Field trip guidebook : Local Triassic outcrops from carbonate platform to evaporite

September 2, 2023

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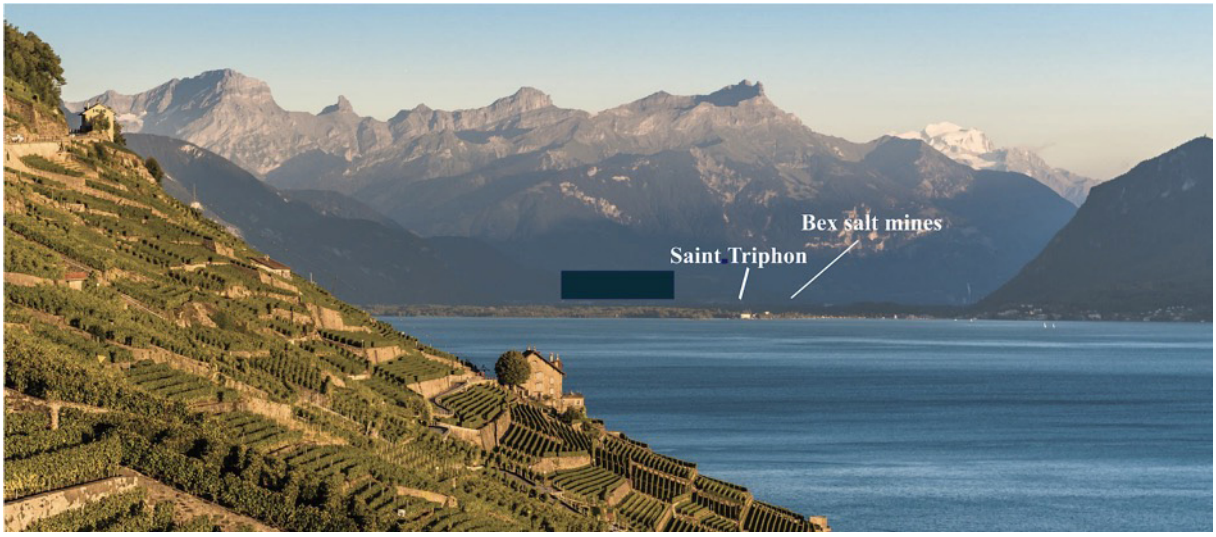

From Lavaux to Rhone Valley with the main stops in white. Lac Léman "Lake Geneva" on the right. The snow-capped "Grand Combin" (4314m. high) in the background and the Morcles thrust sheet Crest ("Hautes Alpes calcaires", Helvetic domain) in the back

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References

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 intraoceanic 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).

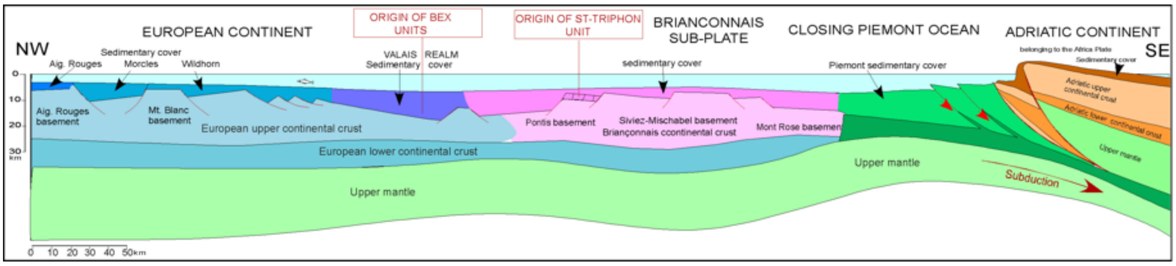

Figure 1 : Middle Cretaceous (100 Ma) geological section with original position of visited outcrops in the Prealps. The European units are getting closer of the Adriatic micro-plate of African origin and, with the subduction, the Piemont oceanic belt is closing. There were no Alps at that time ! (adapted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

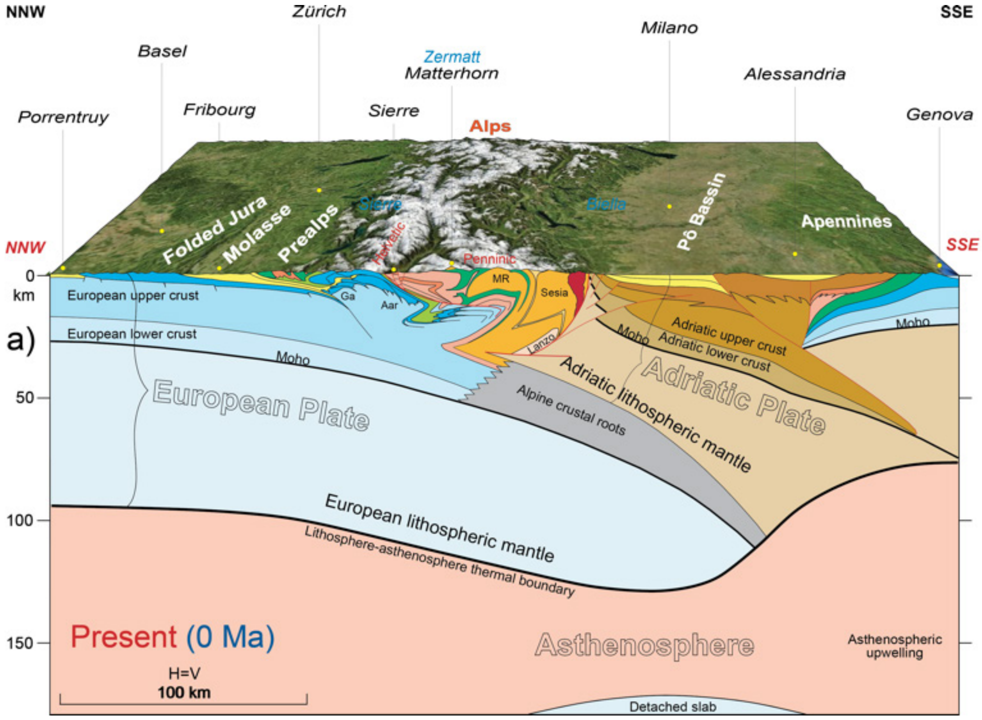

Figure 2 : Block diagram of Western Switzerland from Apennines to folded Jura through the Alps. (R. Marchant, in Guidebook FTB 2, 19th International Sedimentological Congress 2014).

1.2 – The Triassic carbonate and evaporite of Western Switzerland Prealps

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.4).

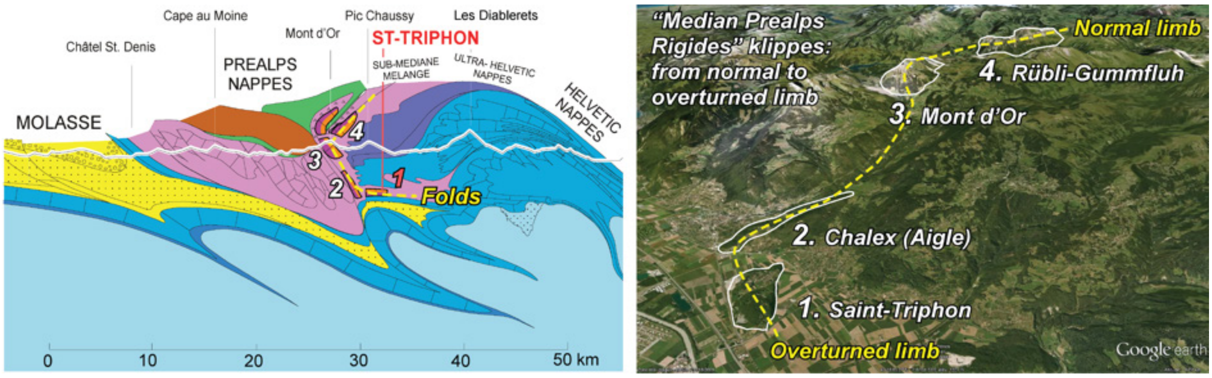

Figure 3 left : Geological cross-section from Molasse to Helvetic nappes. The Saint-Triphon hills are lying in the overturned part of the large Sub-Mediane Melange fold ; right, " Google Earth " view with the position of the Mediane klippes from normal to overturned limb (adapted from A. Escher, in Baud et al., poster, 2012).

