13/01/2022

A geological boat trip on Lake Lucerne

Walter Wildi & Jörg Uttinger
2019

https://www.erlebnis-geologie.ch/geoevent/geologische-schifffahrt-auf-dem-vierwaldstaettersee-d-e-f/

A geological boat trip on Lake Lucerne

Walter Wildi & Jörg Uttinger

2019

https://www.erlebnis-geologie.ch/geoevent/geologische-schifffahrt-auf-dem-vierwaldstaettersee-d-e-f/

Abstract

This excursion guide takes you on a steamboat trip through a geological section from Lucerne to Flüelen, that means from the edge of the Alps to the base of the so-called "Helvetic Nappes".

The introduction presents the geological history of the Alpine region from the Upper Palaeozoic (about 315 million years ago) through the Mesozoic era and the opening up of the Alpine Sea, then to the formation of the Alps and their glacial erosion during the Pleistocene ice ages.

The Mesozoic (from 252 to 65 million years) was the period of the Helvetic carbonate platform, associated with a high global sea level. The Alpine folding started in the southern part of the Alpine sea in the Upper Cretaceous (some 100 million years ago). It then migrated to the northern part of the Alps in the Eocene (40 million years) accompanied by flysch sedimentation and continued during the Oligocene and the Miocene, to the folding of the Jura mountain range during the Pliocene.

Molasse sediments composed of erosion products of the rising alpine mountains have been deposited in the Alpine foreland from the Oligocene to Upper Miocene (about 34 to 7 Milion years). Today's topography of the Alps with sharp mountain peaks and deep valleys is mainly due to the action of glaciers during the last 800,000 years of the ice-ages in the Pleistocene.

The cruise starts in Lucerne, on the geological limit between the Swiss Plateau and the Subalpine Molasse. Then it leads along the Rigi mountain chain composed of so-called Subalpine Molasse. In Vitznau, the boat penetrates into the spectacular Helvetic Nappes and crosses the Drusberg and Axen nappe all along Lake Uri. The trip ends in Flüelen, in the much gentler landscape of the sedimentary cover of the Aar massif.

Walter Wildi, Département F.A. Forel des sciences de l'environnement et de l'eau, Université de Genève, Uni Carl Vogt - 2ème étage, 66 boulevard Carl-Vogt, CH-1211 Genève 4. Privatadresse: Chemin des Marais 23, 1218 Le Grand Saconnex. walter.wildi@unige.ch

Jörg Uttinger, Weidhuobli 3, 6430 Schwyz, joerg.uttinger@bluewin.ch

«The lake is smiling, inviting for a bath»*

("Es lächelt der See, er ladet zum Bade")

For romantic individuals, painters and poets, Lake Lucerne is in the centre of a picturesque and impressive mountain landscape. This lake is a sports ground for sailors and children's wading pool. For professional fishermen, it means a livelihood. A geographer will also recognize it as a transport route. The lake is an ecosystem and a habitat for plants and animals. For the geologist, the alpine lake bears the unmistakable signature of past ice ages, that is, the greatest climate changes in the Earth's history.

With the present excursion guide, we would like to experience Lake Lucerne in a special way, namely as easy access for a look into the depth of the geology of the Alps. To this end, we propose to experience a geological trip from Lucerne to Flüelen, i.e. from the edge of the Alps to the base of the so-called "Helvetic Nappes" on a steamboat cruise.

This "adventure trip" is not entirely new: it was already described in the Swiss Geological Guide in 1934. However, it has since been somewhat forgotten. With the present guide, we wish to update the adventure.

It is best to plan the trip on a sunny day, in spring, summer or autumn. But the shipping company offers services during the whole year, including in winter, rides between Lucerne and Flüelen.

** Friedrich Schiller 1804: «Wilhelm Tell», erster Aufzug, erste Szene*

Figure 1: The «jump of Tell» during a Föhn-storm on Lake Lucerne (Tellskapelle)

Key data on Lake Lucerne

Lake Lucerne is an alpine border lake with a strange form resembling a salamander. The lake is 434 m above sea level, has an area of 14 km2, volume is 12 km3 and a maximum depth of 214 m in the Gersau basin.

The surface temperature of the water varies and is a function of the seasons usually slightly above the freezing point in winter and about 22 ° C in summer. In the depth of the lake basin, the temperatures are around 5 to 6 ° C. The residence time of the water is 3.4 years on average.

The most important tributaries are the Reuss, the Engelberger Aa, the Sarner Aa and the Muota. The cantons of Central Switzerland of Lucerne, Schwyz, Uri and Unterwalden share the impetus to the lake. The Reuss is also the effluent of the Lake.

The various pools of the lake carry local names: Luzernersee, Küssnachtersee, Alpnachersee, Stanser Trichter, Chrüztrichter, Vitznauer Bucht, Gersauer See, Buochser Bucht, Urnersee.

A short history of Earth History from the alpine sea to the folding of the alpine ranges, to the ice ages and modern times

To follow the geological cruise, some information about the geology of the northern part of the Alps and the Earth history may be useful. This introduction will provide this very basic knowledge. For a detailed Earth history of the region, please read the excellent book chapter (in German . . .) by Beat Keller (2007):

https://www.researchgate.net/profile/Beat_Keller4/publication/282979520_So_entstand_der_Vierwaldstattersee/links/5625357908aeabddac91c86a/So-entstand-der-Vierwaldstaettersee.pdf

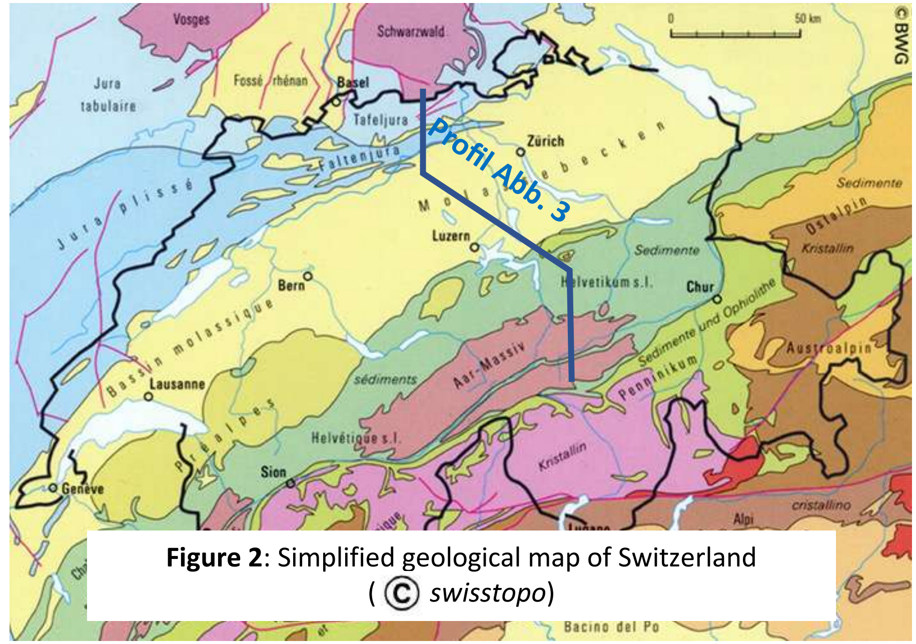


Figure 2: Simplified geological map of Switzerland (ⓒ *swisstopo*)

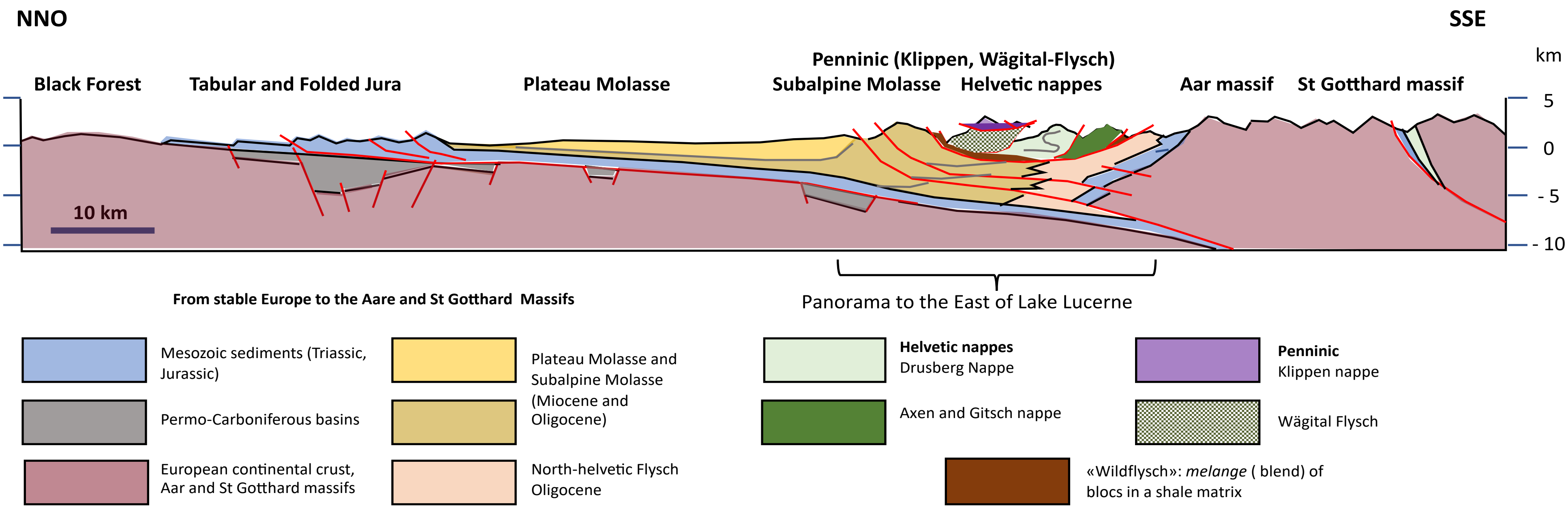


Figure 3: Geological section form the Black Forest in the north to the St Gotthard massif in the south (www.nagra.ch, ergänzt)

Planet Earth is as old as 4.6 billions of years. However, the oldest rocks in the geological section from the Black Forest to the Gotthard Alps are considerably younger (Fig. 2, 3, Table 1). These are essentially granitic rocks originating from magmas formed during two Palaeozoic orogeneses (mountain formations), either during the so-called "Caledonian" period (about 450 - 420 million years) or the "Hercynian" period (360 to 270 million years). The granites are surrounded by transformation rocks (called metamorphic rocks), mainly gneiss, which were created during the orogenesis mentioned above, or sometimes even before.

