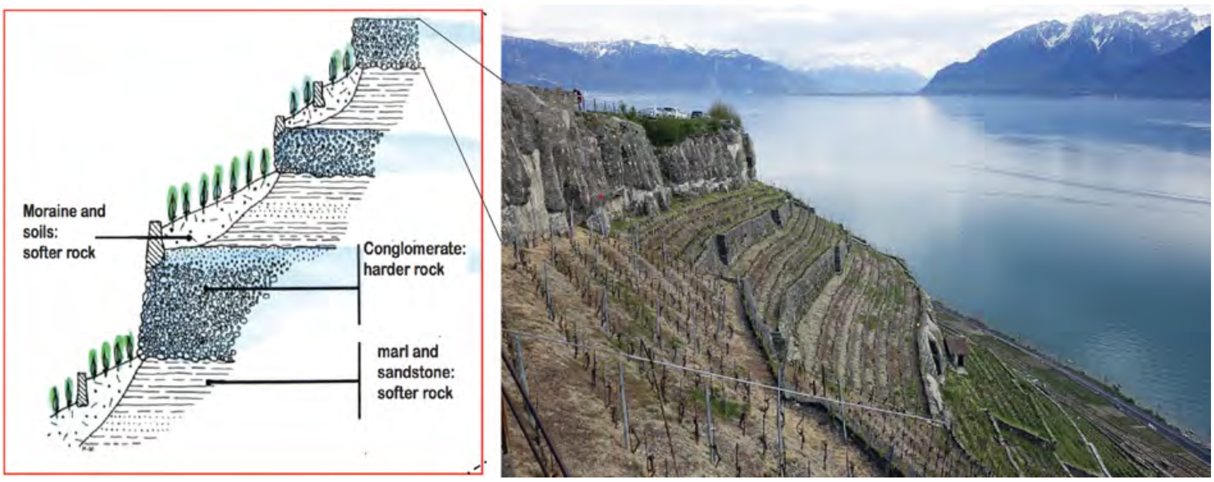

Figure 46, stop 4, left: Vineyard lithological section (sketch adapted from M. Weidmann, unpublished); right: the Lavaux vineyard steep slope with the reinforced Mont Pélerin conglomerates cliff on the upper left side.

Figure 47, stop 4, left: Other side of the Lavaux vineyard steep slope; right: a close view on the Mont Pélerin polygenic conglomerates with well rounded pebbles .

As reported in the chapter 1.3.1, the pebbles have a long, polyphased story well recounted by Trümpy in his famous paper "Du Pélerin aux Pyrénées" (1976).