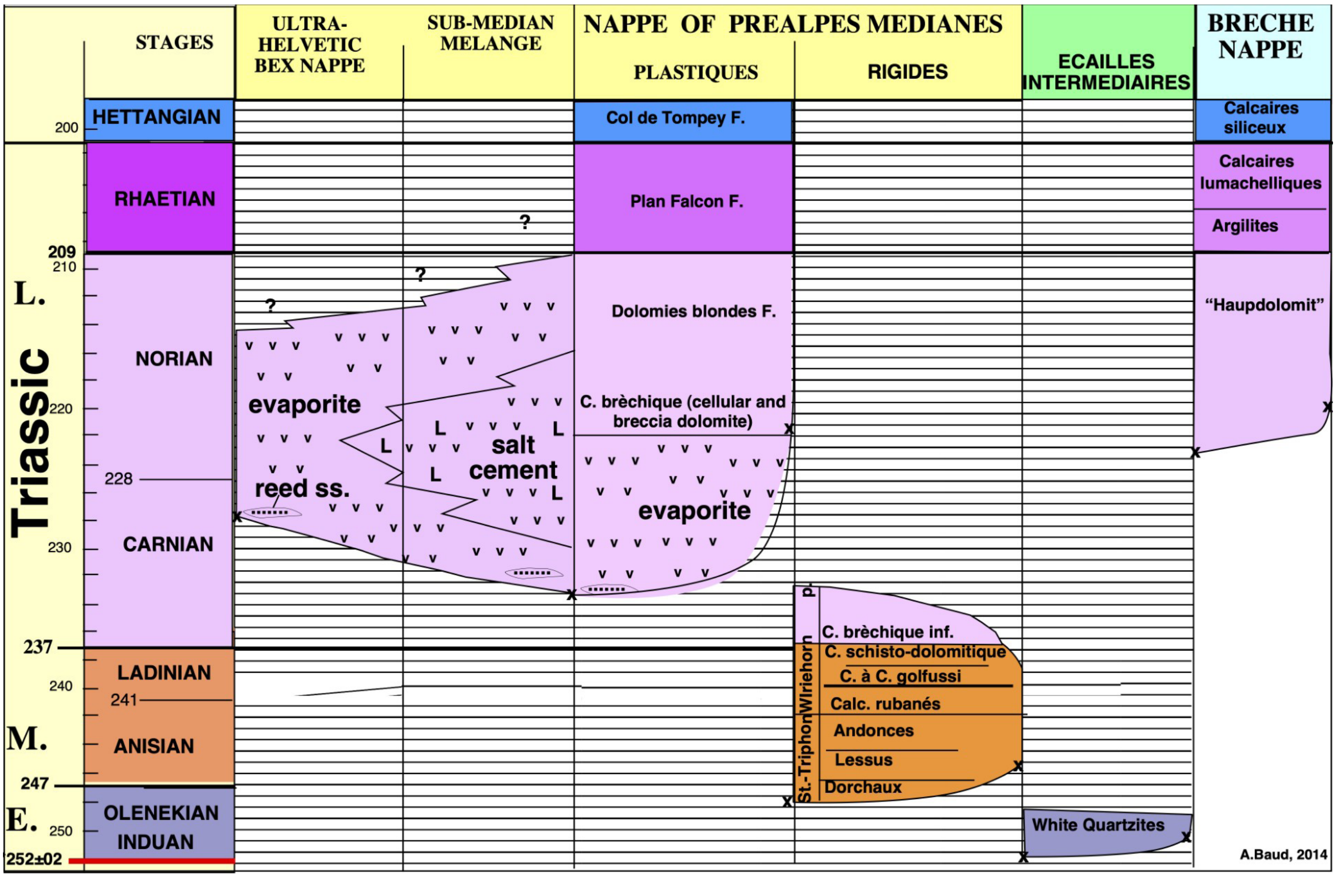

Figure 3 : Sketch of the Triassic Units within the Western Switzerland Prealps (adapted from Baud in Mégard-Galli & Baud,1978). During the fieldtrip, we will look at the Anisian limestone of the Saint-Triphon Formation (Prealpes Medianes Rigides tectonic unit, Baud, 1972) and at the Late Triassic Evaporite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

1.2.1 – The Anisian Saint-Triphon Formation, (Baud, 1987, fig. 5, Baud, 2022).

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.

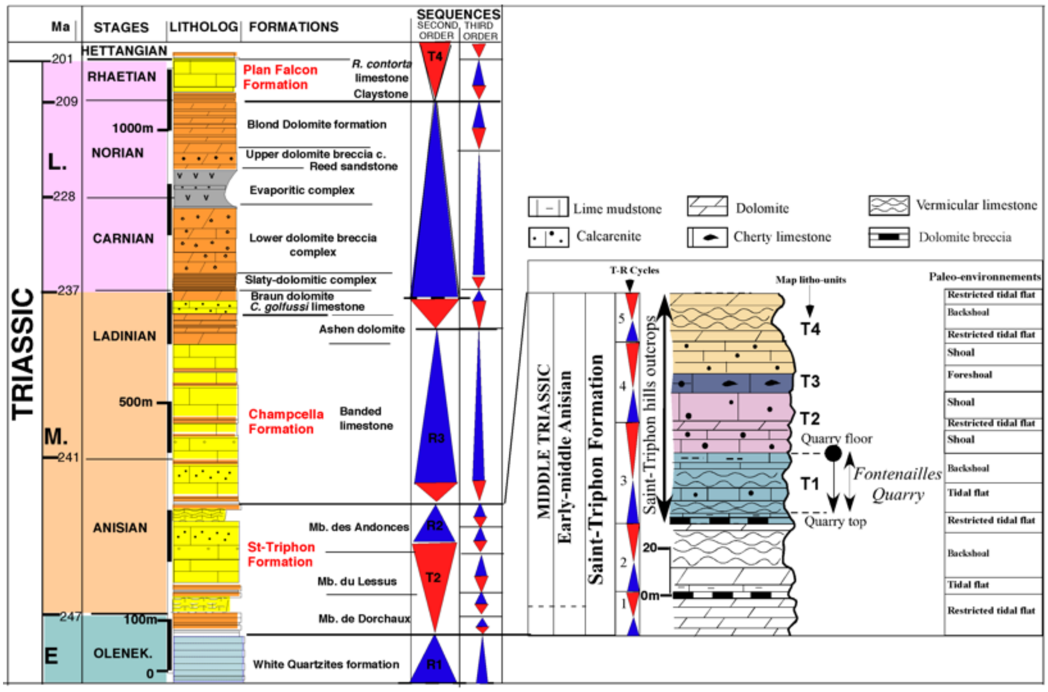

Figure 5 left: Composite Triassic section of the "Préalpes Medianes" Nappe with second and third order sequences (Baud, 1972 and 1987); right, composite Saint-Triphon Formation section from the type locality area (after Baud in Baud et al., 2012).

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.

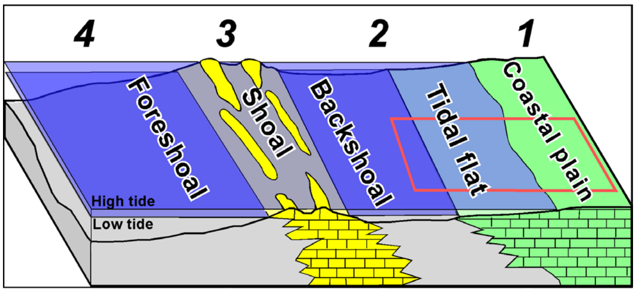

Figure 6: Paleoenvironments sketch of the mature carbonate platform stage. Explanations in the text (Baud, 1987).

1.2.2 – Paleoecology and timing of the middle Triassic microbial mats to sponge-microbial buildups, and bio- events in the Briançonnais epeiric sea, links to the Permian–Triassic crisis aftermath.

Recent works on classic stromatolite (Lee & Riding, 2020), on sponge take over following the end-Permian mass extinction (Baud et al., 2021) and the possible extension of the sponge-microbial buildups in the Germanic basin Triassic carbonate (Pei & Reitner, 2022), led us to question and actualize the so called "algal mats, crypto-sponge and mudmound" of our published work on the middle Triassic carbonate of the neighboring Briançonnais epeiric sea (Baud, 1987; Baud et al., 2016). In this adjacent sea, recorded from central Switzerland to Franco-Italian maritime Alps, a first marine transgression occurred during the Lower-Middle Triassic transition about 247 My ago, characterized by a very large scale, dolomitic microbial mat deposition (a, fig. 7) a first similarity with the post extinction basal Triassic stromatolites of the Tethys. But the presence of nonspicular demosponges in the Briançonnais stromatolites with a mutualistic relationship is here to be resolved.