These ancient mountain ranges have been eroded during the **Upper Carboniferous** and **Permian** of the **Late Palaeozoic.** As witnesses of this erosion, we encounter deep valleys, filled with sediments, the "Permo-Carboniferous Basins". In addition to conglomerates, sandstones and argillites, sediments can contain abundant organic matter and even coal seams. These rocks are found, for example, in the Tödi massif (Canton of Glaris) and in the Jura subsoil in northern Switzerland (Fig. 3).

The rocks of these old basements constitute the geological bedrock of the Black Forest in the north, under the Swiss Plateau and the alpine front to the Aare and Gotthard massifs in the south. The two massifs belong to the European basement, sheared off during the alpine folding and pushed onto their foreland to the north (Fig. 3, Table 1). At the beginning of the **Triassic** period (251 million years ago), the morphology has been flattened by erosion. Eurasia and Africa belonged then to the same giant continent, Pangea. The first marine invasion occurred during the Triassic in the eastern Alps (Fig. 4). During this period, sandstone, salt, gypsum and (during the Middle Triassic) limestones and dolomites were deposited on the European continent in a shallow ”germanic" epicontinental sea. At the beginning of the **Jurassic** period, from 201 million years ago, a slow and steady rise in the level of the oceans was taking place. The European continent was then largely flooded and shallow marine platform sediments (mainly limestone and marl) have been deposited. During the **Lias** (201 to 174 million years), the region around the Aar massif remained emerged ("Alemannic continent").

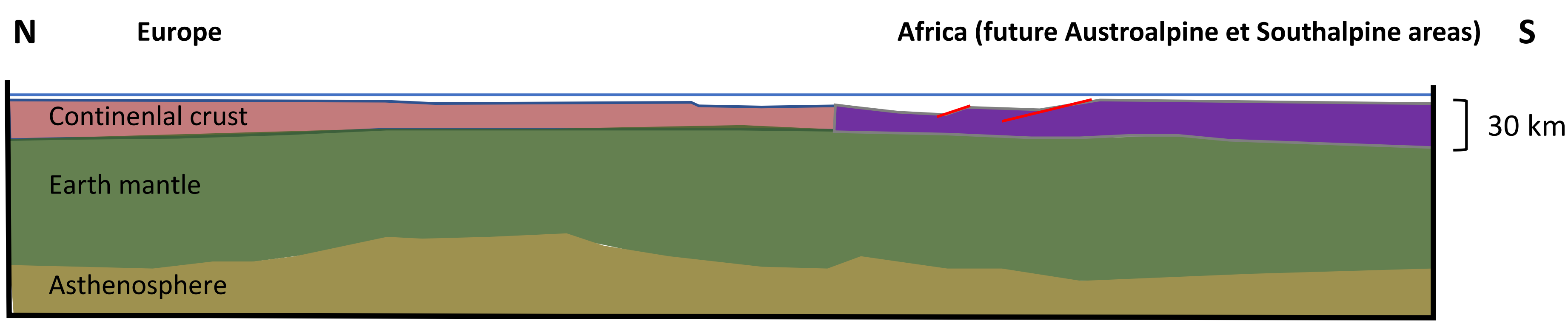


Figure 4: Middle Triassic, schematic geological cross-section of the Earth crust and mantle from Europe to Africa

Table 1: Geological time table and Earth history of Central Switzerland

Era	Period	Epoch			Time marks (million years)	Major events
Cenozoic		Holocene (post glacial)			0.01	• Human occupation about 15’000 years ago.
	Quaternary	Pleistocene	Würm	Ice ages	0.12	
			Riss		0.3 – 0.13 ?	
			Mindel		0.46 – 0.40 ?	• Alternating glacial (cold) and interglacial (warm) climate periods; erosion of the Alpine valleys and lake basins.
			Günz		0.80 – 0.60 ?	
					2.6	• Folding of the Jura mountain ranges
	Neogene	Pliocene				
		Miocene			5	• Sedimentation of Freshwater and Marine Molasse deposits composed of eroded material from the Alps (Subalpine and Swiss Plateau Molasse.
		Oligocene			23	
	Paleogene	Eocene			34	
		Paleocene			56	• Deposition of North-helvetic Flysch.
					65	
Mesocoic	Cretaceaous	Upper Cretaceous				• Late Cretaceous: deep-sea sedimentation of flysch as a result of early folding of the Alps (Schlieren- and Wägital-Flysch).
					100	• Early Cretaceous: Alpine foreland and northern Helvetic realm: no sediments known. South Helvetic (Drusberg nappe), limestone and marl deposits in a shelf sea of changing water depth.
		Lower Cretaceous				
					145	• Jurassic, Alpine foreland, Helvetic and Briançonnais (Klippen): warm an shallow shelf sea; deposition of carbonates; bivalves, ammonites, crinoids, corals. Opening of the Alpine Sea, deep-sea sediments in the North-, South-penninic and the Austroalpine realms.
	Jurassic	Malm			164	
		Dogger			174	
		Lias			201	
	Triassic	Keuper			235	• Triassic: desert climate, deposition of sulfates (gypsum) and salt in sebkhas (salt deserts); shallow sea of the Muschelkalk.
		Muschelkalk			243	
		Buntsandstein			251	
Paleozoic	Permian					• Permian: erosion of the hercynian mountain ranges and deposition of red terrestrial sediments (river and floodplain deposits).
					299	• Northalpine foreland, Aar massif: Subsidence of deep sediment troughs (Permo-Carboniferous basins), sedimentation of erosion material and organic debris (coal measures) at the end of the hercynian orogenesis.
	Carboniferous				359	

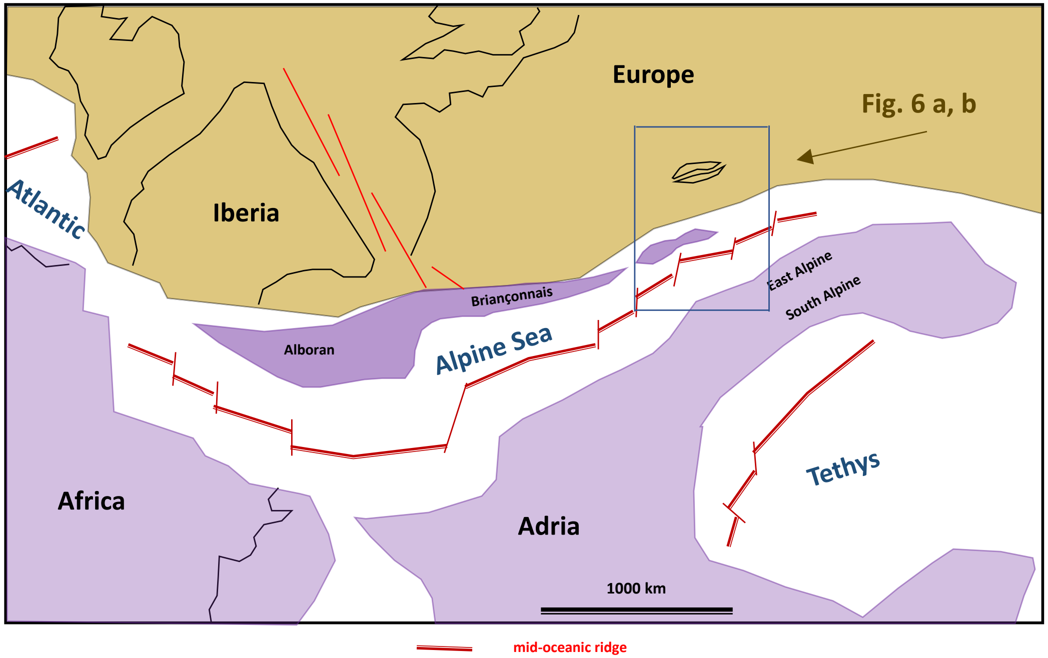
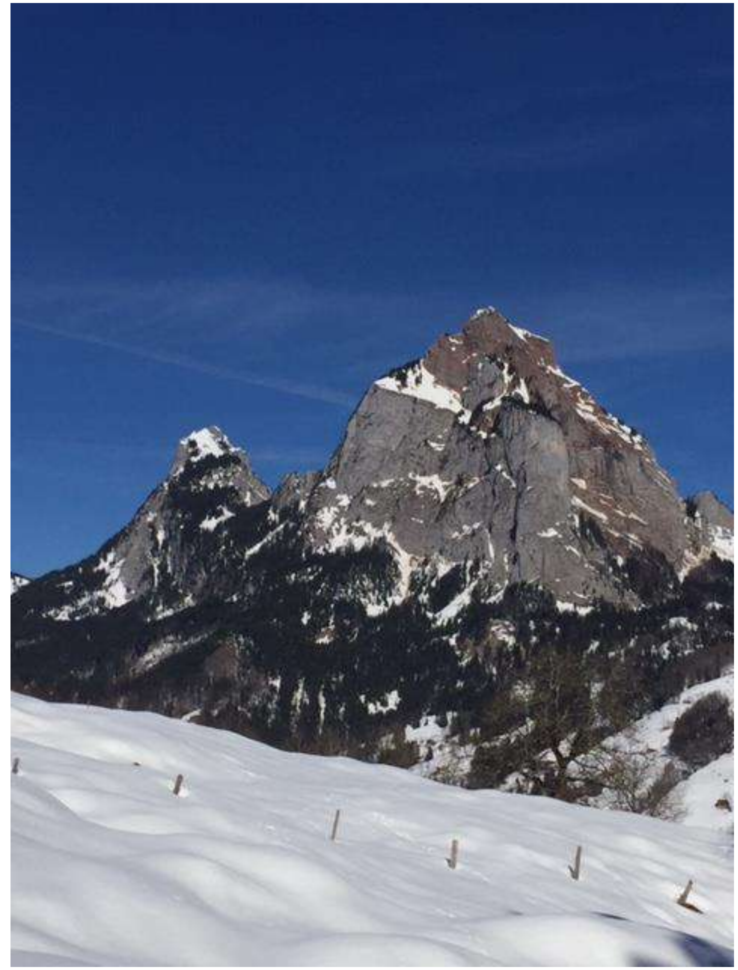