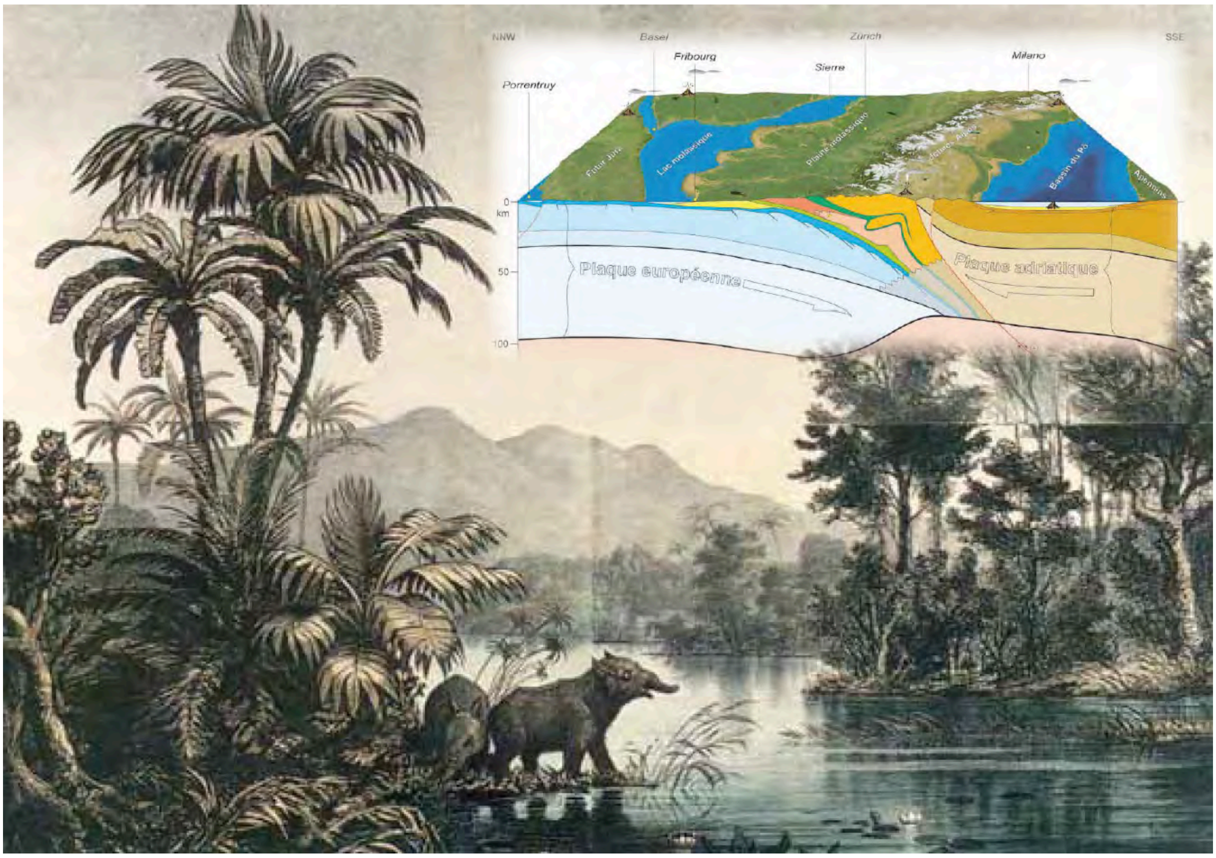

Figure 48: Subtropical landscape with primitive Tapirs in front. In the ground, the erosion of the Early Alpine mountains is providing the terrigenous sediments (pebbles, sand and clay) of the Molassebasin; On the top right, the block diagram of the alpine Range growth, 25 Million years ago, is showing on its right part the shallow plain of the Molasse deposits (R. Marchant, © Geological Museum Lausanne).

3.5 -Stop 5 (17h00-19h00): Le Daley (above Grandvaux village fig. 49).
For our last stop, we will be welcome above the Aran hamlet near Grandvaux by Henri and Vincent Chollet winemaker family in their typical wine grower house surrounded by the vineyard growing on the "Molasse rouge" . We will have the unique opportunity to taste the wine coming from the different terroirs crossed during our fieldtrip and detailed in the second chapter of this guidebook.

Figure 49: Vineyard "Domaine Mermetus" and landscape by Henri and Vincent Chollet.

Acknowledgements

Thanks to Gilles Borel, director of the Geological Museum to help us and to allow his collaborators to work with this guidebook.
We are particularly grateful to Michel Jaboyedov for all the information on the "Ovaille" landslide and to his collaborator G Garcia for the Fontenaille quarry north wall picture. Aurélie Angeloz provides us part of her masterwork manuscript and reference list, thanks to her. We thank also David Giorgis who kindly offered his set of geological map on 3D relief topography. Thomas Mummenthaler help us with the data on the book in work "Roche et vin" and the contact with the Chollet family and we are grateful to him. And thanks to Stefan Ansermet for the Bex mineral slides.

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Website of the tasted wines

1- Saint Triphon white wine, Chasselas grapes and red wine, Mondeuse grapes:
http://www.baud-bel.ch/crbst_3.html

2- Bex, Montet Hill, white wine, Chasselas grapes: http://rapazfreres.ch/belenos.htm
and red wine, Pinot noir grapes: http://www.charlyblanc.ch/nos-vins-blancs-fr15.html

3- Yvorne, Ovaille white wine, Chasselas grapes: http://www.ovaille.ch/index.php
red wine, Mondeuse grapes: http://www.charlyblanc.ch/nos-vins-blancs-fr15.html

4- Lavaux, Chollet Familly, white wine, Chasselas grapes and red wine, Mondeuse grapes: http://www.mermetus.ch/vins

5- World Heritage Site of Lavaux, UNESCO: http://whc.unesco.org/en/list/1243/