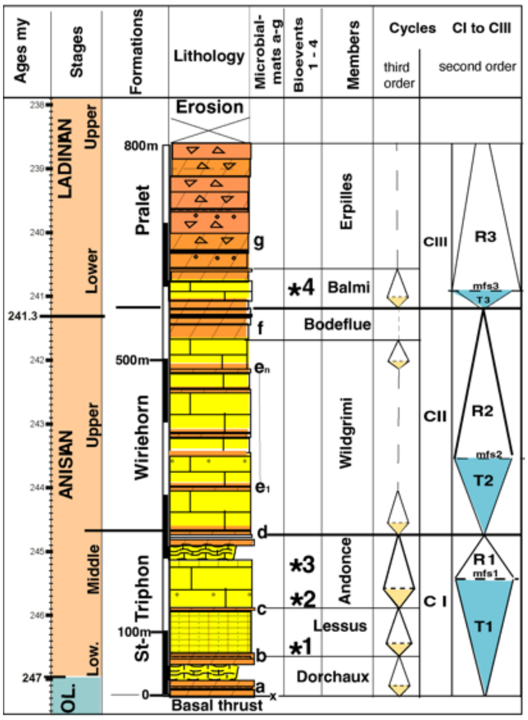

Figure 7 : Stratigraphical sketch of the Middle Triassic succession of the Briançonnais domain in Western Switzerland with microbial mats levels and bioevents. Captions : limestone in yellow and dolomite in braun. T=transgressive system-track ; R=regressive s-t ; mfs=main flooding surface ; Absolute ages in millions of years (My) according to recent chronostratigraphic charts.

During the Lower Anisian time (247-246 My), a new, large scale dolomitic microbial mat, caps (b, fig. 7) the open shallow marine deposition of the 20m thick vermicular limestone of the Dorchaux Member. The next third order transgressive cycle (Lessus Member) is showing a first bio-event (*1, fig. 7) with the lower Anisian sudden recovery of abundant calcareous algae, which disappeared during the end-Permian great extinction and were absent during Early Triassic time. At the top this Lessus Member (middle Anisian about 246 My ago), a local dolomitic microbial mat was well recorded (c, fig. 7). The new transgressive system track of the Andonce Member brought two bio-events (*2 and *3, fig. 7): the first concerns the resurgence and abundance of siliceous sponges, bio-event at the origin of the first chert bands in the limestones. Due to an Ammonoid finding, the second bio-event is well dated of the middle Anisian *B. cadoricus* zone and consists of the recovery of a corals type *Thamnastrea*, and of calcareous and non-calcareous spicular sponges' growth. Also, unique and close in time, a level of a thrombolitic buildup up to 4 m thick were found in the Rothorn section, all described in Baud, 1987, "mudmound" showing similarity to the post extinction basal Triassic sponge microbial buildups (Baud et al., 2021).

At the middle-upper Anisian transition between 245 and 244 My ago, the regressive top of the Saint-Triphon Formation is characterized by a very large scale, dolomitic microbial mats deposition (d, fig. 7) recorded within the whole Briançonnais domain. The overlying Wildgrimmi Member of the Wiriehorn Formation consists of a 220 to 340 m succession of peritidal carbonate deposits with a shift to pluri-metric scale shallowing-upward cycles, each topped by a dolomite bed possibly of microbial origin (e1 to en, fig. 7), like to same age South Alpine lagoonal Latemar shorter cycles. The upper regressive part of the Wiriehorn Formation is characterized by dolomitic beds partly built by stromatolites (f, fig. 7). In the following transgressive part of the Pralet Formation, the recorded conodont *trumpyi* allowed us to date the upper bio-event (*4 *fig. 7*) of the basal Lower Ladinien, about 241 My ago. It consists of a short living rich assemblage of crinoids, gastropods, brachiopods, bivalves, and siliceous sponges. Then due to aridity and higher salinity, the carbonate factory moves to dolomitic production with increase in microbial activities (g, fig. 7) and loss of skeletal material in the upper Pralet Formation still Ladinien in age (240-238 My).

1.2.3 – 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. 8), 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.

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. 9).

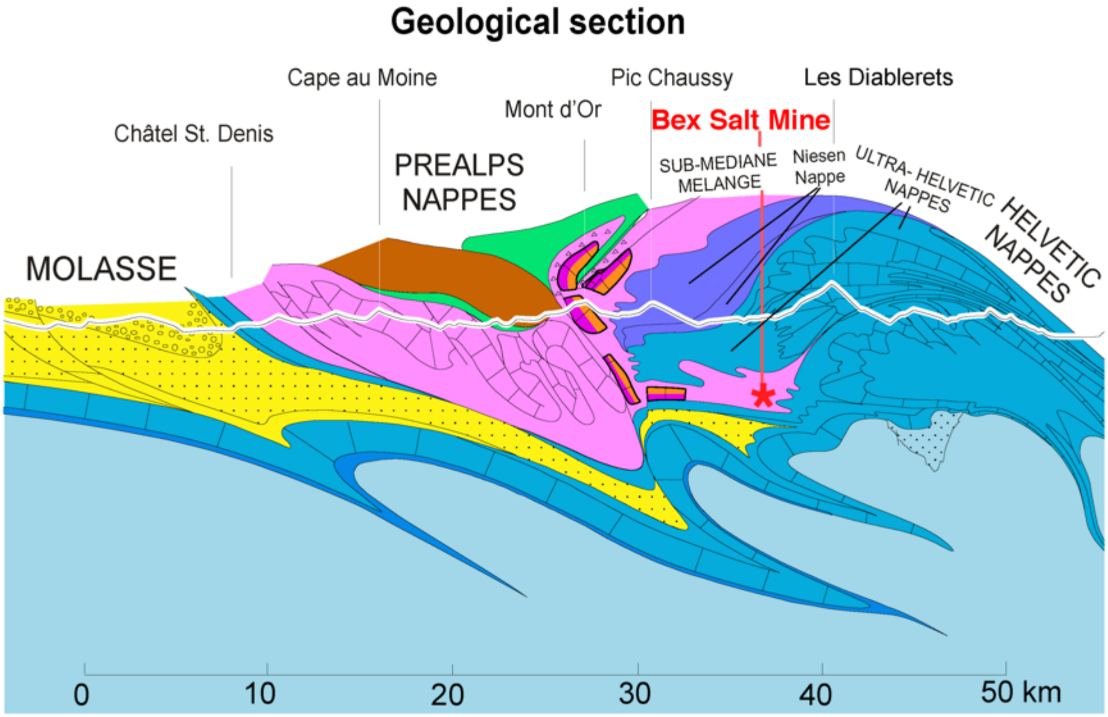

Fig. 8 : Geological section (NW-SE) through the Western part of the Swiss Alps along the Rhone valley (adapted from A. Escher in Baud et al., poster, 2012).

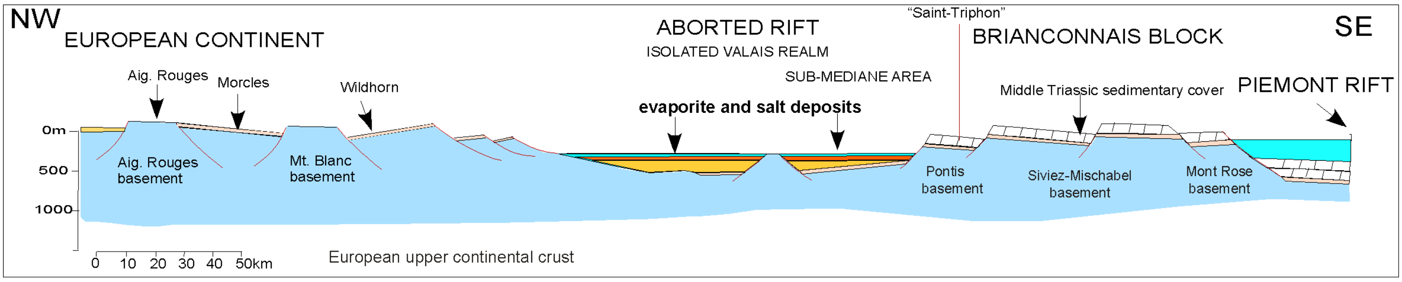

Fig. 9 : Late Triassic geological sketch with the original position of the evaporite basins (A Baud).

