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A trip through the Wildhorn Nappe from Cretaceous to Neogene time (Helvetic Nappes, Switzerland)

Tectonic Studies Group of the Swiss Geological Society - Summer excursion, 2015

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A trip through the Wildhorn Nappe from Cretaceous to Neogene time (Helvetic Nappes, Switzerland)

Tectonic Studies Group of the Swiss Geological Society, Summer excursion, 8th – 9th August, 2015

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Abstract

A field trip across the Wildhorn Nappe (SW Switzerland), forming part of the Helvetic nappes, is presented here. The field trip, which took place on the 8-9th August 2015, was the annual excursion of the Tectonic Studies Group of the Swiss Geological Society. It has been organized as a 2-day itinerary along the southern slopes of the Helvetic Alps between Kanton Bern and Valais (Fig. 1). This guide contains a brief structural and stratigraphic overview followed by Stop descriptions along a main geological cross-section that, from south to north, shows both the Neogene and the Cretaceous faults and their different structural characteristics. Neogene faults are associated with veins and ductile to brittle structures. Cretaceous faults are comparatively dry, discrete and related to palaeo-escarpments associated with stratigraphic unconformities, fault-growth geometries, slumps and sedimentary dykes. The temporal evolution of the Cretaceous syn-sedimentary fault system is also documented by spectacular panoramas and briefly discussed in relation to nappe-stack development and subsequent Neogene orogen-parallel extension.

Key words: Helvetic nappes, brittle-ductile faults, veins, syn-sedimentary faults, palaeo-escarpments

Riassunto

In questa guida presentiamo un percorso attraverso la Falda del Wildhorn (Svizzera sudoccidentale), una delle falde strutturalmente più alte delle coperture elvetiche. L'escursione ha preso luogo tra l'8 e il 9 agosto 2015 in quanto scelta come escursione annuale del Gruppo Studi Tettonici della Società Geologica Svizzera. Il percorso è stato organizzato come un itinerario di 2 giorni lungo i fianchi meridionali delle Alpi Elvetiche tra il Canton Berna e il Vallese (Fig. 1). Questa guida contiene anche un breve inquadramento strutturale e stratigrafico, seguito dalla descrizione degli Stop lungo una sezione geologica di riferimento che da sud a nord mostra sia le strutture del Neogene che quelle Cretacee, concentrandosi sulle loro diverse caratteristiche strutturali. Le faglie neogeniche sono associate a vene e strutture da duttili a fragili. Le faglie cretacee invece sono associate a fratture non riempite, sono discrete e relazionate a paleo-scarpate associate a contatti stratigrafici inconformi, geometrie di faglie di crescita, slumps e dicchi sedimentari. L'evoluzione temporale del sistema di faglie sin-sedimentarie cretacee è documentato anche da foto panoramiche spettacolari ed è brevemente discusso in rapporto anche allo sviluppo del sistema a pieghe e sovrascorrimenti e alla successiva estensione parallela all'asse principale dell'orogene alpino.

Parole chiave: Successioni carbonatiche, tettonica cretacea, tettonica neogenica, faglie sinsedimentarie, transizione fragile-duttile