Figure 5 a: Palaeogeography of continents and oceanic areas during Late Jurassic (150 mio years ago).

b: The "Grosser Mythen" belongs to the Klippen nappe, which originated in an area of shallow water in the northern part of the Alpine Sea, the so-called "Briançonnais"-realm. The massive limestone at the base of this mountain pyramid has been deposited in shallow water. Red marls of the «Couches Rouges» of the Cretaceous overly the limestones (Photo J.U.)



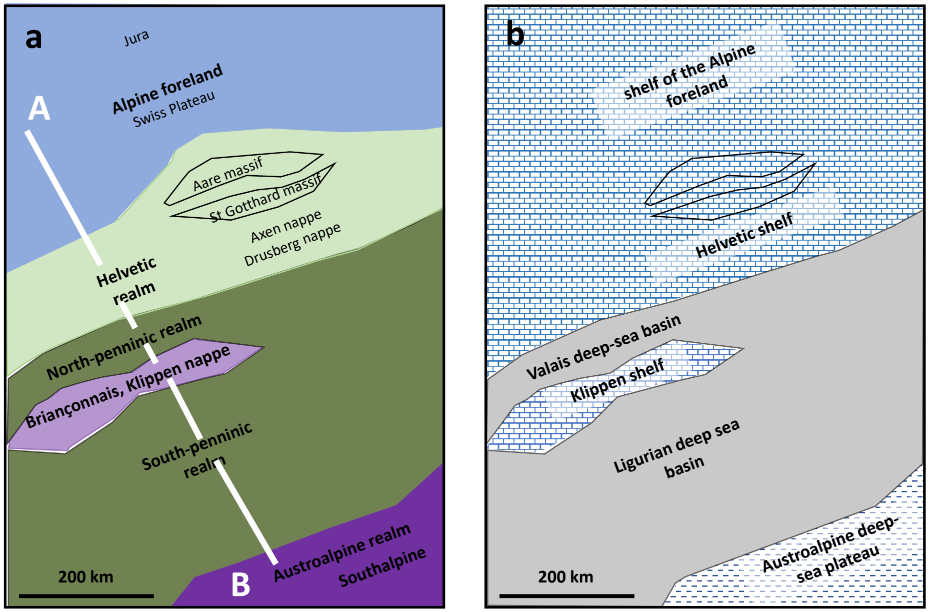
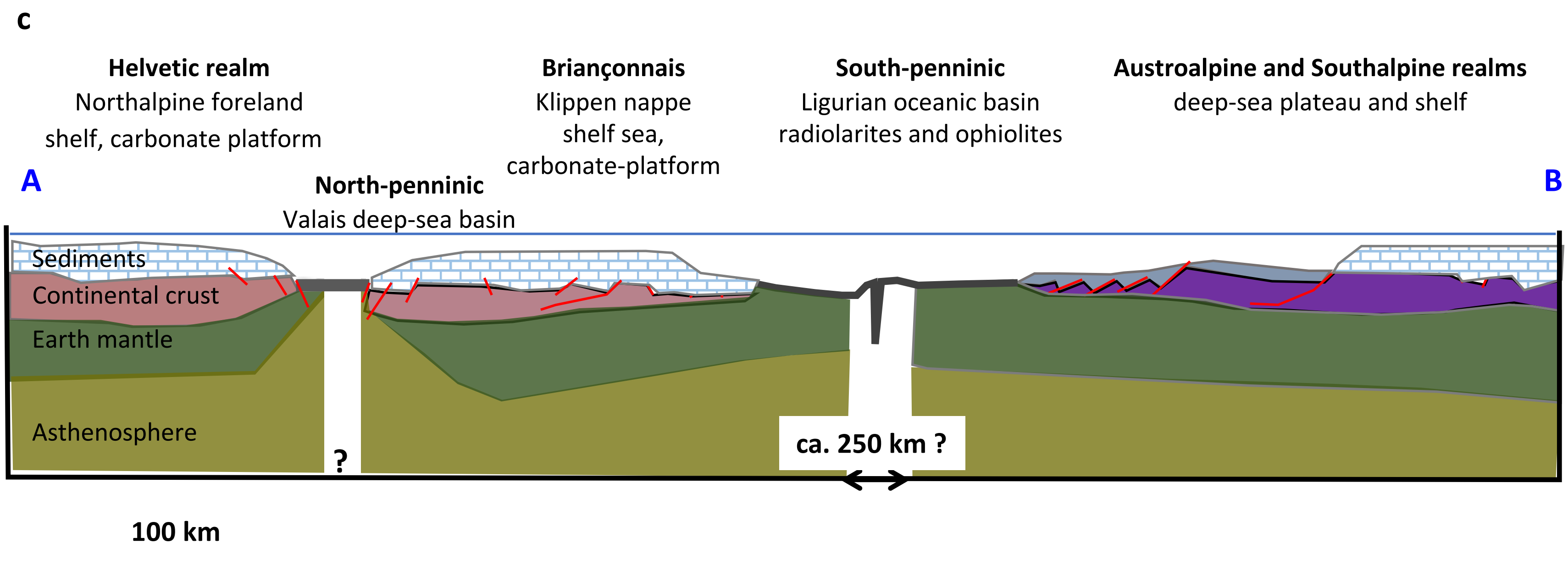


Figure 6 a: Paleogeographic reconstruction of the position of the main geological units from the Jura in the north to the Southalpine realm during the Late Jurassic (150 mio years ago).

b: Sediments

c: A – B Simplified cross-section from the Alpine foreland to the Southalpine realm



In the Middle and Upper Jurassic (**Dogger and Malm**, from 174 to 145 million years ago), Europe and Africa were drifting apart. The Alpine Sea opened between the two continents,with the deep Valais basin (North-Penninic) and the Ligurian Ocean (South-Penninic, Fig. 5 and 6). During this period, all paleogeographic realms which are represented in the alpine nappe pile by their rock formations were formed. In the northern Alpine foreland, in the Helvetic realm, on the sea platform of the "Briançonnais" (Klippen shelf) and in the Southern Alps, limestone and marls were deposited. Water depth changes derived from the composition of the sediments are explained by so-called "eustatic", worldwide oceanic fluctuations, due to climate changes and volcanism on the mid-ocean ridges, as well as by the subsidence of the seabed. Deep-water sediments, radiolarites and even volcanic oceanic rocks (so-called ophiolites) can be found in the deep Penninic sea basins, in particular in the Ligurian ocean.

During the **Cretaceous** (145 to 66 or 65 million years), the Earth experienced the highest sea levels since the Palaeozoic. However, in the Alpine foreland, above the Aar massif and in the most northerly areas of the Helvetic platform (see Fig. 6 and 15), no sediments of this period are known, either because they did not deposit or because they were eroded again after their deposition. The first indications of the convergence of the African and European continents can be traced back to the base of the Upper Cretaceous in the Valais trough and the Ligurian ocean. In the cross-section of Lake Lucerne, we find these sediments in a tectonically far northbound position in the Wägital-Flysch (Fig. 3 and 13) and the Schlieren-Flysch ,

The deposition of flysch continued in the deep marine basins during the **Paleocene** and **Eocene** (65-34 million years), as well as the deposition of platform sediments in shallower water depths in the Helvetic realm.