2 – Geological itinerary and stops (Figs. 10 and 11)

The Saint-Triphon hills, which host the Formation stratotype, are home to some of the most fascinating outcrops in the Briançonnais region of the Western Alps, not only in terms of the history of geological sciences, but also in terms of the history of georesources in the Vaud region, with the exploitation of ancient quarries described and illustrated by Pradervant and Baud, (2007). There are also unique and educational outcrops for teaching earth sciences and continuing education. A large panel of geological explanations has been installed in the Fontenailles quarry at the instigation of the Fondation Nicole Debarges (Baud et al., 2012).

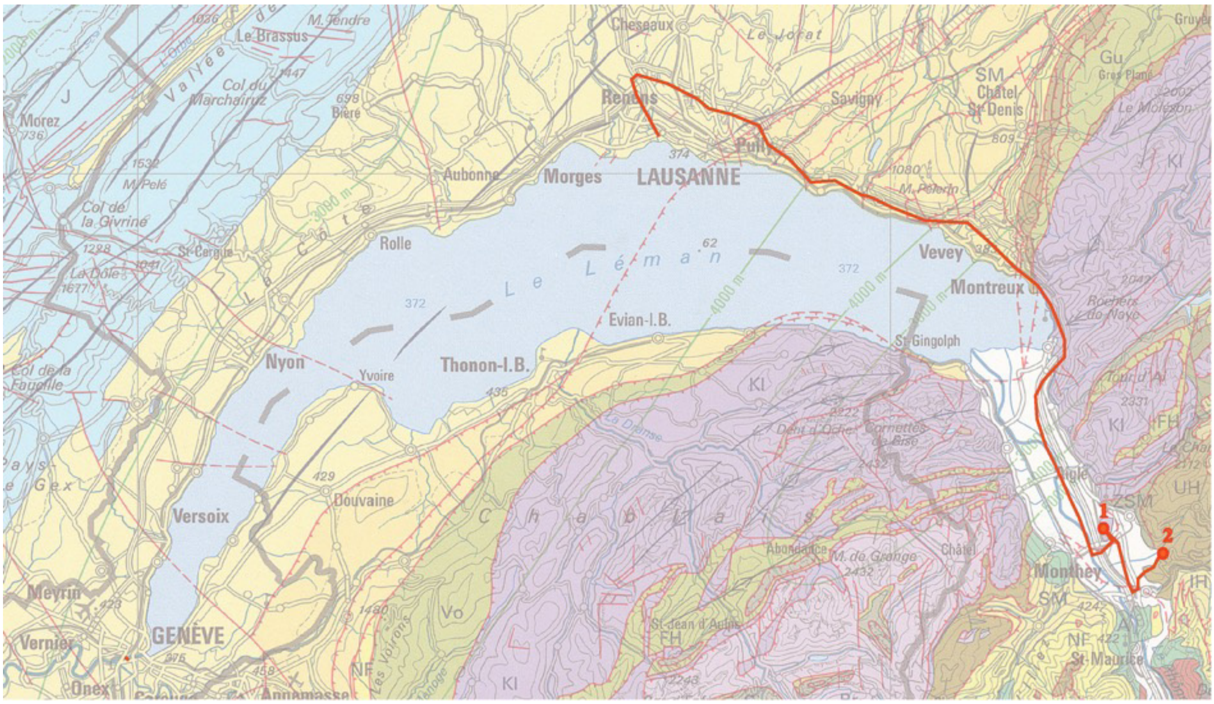

Figure 10 : Tectonic map of Western Switzerland with, in red, the itinerary and the two stop places ; stop 1, Saint-Triphon, Fontenaille quarry ; stop 2, visit of the Salt mine of Bex.

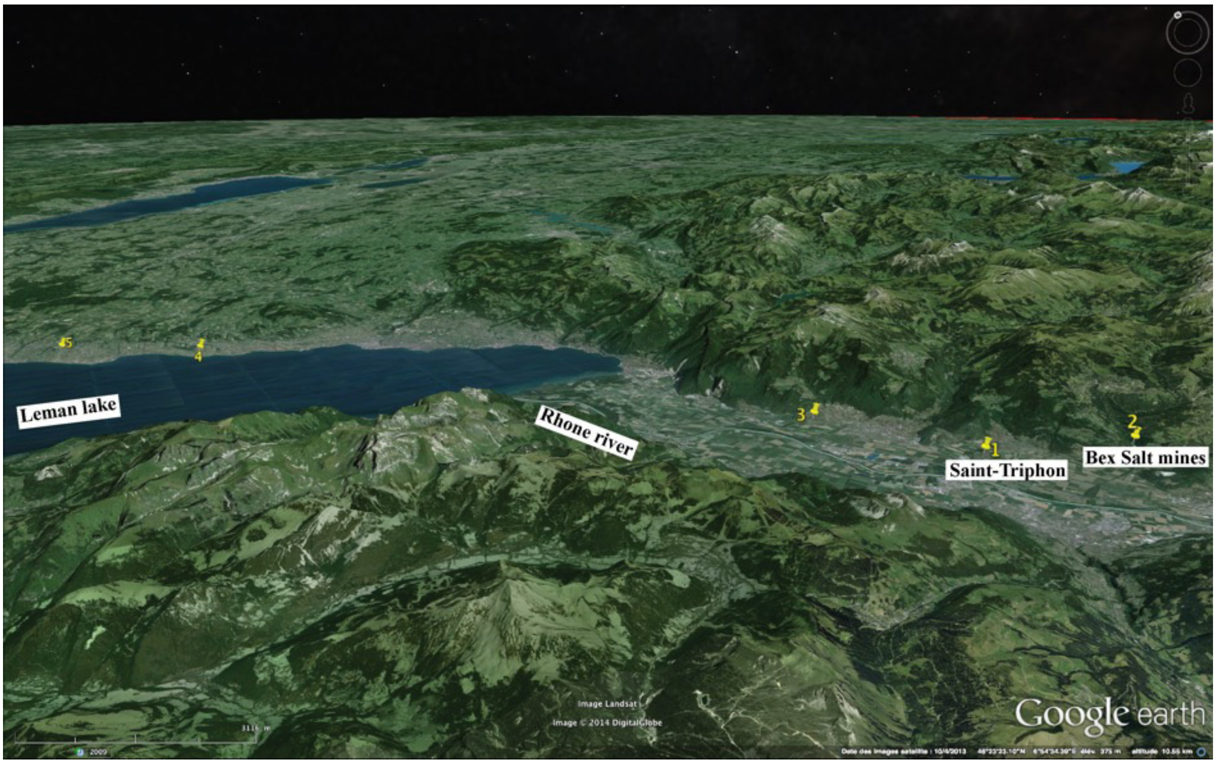

Figure 11 : Google Earth oblique view with the five main stops of the day as presented in the map above.

2.1 – Stop 1 : Saint-Triphon, Fontenaille quarry (A.Baud, Figs. 12 to 15)

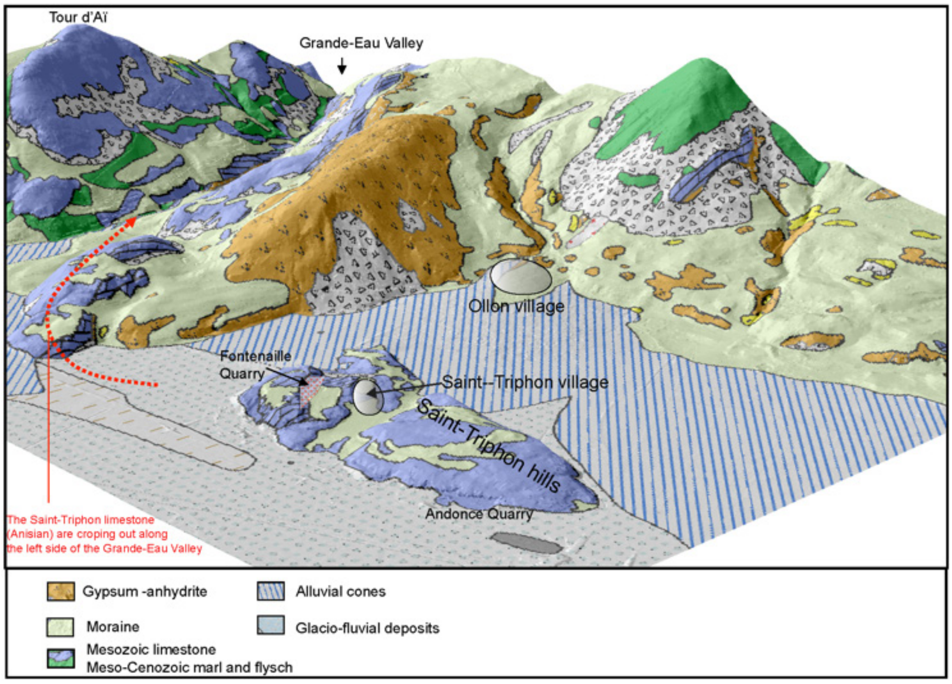

Figure 12 : Geological map of the Saint-Triphon area on a 3D relief (adapted from Giorgis. 2012)

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 quarry along the hills. A composite section of the hills compared to the main Prealps Triassic composite section is given at the Fig. 28 .