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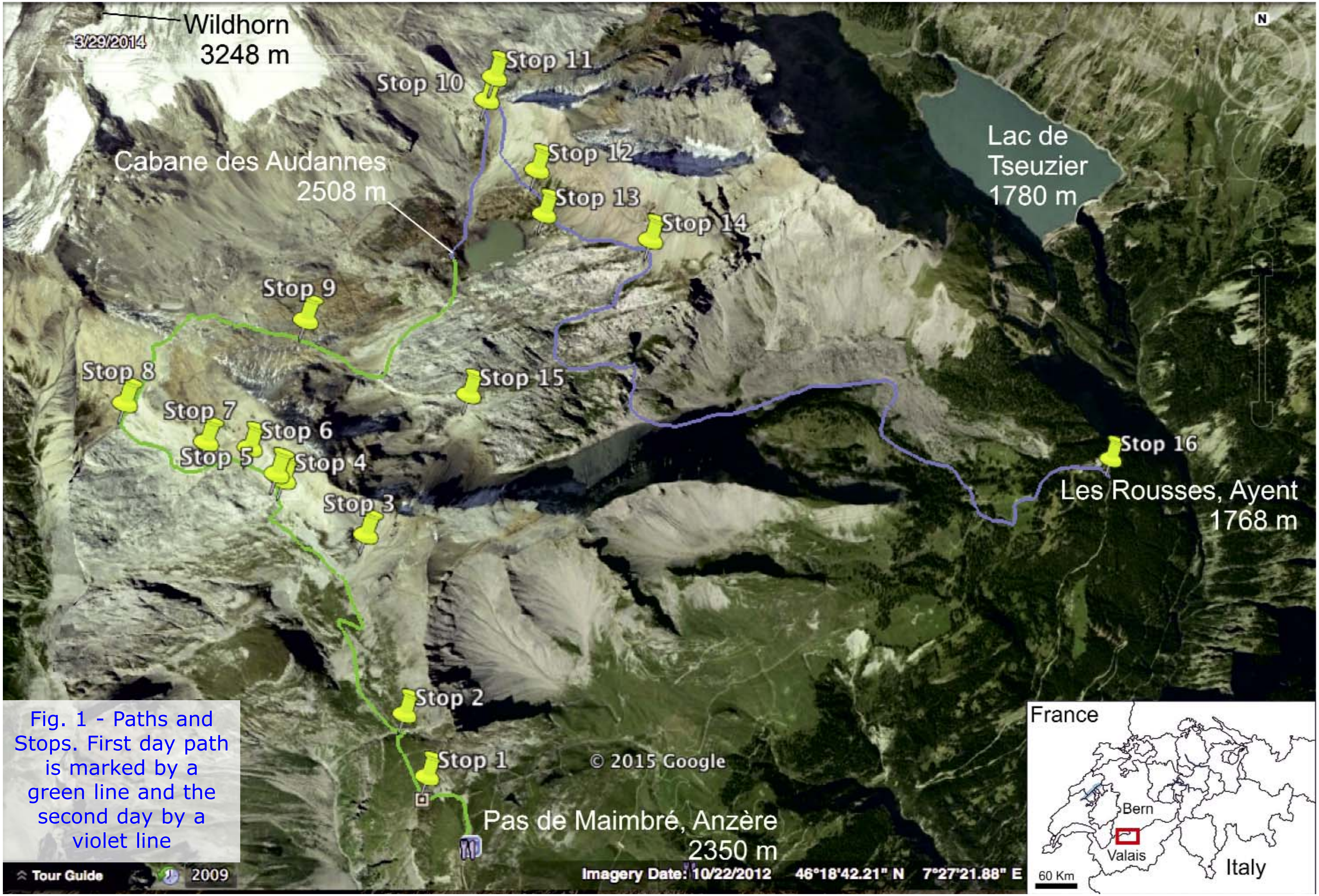

Fig. 1 - Paths and Stops. First day path is marked by a green line and the second day by a violet line

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Program

The excursion is based on public transport and walking in rather high but not difficult mountain conditions. The best time for this field trip is in the late summer when snow cover is limited. In order to have two full and efficient days, it is recommended to start already at 8:00 at the bus station of Sion Post, Place de la Gare (directly opposite the main railway station). For most participants, this will mean overnighting in Sion on the previous evening. Cheap accommodation is available at the Youth Hostel, which is very close to the train station. On reaching the cable car of Anzère, you should get out at the final station called Pas de Maimbré (Fig. 1), from where the trip continues on foot. For cable car time schedules in summer time or to book for a group write an email well in advance to info@teleanzere.ch. Overnighting in the field, dinner and breakfast are suggested at the Cabanne des Audannes, where a preliminary reservation is recommended for groups in high season. You can book at this website : http://www.audannes.ch.
On the afternoon of the second day, there will be a bus from Les Rousses to bring you back to Sion. Please check out all time schedules of the Swiss public transportation at http://www.ffs.ch/home.html. Participation in the excursion is at your own risk. The field trip involves hiking in alpine terrain at altitudes up to ca. 2600 m. Adequate mountain gear is necessary, in particular mountain boots and warm clothing. Please take along a picnic for 2 days. More detailed topographic and geologic support is provided by the 1:25.000 St-Leonard sheet, which you may wish to borrow or buy. A pre-trip reading of Cardello & Mancktelow (2014, 2015) is recommended.