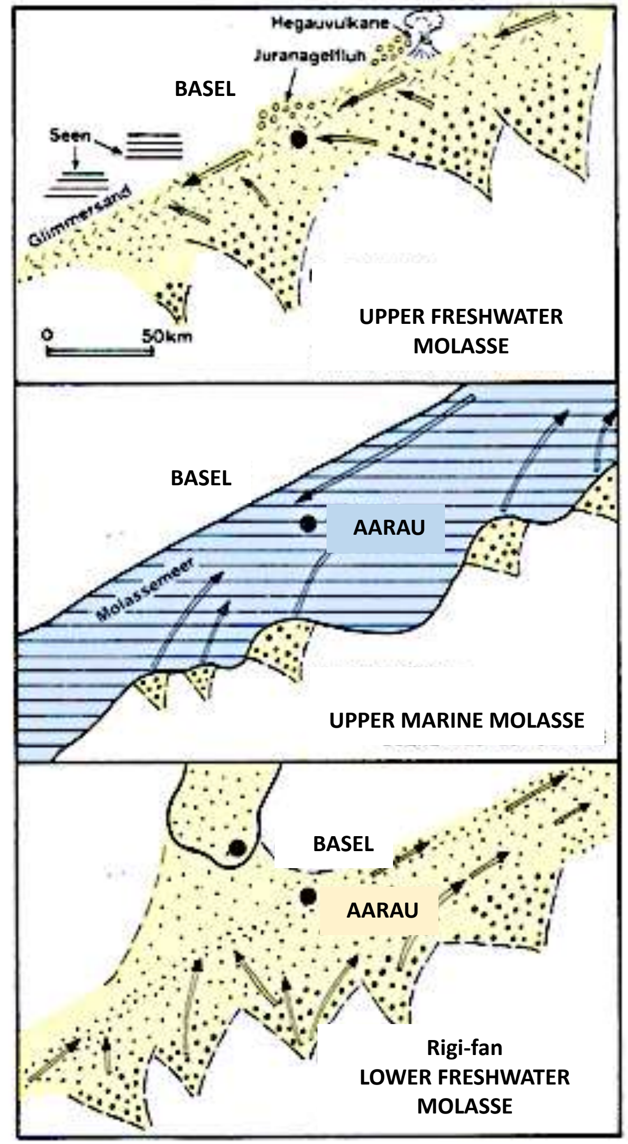


Figure 7: Paleogeography of the Molasse basin from the Middle Oligocene (Lower Freshwater Molasse) to Late Miocene (Upper Freshwater Molasse, Trümpy 1980).

The Jura area was above the sea level and weathering led to the formation of iron oxides in nodular form ("bolus") under tropical conditions.

In the **Upper Eocene** and at the beginning of the **Oligocene**, the construction of the Alps progressed rapidly. This led to the deposition of the so-called North-helvetic Flysch in a narrow seaway, the last marine sediment formation in the Alps.

In the Early Oligocene (shortly after 34 million years), sedimentation migrated to the foothills of the Alps, in the area from the north of the Aar massif to the southern Swiss Plateau, where the so-called Lower Marine Molasse formed in a narrow east-west oriented estuary. This seaway was quickly filled up; then, the sea level dropped and the Lower Freshwater Molasse accumulated on large fluvial fans from Mt. Pélerin Lake Geneva area) to the Napf, the Rigi and the Hörnli (eastern Switzerland, Fig. 7)

During the **Miocene**, starting in the so-called Burdigalian (20.5 million years ago), the Alpine folding progressed further north. The debris cones of the Lower Freshwater Molasse were tectonically pushed to the north. The sea level rose again and flooded the area from the central Swiss Plateau to the Jura. This Upper Sea Molasse extends from the Vienna Basin through the Swiss Plateau to the Mediterranean Sea. After the retreat of the sea, the debris fans advanced again form the edge of the Subalpine Molasse in the south to the Jura area in the north. A river system supplied mica sand from the Eastern Alps as far as the Tabular Jura.

Shortly before the end of the Miocene, about 10 million years ago, sedimentation in the Alpine foreland was completed. Also, the surface morphology was pronounced and rivers transported the eroded material from the Alps directly into the Mediterranean Sea and to the North Sea.

As the last event of the formation of the Alps, the Jura mountain chain was formed during the Pliocene.

The relief of the Alps, with high mountain peaks and deeply buried valleys, was formed by glacier erosion as a result of a climate crisis, the ice ages (Figs. 8 and 9).

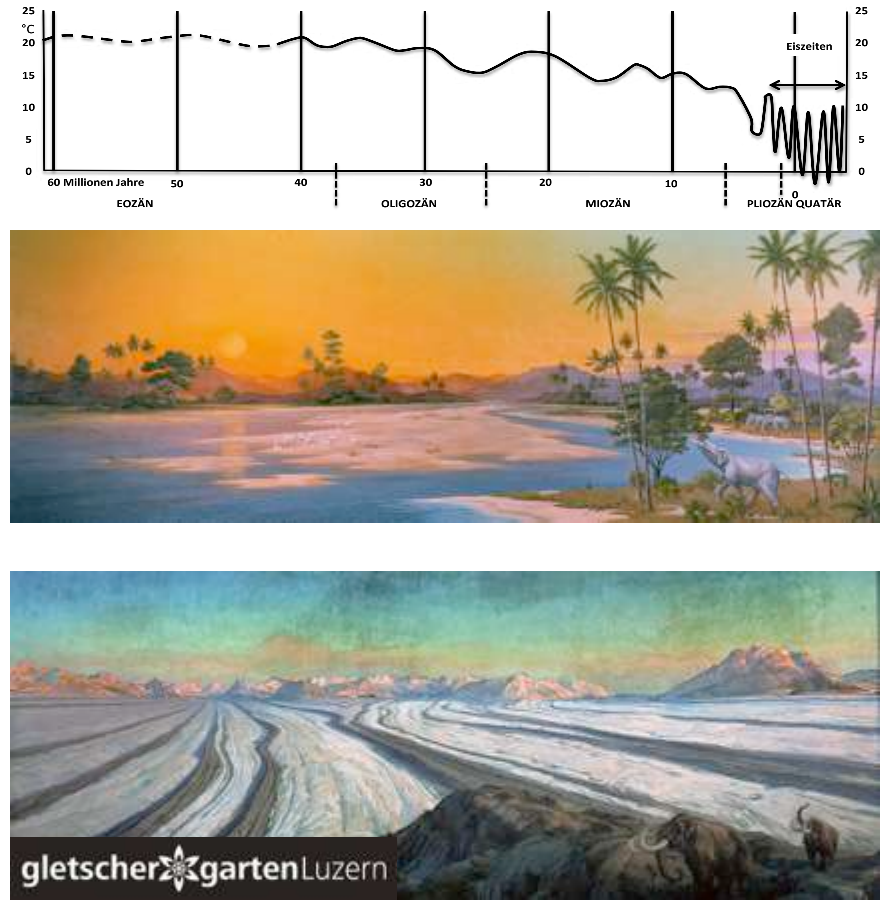


Figure 8, top: evolution of average global temperatures over the last 60 million years; centre: Lucerne in subtropical climate 20 million years ago; bottom : Lucerne during the last Ice Age (Lucerne Glacier Garden, oil painting by Ernst Hodel, designed by the geologist Albert Heim). The three figures represent the landscape change as a result of the great climate change.

The **glaciations** started two million years ago, but, at the beginning, left hardly recognizable traces in the Alps. Then, from about 800,000 years ago to the present, four longer cold periods with glacier advances down to the Swiss Plateau and even to the Jura occurred. Each of these ice ages knew several glacier fluctuations. Since the publication of the pioneer work of Penck and Brückner in 1909, these glaciations have been referred to as **Günz, Mindel, Riss and Würm**, based on their type localities in the Bavarian Alpine Foreland.

Today's deep Alpine valleys and lake basins were excavated during the Würm glaciation. In the northern hemisphere the course of this last cold period can be described as follows:

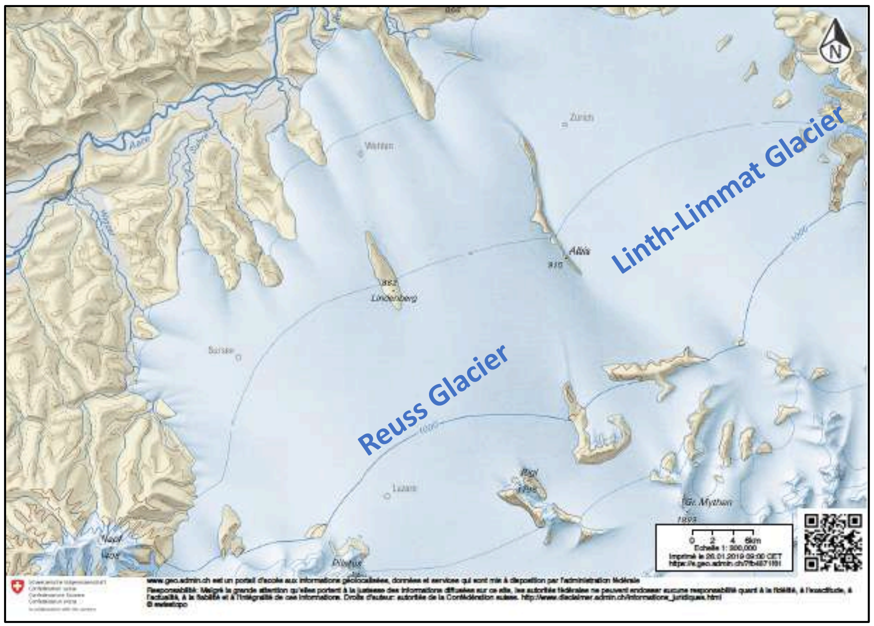


Figure 9: Maximaum extension of the Reuss Glacier during the last glaciation (© swisstopo).

- 122'000 years ago the ice caps grew strongly at the poles and in the mountain areas.
- After a long period of glacier fluctuations, a first major glacier expansion was achieved 70'000 BP*. It lasted up to 60'000 BP.
- The story continued with swift fluctuations. 35'000 - 30'000 BP, the second period of maximum ice expansion began. It lasted up to 23'000 or 22'000 years ago and one last glacial maximum is dated 20'000 years ago.

The maximum extension of the Reuss- and the adjacent Linth-Limmat Glacier is shown in Fig. 9. At that time the glacier was a little higher than shown in Fig. 8 (below).

When retreating, the Reuss Glacier left pronounced terminal moraines near Vitznau and Gersau, as shown by the bathymetric map (Fig. 10). After the glacier retreat landslides and rock falls occurred until recent times.