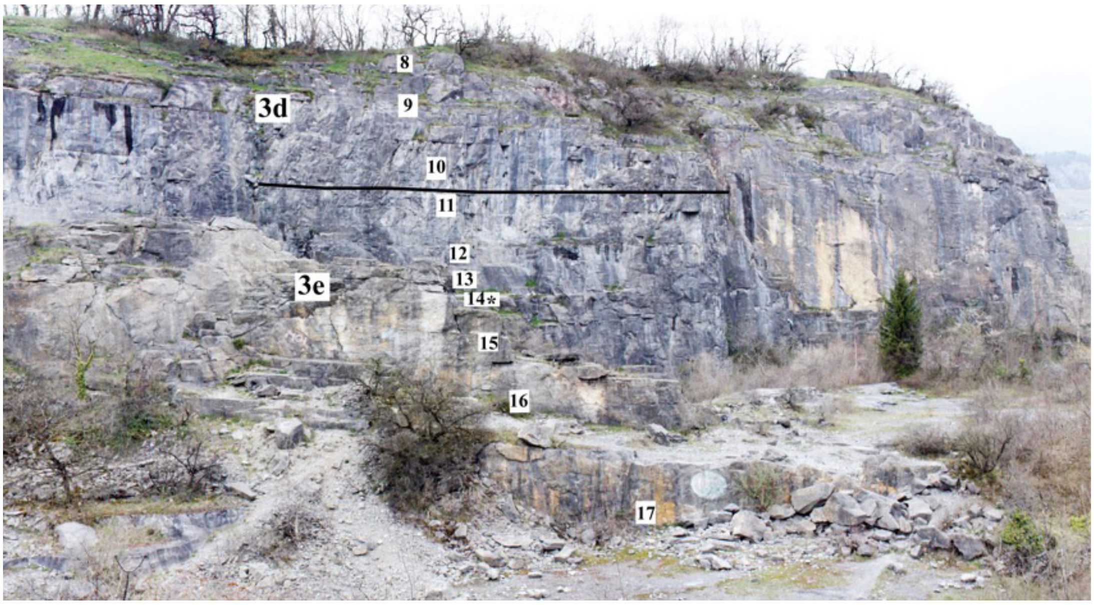

Figure 13 : Stop 1, the Fontenaille quarry with overturned middle Anisian limestone ; the units 3d and 3e and the bed nombers8 to 17 refers to the lithological section shown at the Fig. 14.

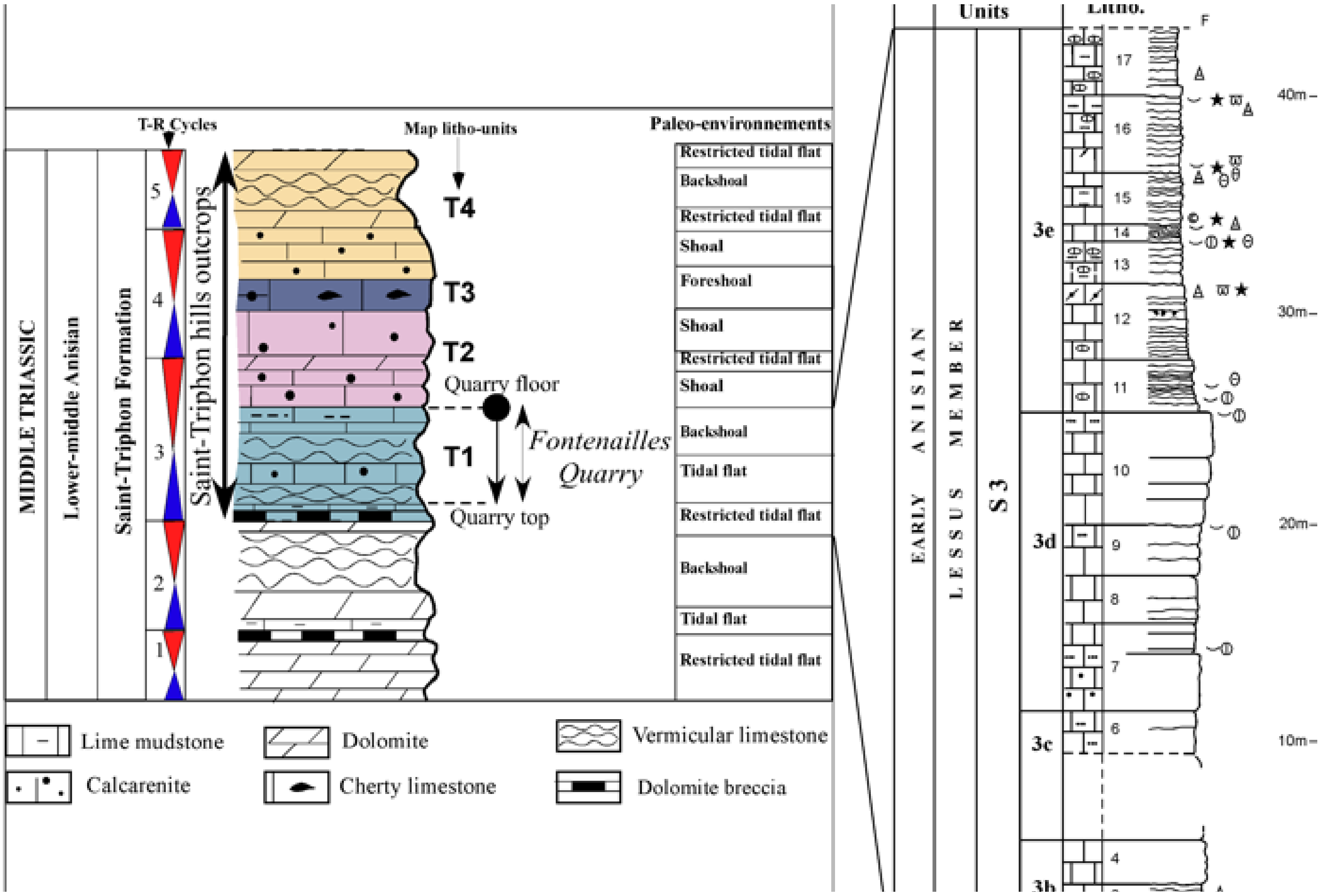

Figure 14 : Composite Saint-Triphon Formation section from type locality area on the left (adapted from Baud et al., 2012). The color of the lithological units T1 to T4 are the same as in the geological map below (Fig. 15) ; on the right is the lithological section of the Fontenaille quarry (Baud, 1987) ; the bed numbers are reported on the quarry wall picture Fig. 13.