Accomodation

Auberge de Jeunesse Sion – Ostello della Gioventù di Sion. Rue de l’Industrie 2 1950 Sion (VS) – Tél: +41 27 323 74 70 – i-contacts: sion@youthhostel.ch;

Useful numbers in case of emergency

General Emergency – 112 – Emergenze generiche
Firefighters – 118 - Pompieri
Police – 117 - Polizia
Ambulance – 144 - Ambulanza
Rega (elisoccorso) – 1414 – Elisoccorso alpino

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Geological background

The SW Helvetic Alps (Fig. 2) record several tectonic events such as syn-rift extension, post-break-up extension, foreland extension, orogenic compression and orogen-parallel to orogen-perpendicular extension during continued convergence. As a result, different generations of faults were produced from the Mesozoic to the Neogene. Similar to what is observed elsewhere (e.g. Mohn et al., 2010; Cardello & Doglioni, 2015), the Helvetic succession was repeatedly affected by syn-sedimentary normal faults, some of which have considerable displacement (up to ca. 500 m) and strongly affect the distribution of sedimentary facies (e.g. Günzler-Seiffert, 1941; Hänni & Pfiffner, 2001; Kempf & Pfiffner, 2004; Cardello & Mancktelow, 2014).

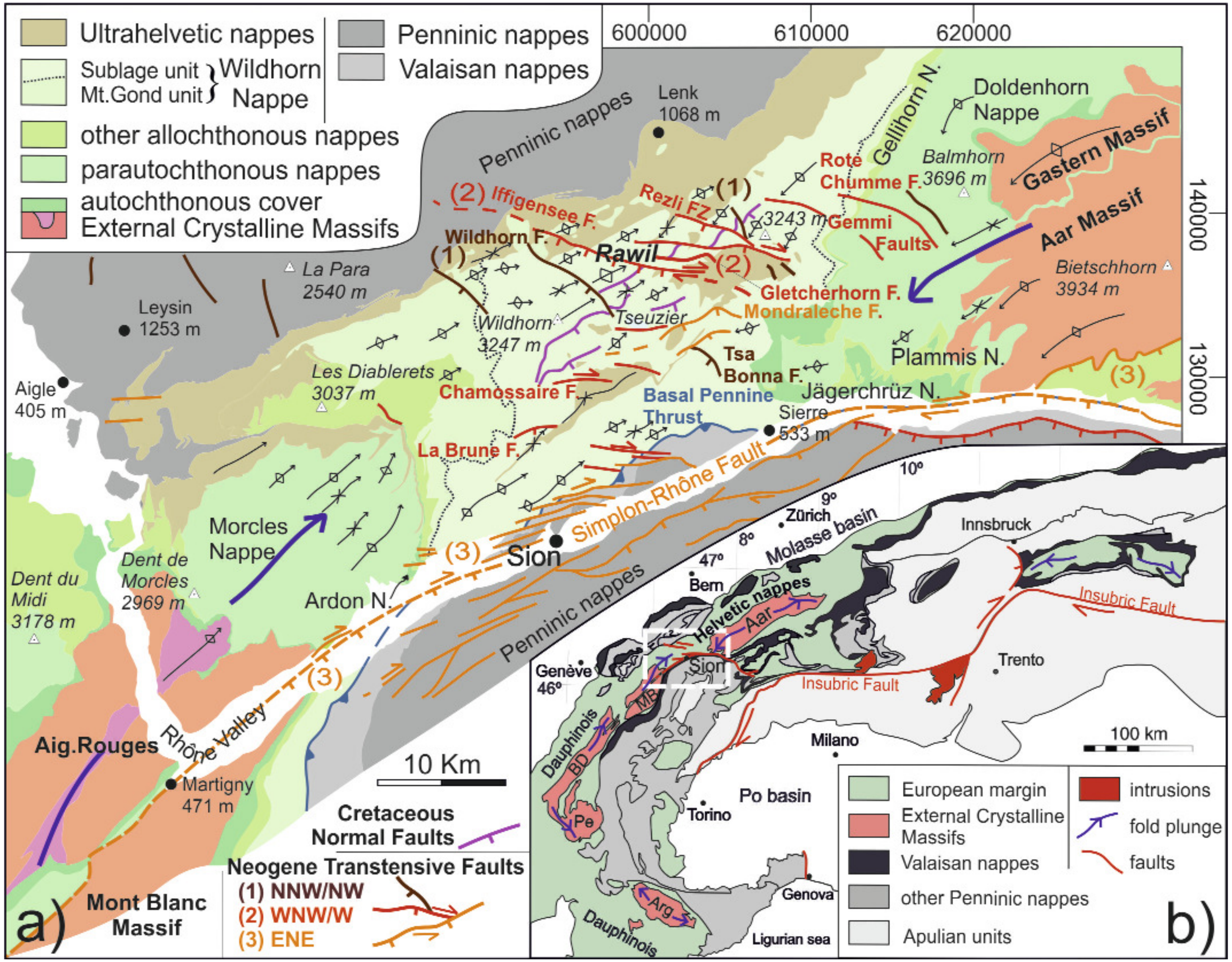

Fig. 2 - **a)** Simplified tectonic map of SW Switzerland. In blue, axis of the Rawil Depression, with the plunge direction indicated (modified from Cardello 2013, after Tectonic Map of Switzerland, and Steck et al. 1999); **b)** Tectonic map of the Alps, with the location of a) indicated by the white rectangle.

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During the Alpine convergence, two major stages can be distinguished (Heim, 1920; Ramsay et al., 1983; Burkhard, 1988; 1993; Jeanbourquin, 1994; Maurer et al., 1997; Pfiffner, 2009). Thin-skinned tectonics during the first stage produced folds and thrusts, with the major thrusts with displacements of (many) 10's of kilometres marking the base of distinct, named "nappes" (e.g., the Wildhorn Nappe). On a broad scale, the resultant nappe stack is composed of Penninic, Ultrahelvetic and Helvetic nappes, which were emplaced in the time period from ca. 32 to 15 Ma (Trümpy, 1960; Crespo-Blanc et al., 1995; Steck et al., 1999; Kirschner et al., 2003). The second stage of compression is associated with cooling