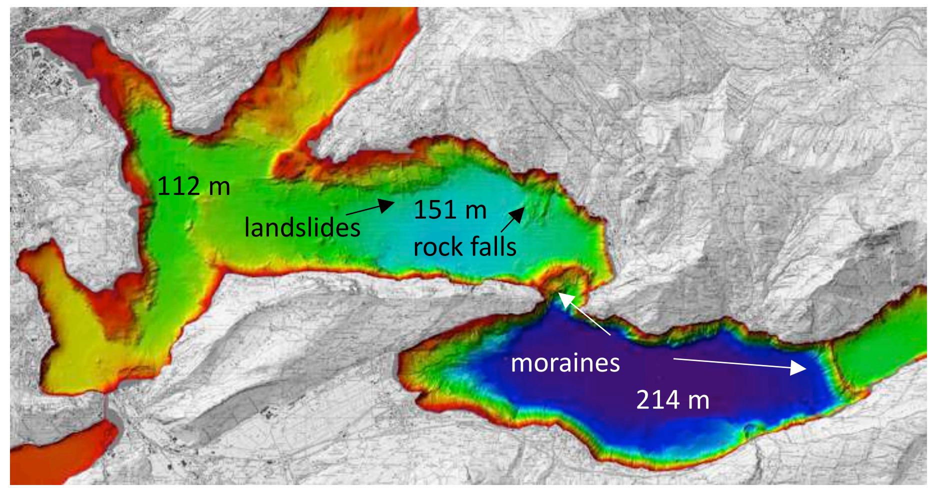


Figure 10: Bathymetric map (water depth) of Lake Lucerne (http://www.geo.unibe.ch/research/quaternary_geology_and paleoclimatology/index_eng.html).

frequently triggered by earthquakes and tsunamis (Hilbe et al., 2011).

Little more than 10’000 years ago, the glaciers in the Alpine region were back to where we know them today. At that time Lake Lucerne had about the same extent as today. Only the river deltas have since pushed a little further into the lake.

The geological context of Lake Lucerne

From the nappe theory to palaeogeography

The **“nappe theory"** was developed at the turn of the 19th to the 20th century. Geologists had observed that in the Alps - and in other mountain ranges - older strata of rocks lay in sharp contact over younger strata. This could only be explained by the fact that the older layers had been mechanically pushed into this position during the formation of the mountains. The geological mapping indicated that these thrusts affected rock formations several kilometers wide and hundreds of meters thick, the actual ”nappes". The current geological picture of the Alps shows that the entire mountain range is characterized by this nappe architecture: In the collision between Europe and Africa, sediment layers and slices of the upper crystalline Earth crust were sheared off from their substrate and pushed either to the north to the European, or south to the Adriatic (or African) foreland.

The geological profile of Fig. 3 shows this nappe structure in the cross section of Lake Lucerne. If one wants to bring the sediments and the rocks of the crystalline basement of this profile back to their original geographical position, one has to move the nappes to the south. By doing so, one gets a "**paleogeographic map**" as shown in Fig. 6. However, in this figure, the sequence of the paleogeographic realms of the different geological units from north to south does not simply correspond to the vertical distribution of the geological units of Fig. 3. This may be explained by complications in the set up of tectonic events during the Alpine folding, which we will not address here.

If one connects the geological units in the profile of Fig. 3 with the paleogeographic spaces in Fig. 6, the following correlation results:

Geological unit	Paleogeographic realm
• Black Forest, Jura and Plateau Molasse • Subalpine Molasse	Northalpine foreland
• Aar- and ev. Gotthard massifs Helvetic nappes (Gitschen, Axen and Drusberg nappes)	Helvetic realm
• Missing? Ev. “Wildflysch”? ev. Wägital-Flysch?	North-penninic realm, Valais basin
• Klippen nappe	Central-penninic realm, “Briançonnais“
• Ev. Wägital-Flysch?	South-penninic realm, Ligurian basin
• Missing	Austroalpine and Southalpine realms

In this geological cross-section, the exact paleogeographic positions of the Gotthard massif and the Wägital-Flysch are still controversial.

The detailed description of the geological profile will be given in the next chapter, as part of the boat trip from Lucerne to Flüelen.

Figure 11: Steam-boats on Lake Lucerne

The steamboat fleet

In addition to fifteen motor ships, the shipping company of Lake Lucerne operates five historic steamboats during the warm season (https://www.lakelucerne.ch/schiffsmiete/flotte/):

DS City Lucerne: The largest ship for a maximum of 1100 people. The machine was built by the Gebrüder Sulzer (Winterthur); its maiden voyage was in 1928.

DS Schiller: This classic paddle steamer with Art Nouveau saloon holds a maximum of 900 people. This machine was also built by Sulzer; its maiden voyage was in May 1906.

DS Uri: It is the oldest ship, with a maximum capacity of 800 passengers; his maiden voyage took place in 1901.

DS Unterwalden: The ship is a listed building. During the course, it receives a maximum of 700 passengers. It was built by Escher Wyss and went on its maiden voyage in 1902.

DS Gallia: It is the fastest paddle steamer on European lakes (31.5 km / h). The ship was built by Escher Wyss (Zurich) and has been operating since 1913 with a capacity of 900 passengers.

Museums of natural history in Lucerne

Before booking for the geological boat trip we recommend a visite to the Glacier Garden of Lucerne:

gletschergartenLuzern https://gletschergarten.ch/

Another museum near the city center worth visiting is the Nature Museum Lucerne. It offers, in particular, permanent exhibitions with an introduction to the geology of Central Switzerland and paleontology. http://www.naturmuseum.ch/

A geological boat trip on Lake Lucerne

The boat trip takes off from Lucerne to Flüelen. The timetable and further information can be found on the following website:

https://www.lakelucerne.ch/fahrplan-preise/fahrplan/

In the following description, the travel sections are numbered according to Fig. 12.

Fig. 12 presents the geographic frame. Fig. 13 b shows the geographic distribution of the different tectonic units. Fig. 13 a shows a composite geological profile to the east of Lake Lucerne. The numbers 1 - 11 correspond to the sections of the steamship between the stops. Fig. 14 shows the geological profiles on both sides of the Urnersee by Buxtorf (1934), and Fig. 15 shows the sequence of geological formations of the Helvetic nappes.

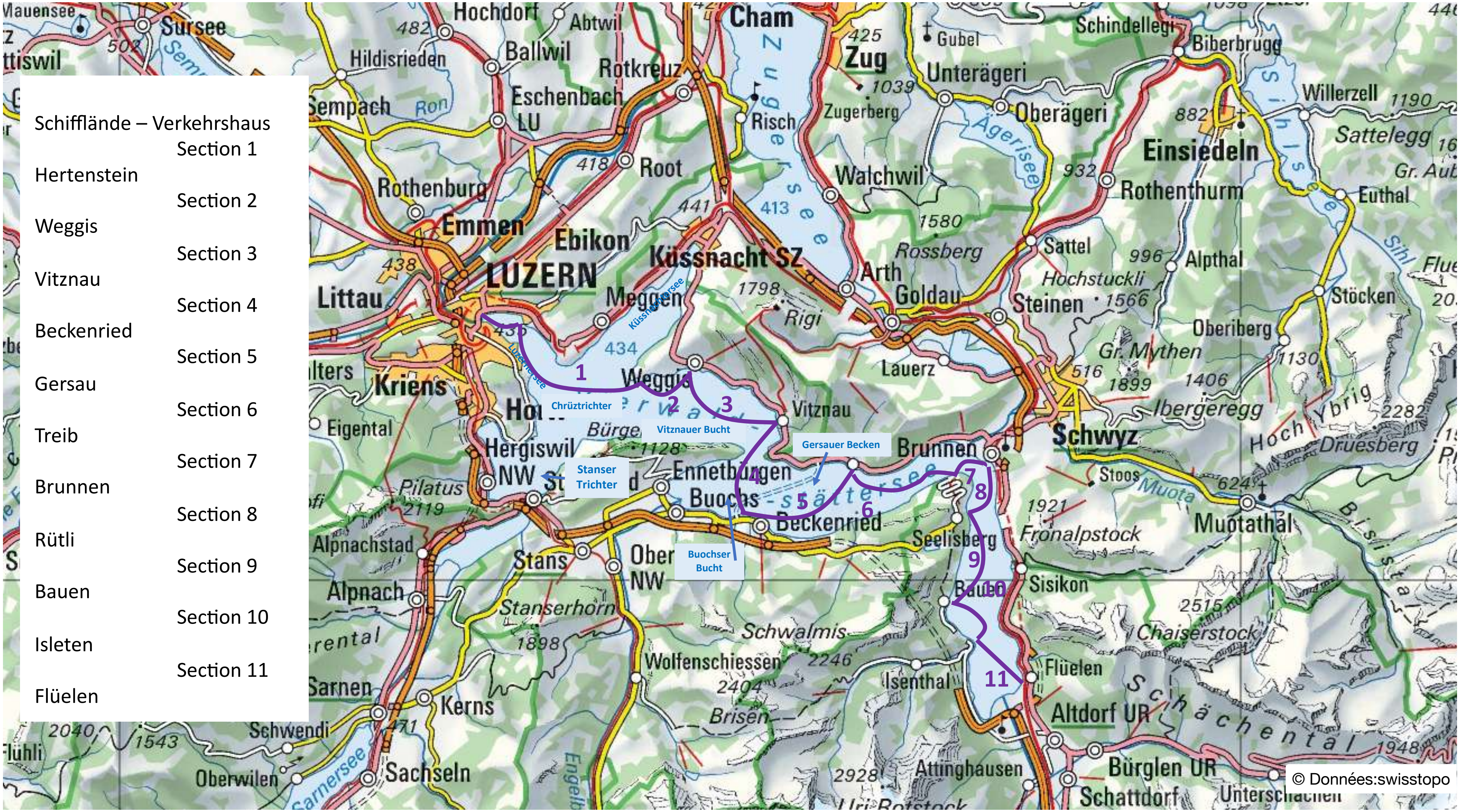


Figure 12: Lake Lucerne, topography and map of the cruise from Lucerne to Flüelen (© *swisstopo*)

(1) Schifflände Luzern – Verkehrshaus – Hertenstein

The journey over the "Chrüztrichter" and the Küssnachtersee (Lake Küssnacht) leads through the alpine foreland, with northeast - southwest oriented hill crests, under which the folded Molasse emerges (Fig. 13 a, b). The overthrust of the Subalpine Molasse on the folded Molasse runs at the foot of the northwest slope of the Rigi.