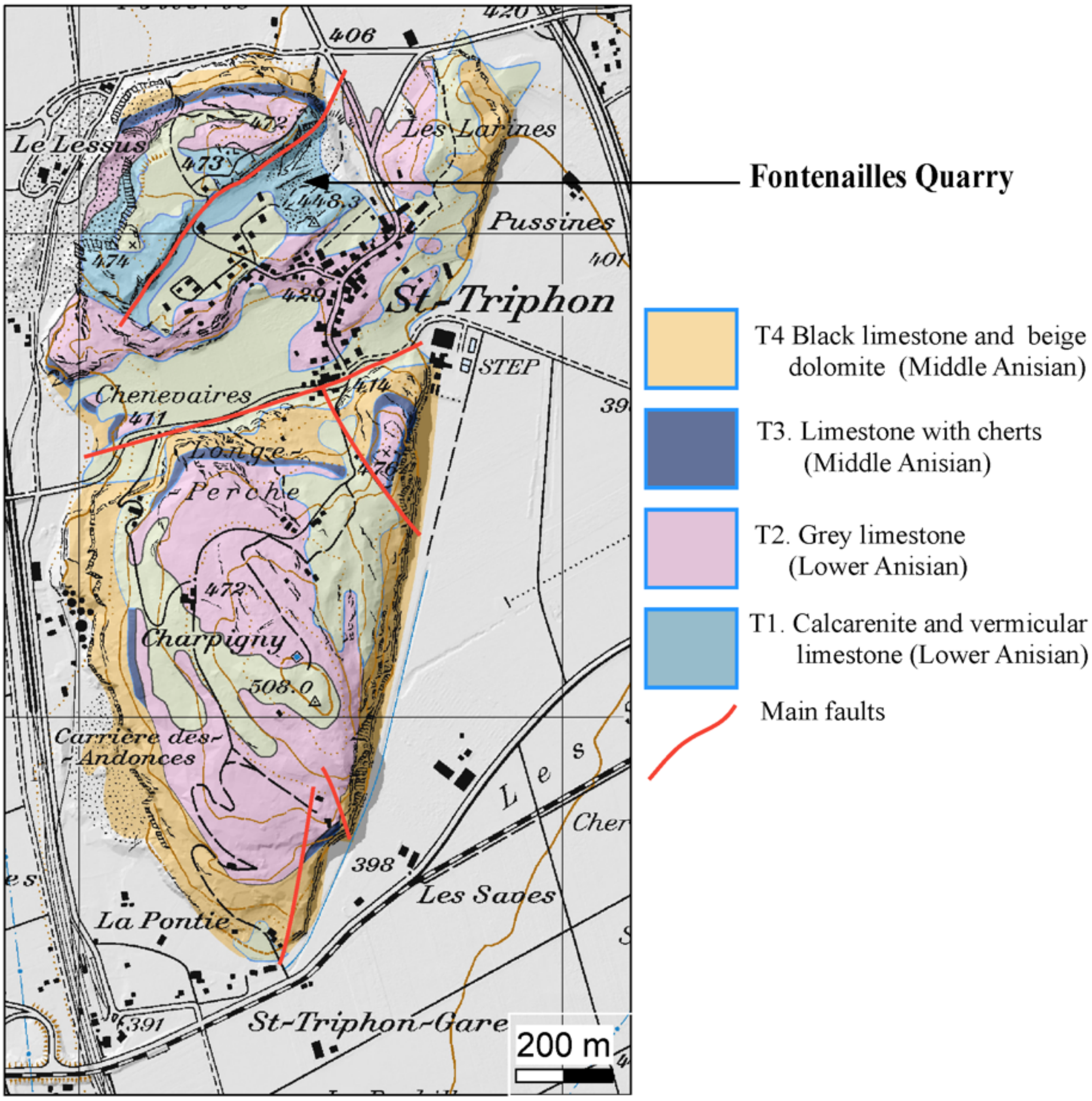

Figure 15 : Detailed Geological map of the Saint-Triphon hills, from Badoux, 1962, colored in Baud et al., 2012).

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. 16). 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. 13 and 14).

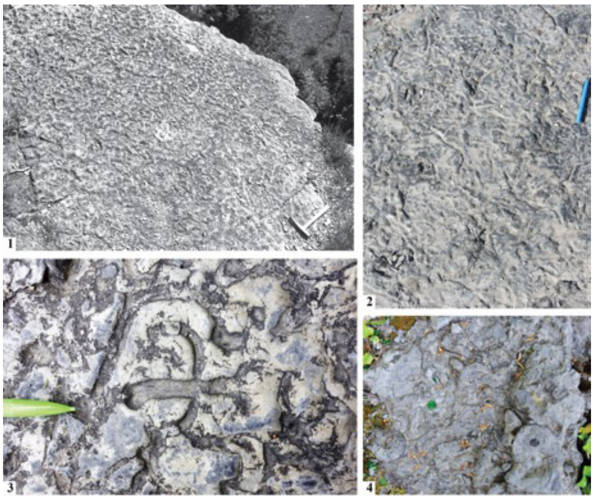

Figure 16 : The vermicular limestones ; 1- vermicular surface near the top of the Fontenaille quarry with Spongeliomorpha suevica trace fossil ; 2- surface in the middle part of the quarry with thiner Spongeliomorpha network ; 3- detail of the branching burrows ; 4- Rhizocoralium jenense burrows from 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. 17 and 18) 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.

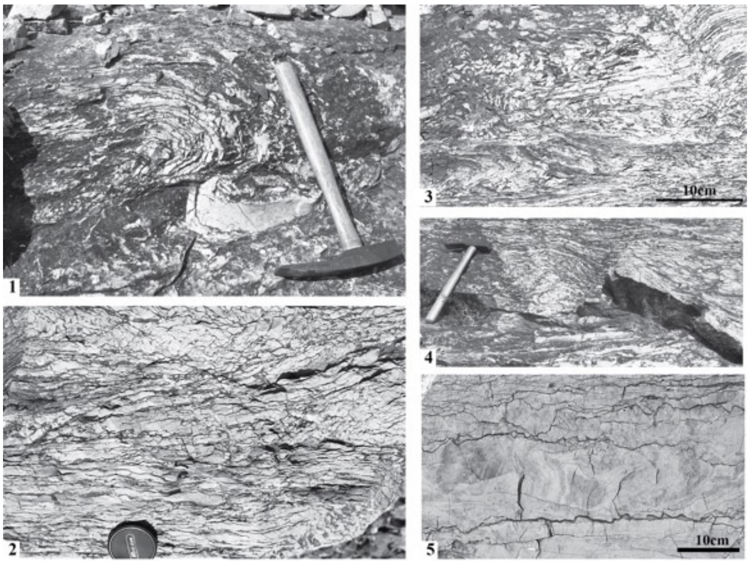

Figure 17 : Seismite soft-sediment deformations ; 1- Recumbent fold, horizontal micro-fault and disrupted lime mud layers ; 2- disrupted and pinch-and-swell layers ; 3- gentle fold inclined over disrupted layers and recumbent fold ; 4-disrupted and brecciated layers ; 5- Soft lime mud injected and folded by disrupted layers (photos A. Baud).

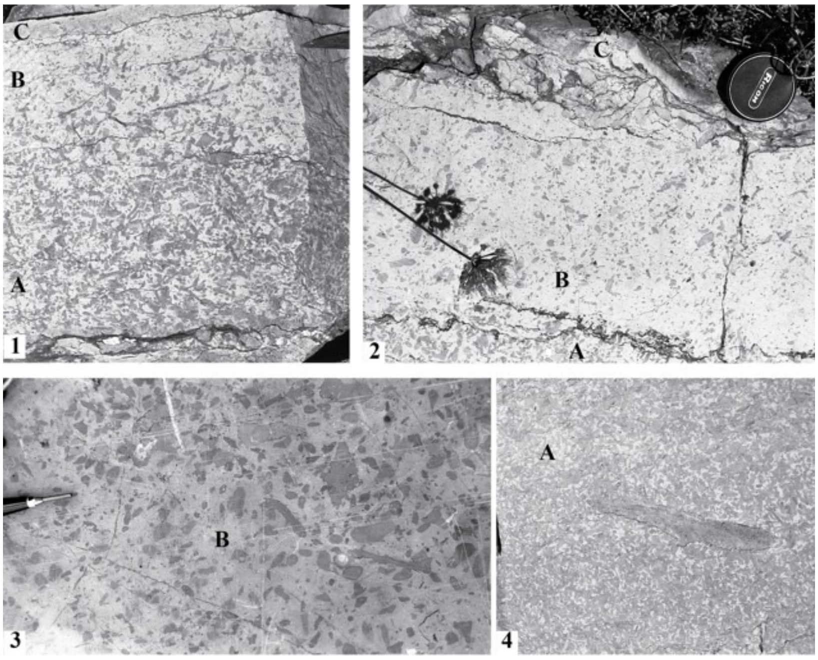

Figure 18 : Seismites, liquefaction of the vermicular limestone matrix ; 1- graded deposition (A, B) of the semi-solid burrow clasts in the quasi-liquid lime-mud matrix (thixotropic shock) ; 2- detailed view of the upper part with high matrix ratio (B), the top level C is showing an erosive base with 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).