and with the progressive exhumation of the Alps (Burkhard, 1988; Vernon et al., 2008, Sternai et al., 2012). The nappe stack was up-domed and folded on a large scale (ca. 10 km across), with an amplitude pointing to crustal-scale thrusting (Pfiffner, 2009; Cardello et al., 2015). The axial depression of this antiform has its structurally lowest point in the Rawil pass region (i.e. the Rawil Depression; Lugeon, 1914-1918; Gasser & Mancktelow, 2010), where U-Th/He zircon age data show that cooling below 200°C occurred in the last 17-15 Ma (Cardello, 2013). The different structural style of the two major compressional events reflects a gradual change from thin- to thick-skinned tectonics within the basement, linked to ongoing deformation of the outer arc of the Western Alps (Maurer et al., 1997; Sue et al., 2007). Veins are a common feature within the Helvetic nappes (e.g. Ramsay et al., 1981; Dietrich et al., 1983; Burkhard, 1988; Cardello & Tesei, 2013; Cardello & Mancktelow, 2015) and are important markers recording the incremental stretching history (e.g. Durney & Ramsay, 1973; Casey et al., 1983). Burkhard & Kerrich (1988) distinguish three different sets of veins: pre-, syn- and post-tectonic according to their involvement in the nappe-emplacement and further deformation. However, none of the veins are strictly post-tectonic because they still reflect the incremental strain at the time of their formation.

Studies north of the Rhône Valley have mainly focused on the neotectonics and the potential relationship of faults to active seismicity. From vein relationships, Franck et al. (1984) established a succession of stretching events in the Sanetsch pass area of the Rawil Depression, relating the youngest NW-striking veins to present-day seismicity, the N-striking veins to nappe-emplacement and the NE-striking veins to syn-sedimentary faulting. During the latest stage of deformation, younger transverse faults were exhumed to the surface in the footwall of the Simplon-Rhône fault, associated with differential uplift of the Mont Blanc/Aiguilles Rouges and Aar/Gastern External Crystalline Massifs and development of the Rawil Depression. These dextral-transtensive Neogene faults generally transect pre-existing syn-sedimentary faults without significant inversion or reactivation.