Whether the name **Rigi** refers to the Latin "Regina" (the queen of the mountains) (Wikipedia: Albrecht von Bonstetten in 1479), or to the grass and rock bands referred locally to as "Rigene", is an open question. Both explanations are plausible.

Seen from distance, the Rigi appears as an enormous mountain block, inclined to the southeast (summit height: 1798 m) with protruding rocky sediment banks. These consist of coarse conglomerates (so-called "Nagelfluh") and sandstone layers. The rock beds were created by the cementation of the gravels and sands which were deposited during the Oligocene, 30 million years ago, by the mountain streams on the huge fluvial cones along the foothills of the Alps.

(2 – 3) Hertenstein – Weggis – Vitznau

On this section, the boat takes you along the foot of the Rigi mountain. The view of the mountain flank shows the bands of meadows and forest that cover the slope, with conglomerate banks protruding here and there (Fig. 16 b,c,d).

On the **Bürgenstock** there is an interesting didactical foot-path, the so-called "Felsenweg". It was built in the north-sloping cliff and gives an insight into nature and landscape.

http://lernpfad-felsenweg.ch/

The opposite, southern shore of Lake Lucerne, shows a completely different picture; the geology on both sides of the lake basin is not symmetrical: The steep cliffs of the **Bürgenstock** (elevation: 1128 m, Fig. 16 b) fall steeply towards the lake. This mountain is already part of the so-called "Border chain" of the Helvetic nappes, that means the frontal chain of this characteristic alpine nappe. The white limestone formations supposedly run horizontally east-west. Seen in space, however, they fall towards the southeast, that is, towards the level of the Engelberger Aa river which is not visible from the lake. The continuation of this nappe is visible to the west on the Pilatus mountains. Here the layers are folded in the summit section (Fig. 16 a). The Pilatus is an impressive mountain. According to a medieval legend, the Roman emperor Pontius Pilate is buried here.

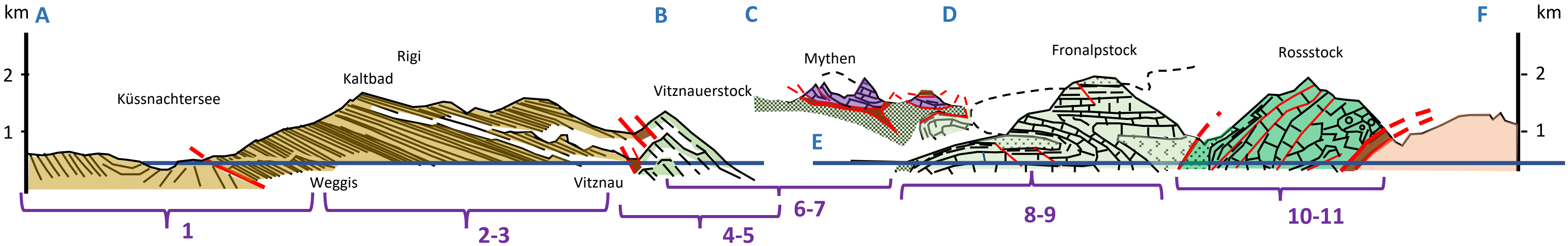
(4 - 5) Vitznau – Beckenried - Gersau

On this section of our travel, we are crossing the base of the Helvetian nappes on the northern shore (Fig. 14). The highest of these nappes, the Drusberg nappe, is superimposed onto a Wildflysch formation, a chaotic mixture of boulders in a marly-clayey matrix. The stratigraphic sequence of this nappe is shown in Fig. 15, in two columns. The sequence on the Vitznauerstock corresponds to that of the Border chain in Fig. 13.

The travel back to the northern shore leads again into the zone of the Wildflysch. This is explained by a lateral tectonic displacement of the Border chain (Fig. 16 g).

(6 – 7) Gersau – Treib – Brunnen

The journey now runs entirely inside the Helvetic nappes. Shortly after leaving Gersau, however, one discovers in the northeast, above the village, the two characteristic pyramids of the Small (*Kleiner*, left) and the Great (*Grosser*) Mythen (right, Fig. 17 a).



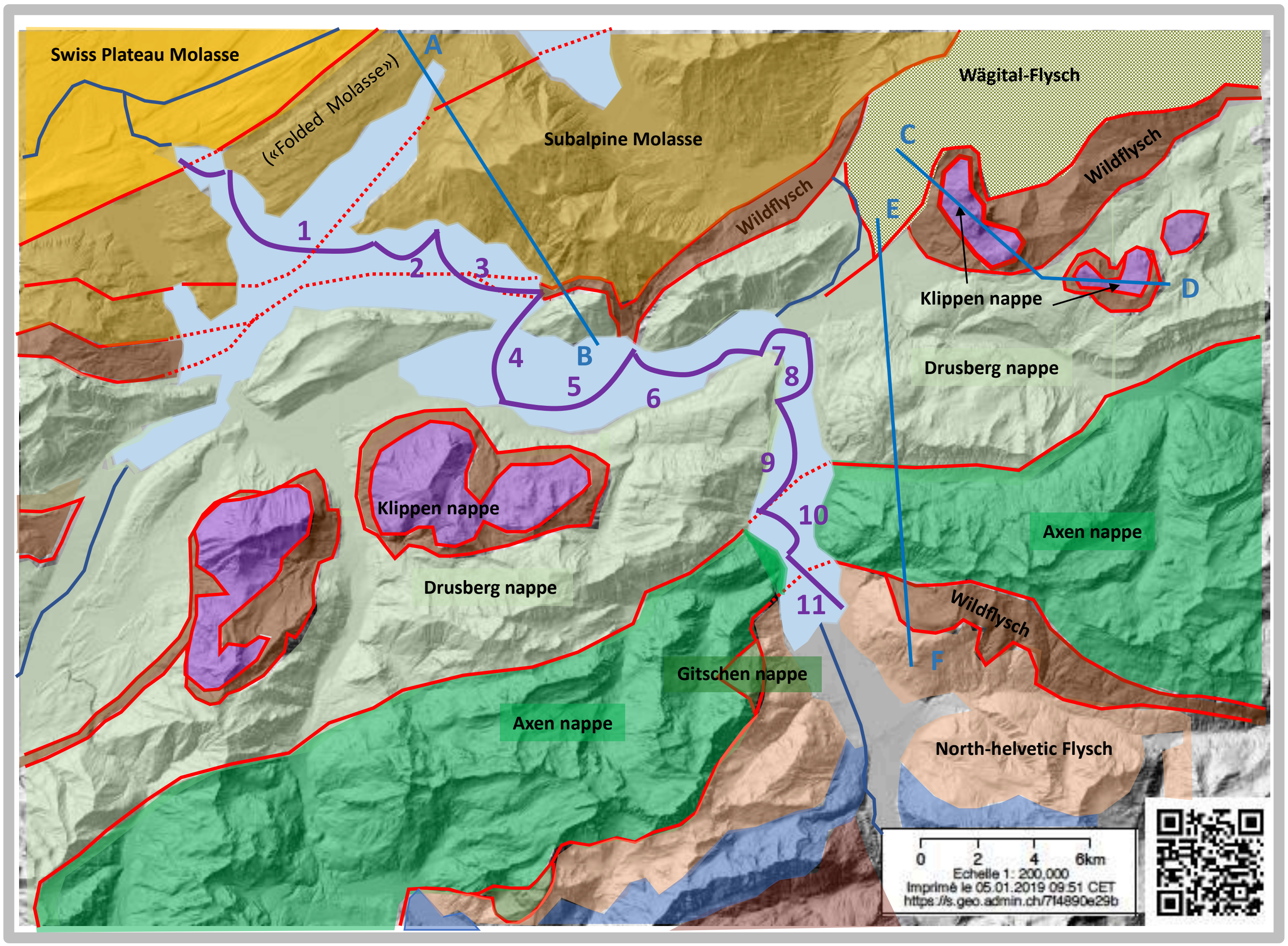


Figure 13 a: Assemblage of geological sections to the east of Lake Lucerne.

b: Tectonic map of Lake Lucerne and its surroundings; 1 – 11 sections of the boat trip..

References: Tectonical map of Switzerland 1:500'000 on swissALTI3D (swisstopo©); Helvetic: Pfiffner (2011, simplified), Mythen: Felber (1984), Rigi: Buxtorf (1914).