2.2 – Stop 2 (11h15-12h) : the large quarry named Andonce

It is in the second quarry visited, near the Railway station (carrière des Andonces). This quarry comprises the upper part of the Saint Triphon Formation, the sequences S4 and S5 (Fig. 19). In the upper part of the quarry. the top of S4 shows calcarenites stratified with current megarides. Most of the walls takes place in S5 : the black limestones of Saint- Triphon are rich in organic matter. in places, they are strongly bioturbated by decapod crustaceans (*Rhizocorallium*. *Spongeliomorpha*) (A. Baud, 1976).

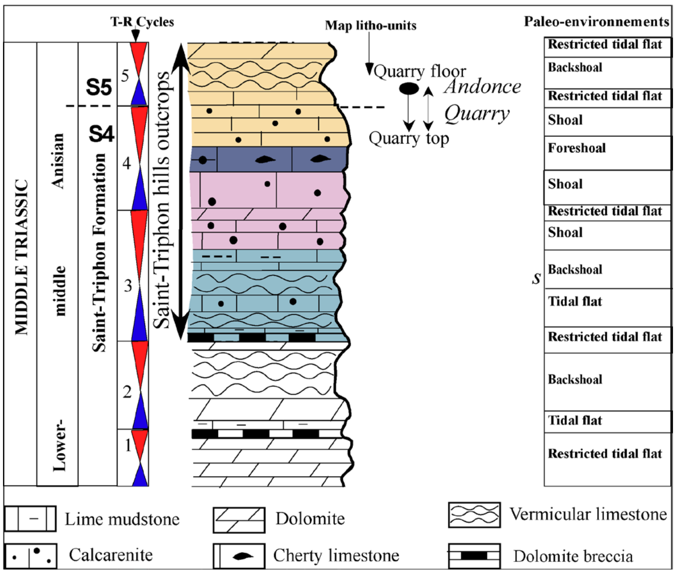

Figure 19 : Composite Saint-Triphon Formation section from type locality area (adapted from Baud et al., 2012).

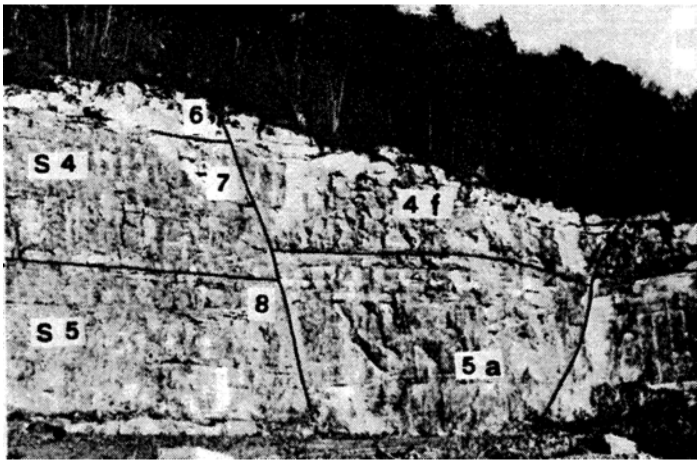

Figure 20 :Andonce Quarry, East wall with overturned middle Anisian limestone ; the units S4 and S5 refers to the lithological section shown at the Fig. 19. (photos A. Baud).

At the base of the East wall, microsequences of storms - centimetre-thick granoclassed calcarenites - alternate with spicule calcilutites. Halfway up the wall, there is a remarkable level of true *Coenorhyris vulgaris* lumachelle with celestine filling (SrS0 4). Blocks of it were found at the foot of the wall.

Following the quarry's railroad line for a hundred meters or so, we reach the artificial West wall described in 1975 by A. Baud and H. Masson who proved an uplift of several hundred of meters of the Briançonnais at the end of the Liassic and beginning of the Dogger times, in an extensionnal – transtensional regime, on the base of paleokarstic and paleotectonic analysis. Modelling the geodynamic of the Alpine Tethys opening, several authors came much later to conclusion of an uplift of the briançonnais shoulder of the rift, not reminding that it was first discovered in the quarry of Saint-Triphon !

Numerous horizontal stylolitic joints are intersected by small conjugate faults (fig. 21, left). On two of these, triangular channels recording paleokarst (fig. 21,right), filled at the base with fine material (dolomitic sand and silt), while dolomitic pebbles and gravels are confined to the upper part. This surprising arrangement is easily explained by the fact that the series is inverted.

Figure 21 :Andonce Quarry, west sawed-of wall. Left : stylolitic joints intersected by small conjugate faults. Right : Karst conduit (15 cm thick) with granoclastic filling in overturned position !

2.3 – Stop 3 (14h30-16h00) : Bex : visit of the Salt Mine (Figs. 22 to 27)

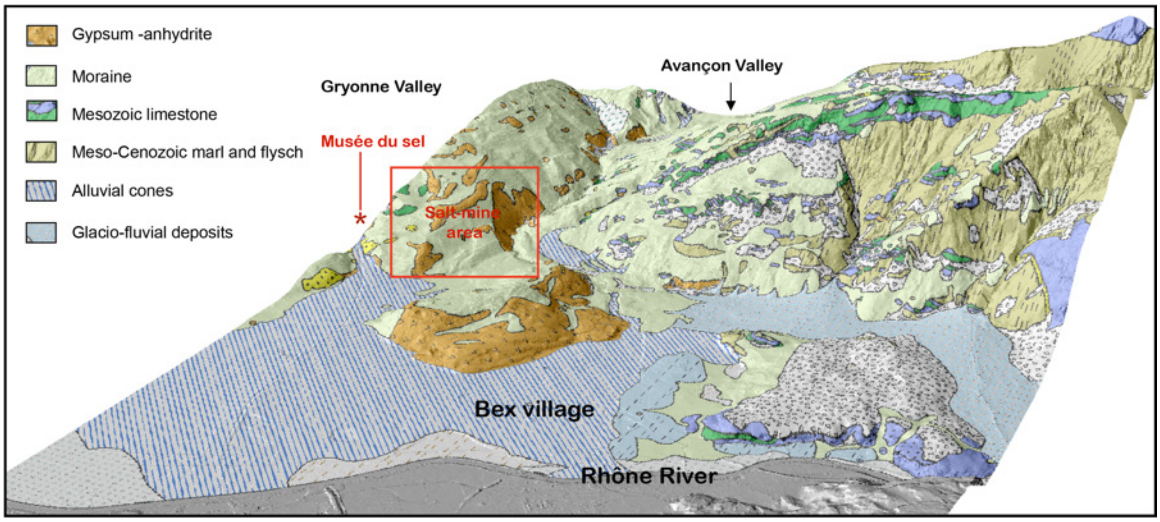

Figure 22 : Geological map on 3D relief topography (adapted from David Giorgis maps, 2012)

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. 23).

4.1 – Resumed approach to the geology of the mines

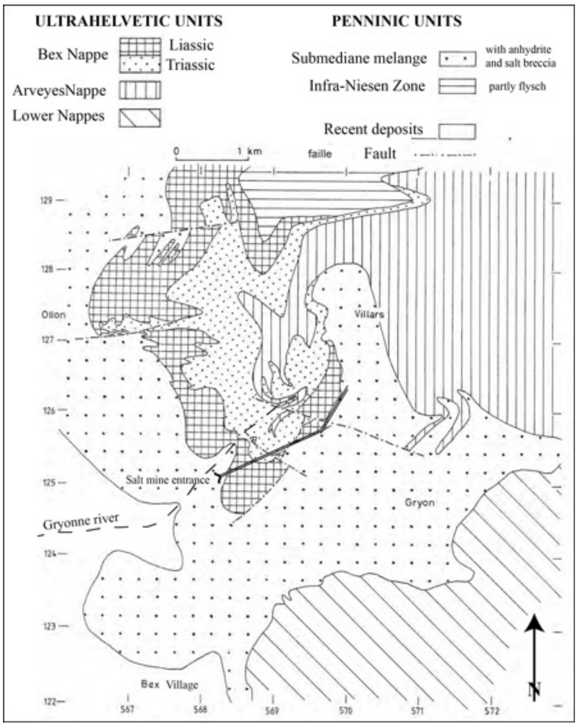

Figure 23 : Tectonic map of the Salt mines area adapted from Graf, 1993 ; the trace of the visited gallery is shown in the middle of the map.