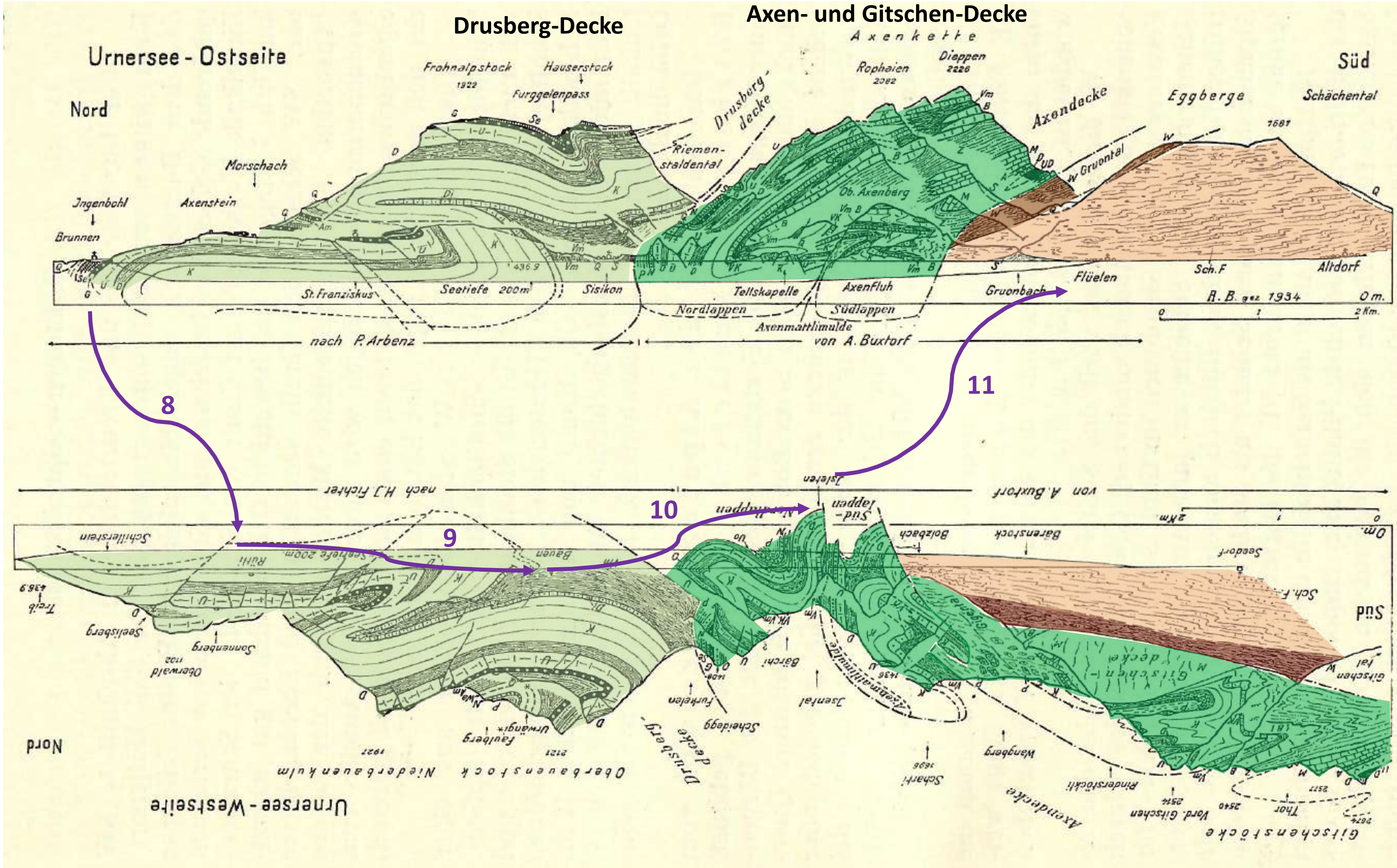


Figure 14: Geological profiles along «Lake of Uri» (Urnersee, Buxtorf 1934, Fig. 4). Figure caption (after Buxtorf, translation): S: slope deposits, Q: moraine, P: Stad- and Pectiniden-shists, C: conglomerates, N: Nummulite-limestone, etc. (Lutetian), Wa: Wang-formation (Maestrichtian, Am: Amden-shists (Senonian), Se: Seewer-formation (Turonian), G: «Gault» (Albian-Up. Aptian), U: Urgonian (Schrattenkalk, limestone and Orbitolina-beds=O), D: Drusberg-formation (Low. Barremian), K: Kieselkalk, silicious limestone (Hauterivian), Vk&Di: «Valanginian-limestone», Diphyoides-limestone, Vm: «Valanginian-marl», B: «Berriasian-marl», Z: Zementstein-shists (Low. Berriasian – Up. Portlandian), M: Malm, A: Argovian, D: Dogger (Callovian-Bajocian), UD: Lower Dogger (Aaleniann), W: Wildflysch, SchF: «Schächtaler Flysch», «parautochthonous» (Altdorf-sandstone)

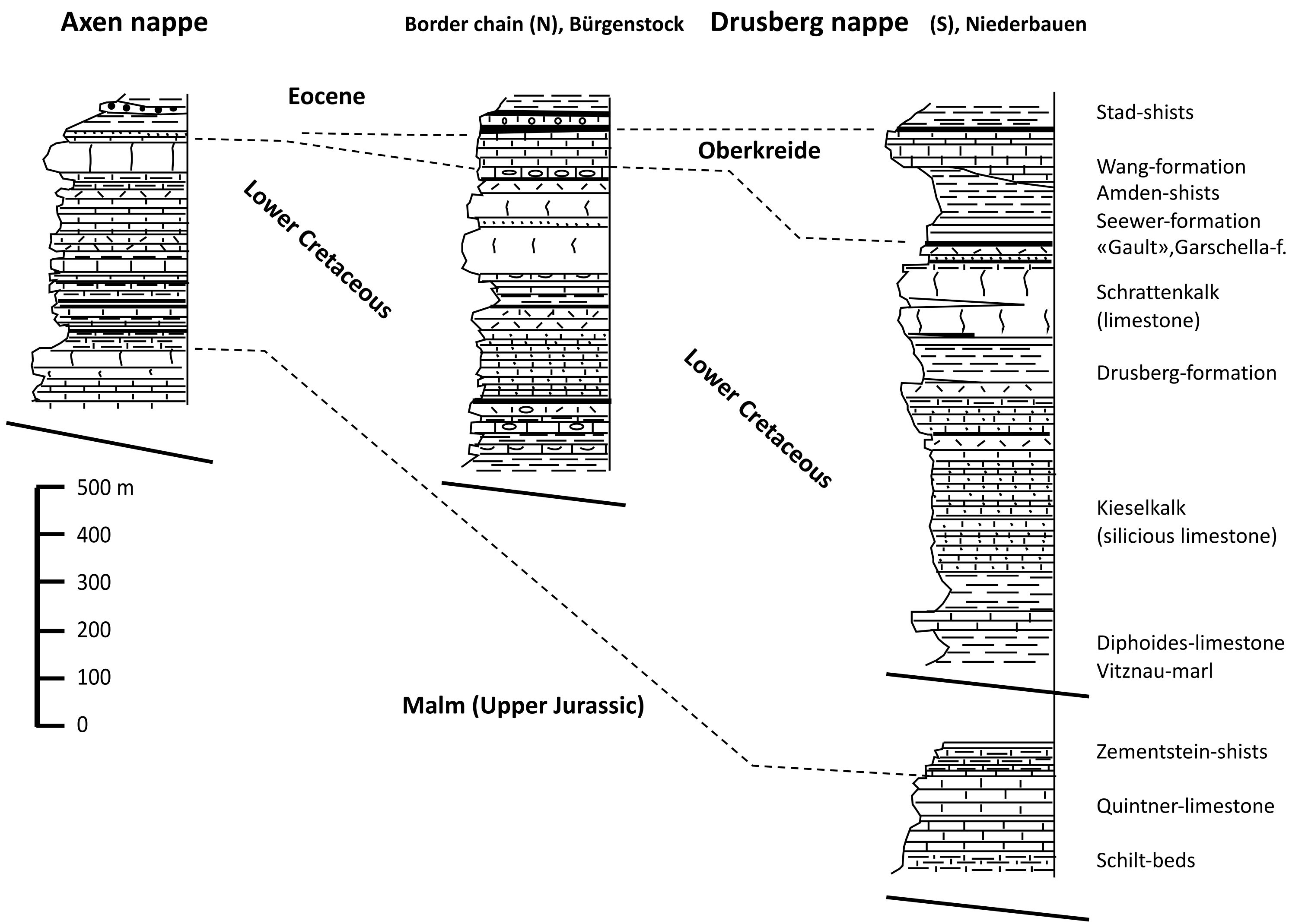


Figure 15: Stratigraphy and age of the geological formations of the Helvetic nappes along Lake Lucerne (after Trümpy 1980, Fig. 19)

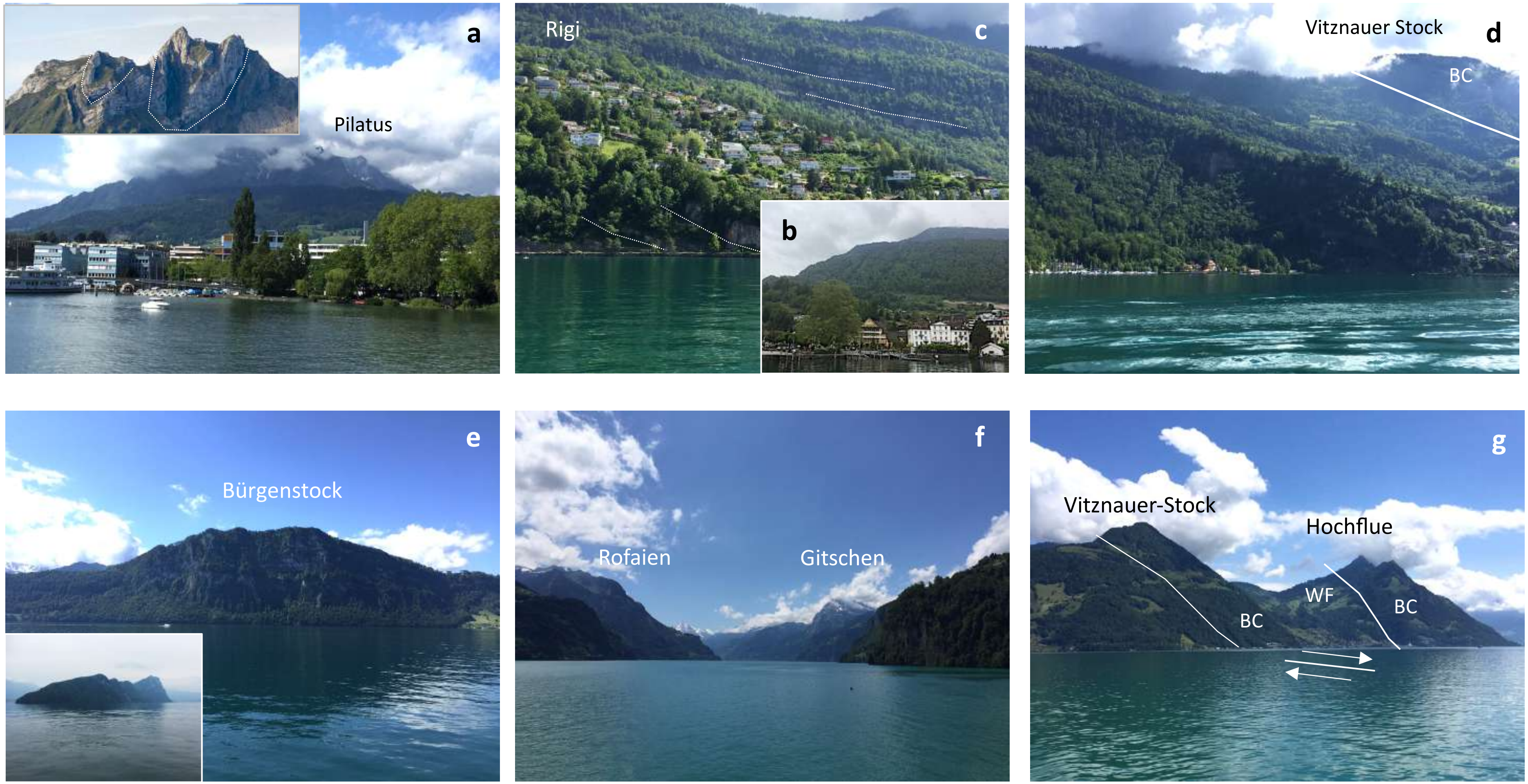


Figure 16: photo-travel from Lucerne to Gersau (photos J.U.): a: Pilatus mountain and it's famous cloud-hut; folds (white lines) in the summit area, a day of clear weather. b: the village of Weggis on the foot of the Rigi; c: conglomerates («Nagelfluh», underlined by white lines) in the Subalpine Molasse close to Vitznau. The strata are inclined towards the south-east. d: main overthrust (white line) of the Border chain (BC) of the Helvetic nappes on the Vitznauer Stock. e: Bürgenstock seen from the north, and profile seen from the east. f: entry of the Gersau basin, between Vitznau and Gersau (view towards the south). g: Gersau bay and Border chain (BC) laterally displaced by a tectonic fault; the soft morphology in the centre is due to the presence of Wildflysch (WF).

Figure 17: photo-travel from Gersau to Flüelen (photos J.U.): a: *Kleiner* (small, left) and *Grosser Mythen* (big, on the right) above the village of Brunnen, seen from the lake in the north-eastern direction. b: Fronalpstock (Drusberg nappe), looking towards the east. c: Axenflue et top of the Rophaien (Axen nappe), looking towards the east. d: «Schillerstein» (Schiller memorial) at the entry to Lake Uri (left shore). Inscription: *«Dem Sänger Tells F. Schiller, die Urkantone 1859»* («To the singer (or story-teller) of Tell, the Cantons of Central Switzerland 1859»). e: Tell-Chappel *(Tellskapelle).* f: mountain tops on the left side of the lake: Oberbauenstock and Niederbauen-Chulm (Drusberg nappe); looking towards the north-west. g: Flüelen, looking south into the lower Reuss valley towards the Bristenstock (Aar massif).

These belong to the so-called Klippen nappe, which is correlated with the nappe of the "Préalpes Médianes" in western Switzerland. The cliffs originate from the so-called "Briançonnais shelf", an elevated area in the middle of the Alpine sea, where dolomite rocks and limestone formed in the shallow waters during the Triassic and during the Jurassic periods (Fig. 6). On the top of the massif limestones of Malm age, one observes directly red marls (so-called "Couches Rouges") of the Cretaceous, which testify of a deeper marine platform.

The slopes at the foot of the Mythen have a softer morphology. Here, one can find sandstones alternating with clay, the so-called Wägital-Flysch, also of Penninic origin (Fig. 6).

(8 - 9) Brunnen – Rütli - Bauen

On this section the steam boat enters the north-south running Lake Uri *("Urnersee",* Fig. 14). Just above the lake level, the rock layers are in a horizontal position. Then, in the upper part of the slope, impressive folds develop on the Fronalp- and Hauserstock to the east, and on the Nieder- and Oberbauenstock to the west of the lake basin, in which most of the rock formations of the Helvetic nappes can be identified, even at a certain distance (Fig. 17 b,f).

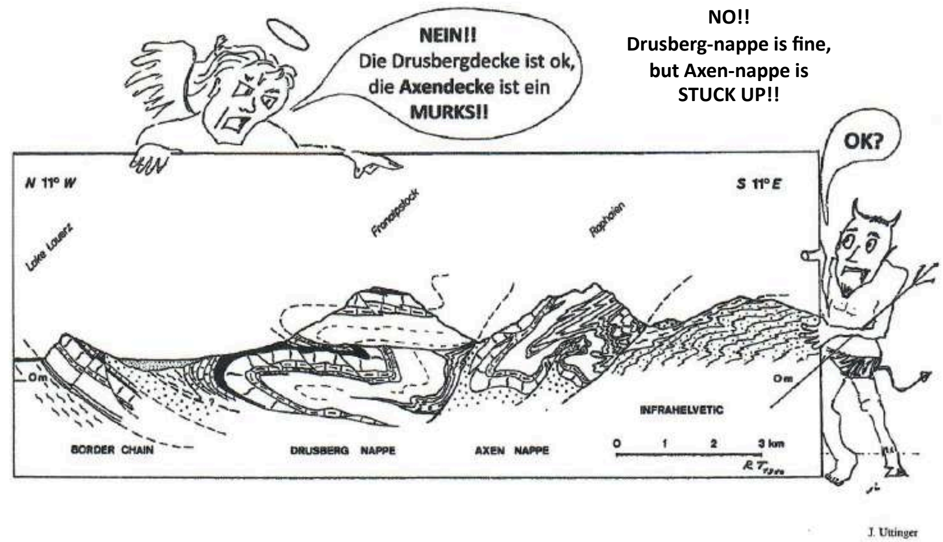
(10 – 11) Bauen - Isleten – Flüelen

On this last section of our travel, we cross the complex geological structure of the northern and southern lobes of the Axen nappe (Fig. 14). On the opposite shore of the lake the Tell Chapel is built on silicious limestone *(Kieselkalk).*

At the terminus of Flüelen the morphology of the landscape is softer again, due to the presence of the North-helvetic Flysch (Fig. 17 g).

References

- Buxtorf A. 1914: Profile zur geologischen Vierwaldstättersee-Karte, 1:50'000. Geologische Kommission der Schweizerischen Naturforsch-enden Gesellschaft. Luzern
- Buxtorf, A. 1934: Vierwaldstätter See. Exkursion 53. Geologischer Führer der Schweiz, Fasc. 10, 701-715, Schweiz. Geol. Gesellschaft.
- Felber, P.J. 1984: Der Dogger der Zentralschweizer Klippen. PhD thesis ETH Zürich, Diss. ETH Nr. 7506.
- Hilbe, M., Anselmetti, F.S., Eilertsen, R. S., Hansen, L. & Wildi, W. 2011: Subaqueous morphology of Lake Lucerne (Central Switzerland): implications for mass movements and glacial history. Swiss J. Geoscie. 104/ 3, 425-443.
- Keller, B. 2007: So entstand der Vierwaldstättersee. In: Vierwaldstättersee. Lebensraum für Pflanzen, Tiere und Menschen. Brunner Verlag, Kriens / Luzern, 31-53.
- Penck, A. & Brückner, E. 1901 -1909: Die Alpen im Eiszeitalter. C.H. Tauchnitz, Leipzig , 1199 S. in drei Bänden.
- Pfiffner, O.A. 2011: Explanatory Notes to the Structural Map of he Helvetic Zone of the Swiss Alps, including Vorarlberg (Austria) and Haute Savoie (France). Geological Special Map 128, Text and 10 plates. Swiss Geological Survey, swisstopo.
- Spillmann, P. 2011: Geologie des Kantons Uri. Natf. Ges. Kt. Uri, 2. Aufl.
- Trümpy, R. 1980: Geology of Switzerland, a guide-book; Wepf Verlag, Basel.
- Wildi, W. 2020 : Traces of the history of the Earth in Switzerland. https://erlebnis-geologie.ch/fr/geothemen/auf-den-spuren-der-erdgeschichte-in-der-schweiz/
- Winkler, W., Wildi, W., Stuijvenberg, J. Van & Caron, Ch. 1985: Wägital-Flysch et autres flyschs penniques en Suisse Centrale : stratigraphie, sédimentologie et comparaisons. Eclogae Geologicae Helvetiae, 78/1, 1-22.



(Geological section: R. Trümpy 1980, cartoon: J. Uttinger)