This stop 3, after the lunch time will be given to the underground visit of the Bex salt mine. Below (Fig. 24) is a picture of the main panel near the entrance of the mine, with the gallery topography and the main underground rooms.

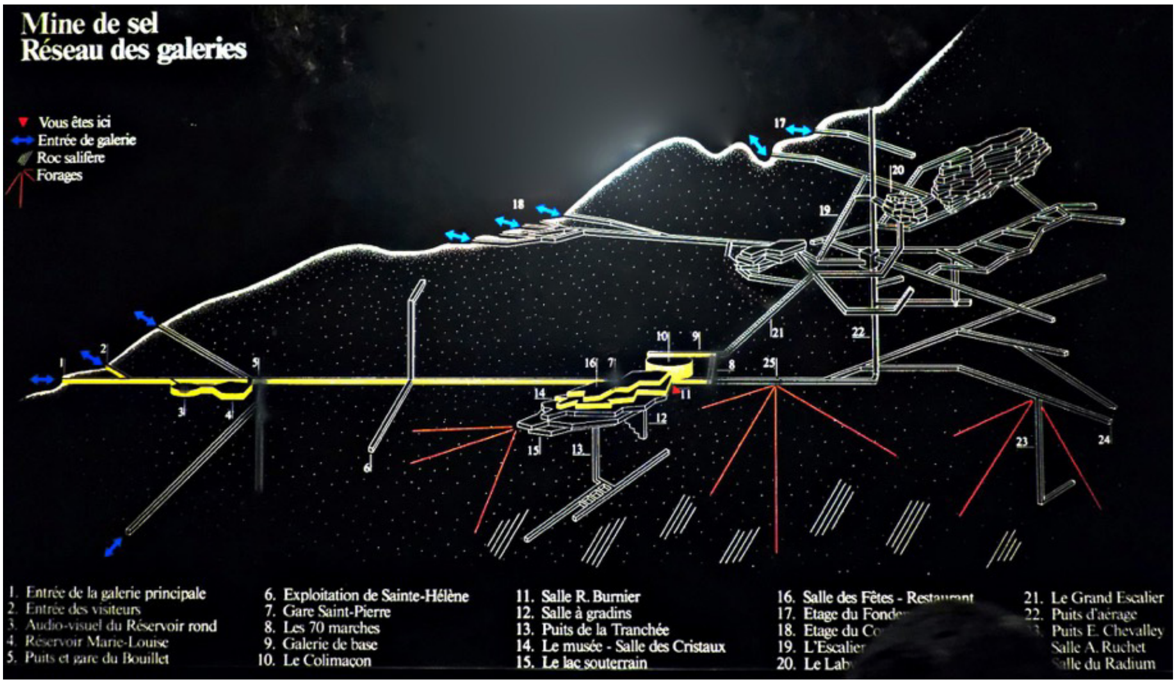

Figure 24 : The gallery network of the Bex salt mines (the visited gallery is in yellow)

A geological cross section of the visited gallery is given below (Fig. 25)

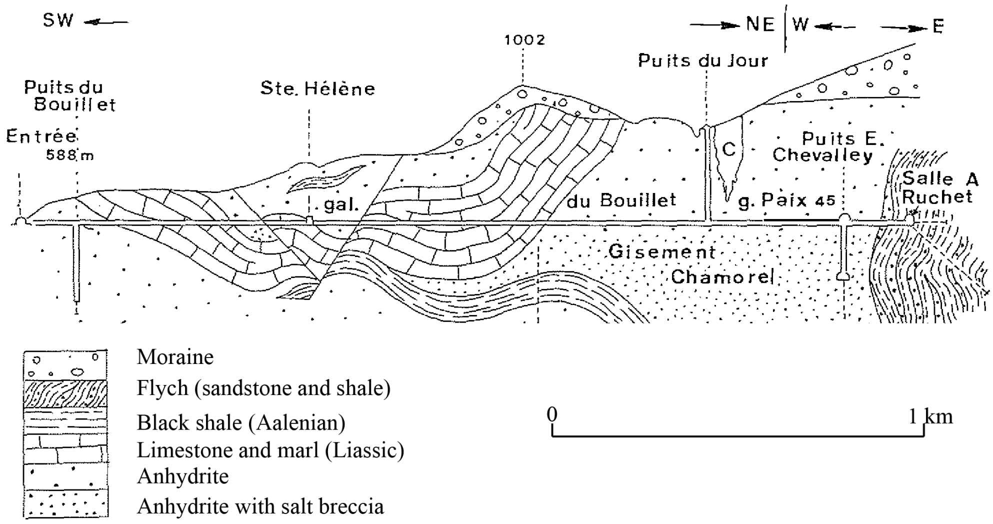

Figure 25 : General cross section through the mine area (adapted from Badoux, 1982).

This complexity of the regional geology is also shown on the tectonic map (Fig. 23) : 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).

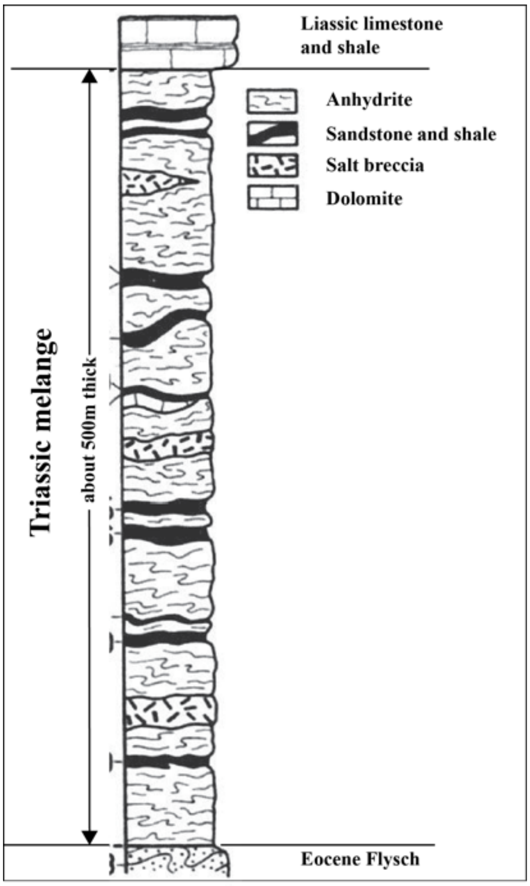

Figure 27 : Lithological sketch across the evaporite (anhydrite –salt breccia) of the salt mine according to Badoux and Weidmann, 1964

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.

4.2 – Mineralogy and sulfur isotopes (Nicolas Meisser, Figs. 28 to 30).

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 worldwide widespread in old mineralogical collections. Most of them are considered as crystallographical morphological types for gypsum (Soret, 1817 ; Dufrénoy, 1848, Meisser, 2014).

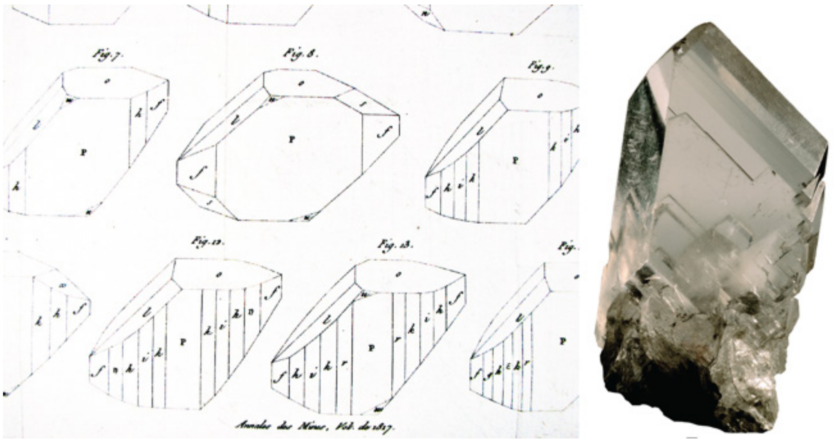

Figure 28 left : Soret (1817) Gypsum plate ; right, Gypsum cristal (paragenesis 2)

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).

Acknowledgements

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. And thanks also to Nicolas Meisser, curator at the Lausanne Geological Museum who provide the mineralogy and sulfur isotopes chapter of the Salt Mine.