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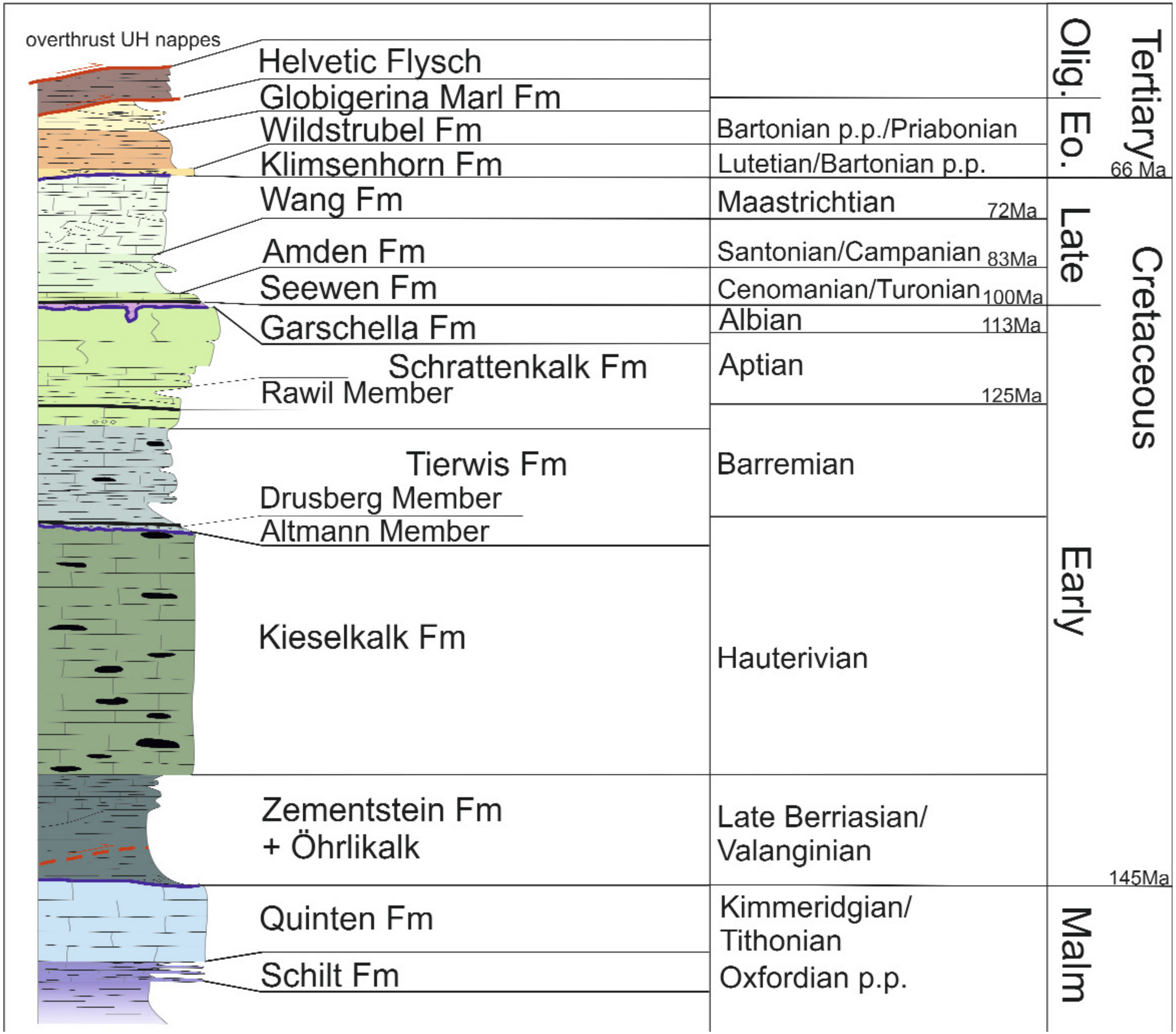

Fig. 3 - Stratigraphic column of the Wildhorn Nappe, modified after Cardello & Mancktelow (2014, and references therein).

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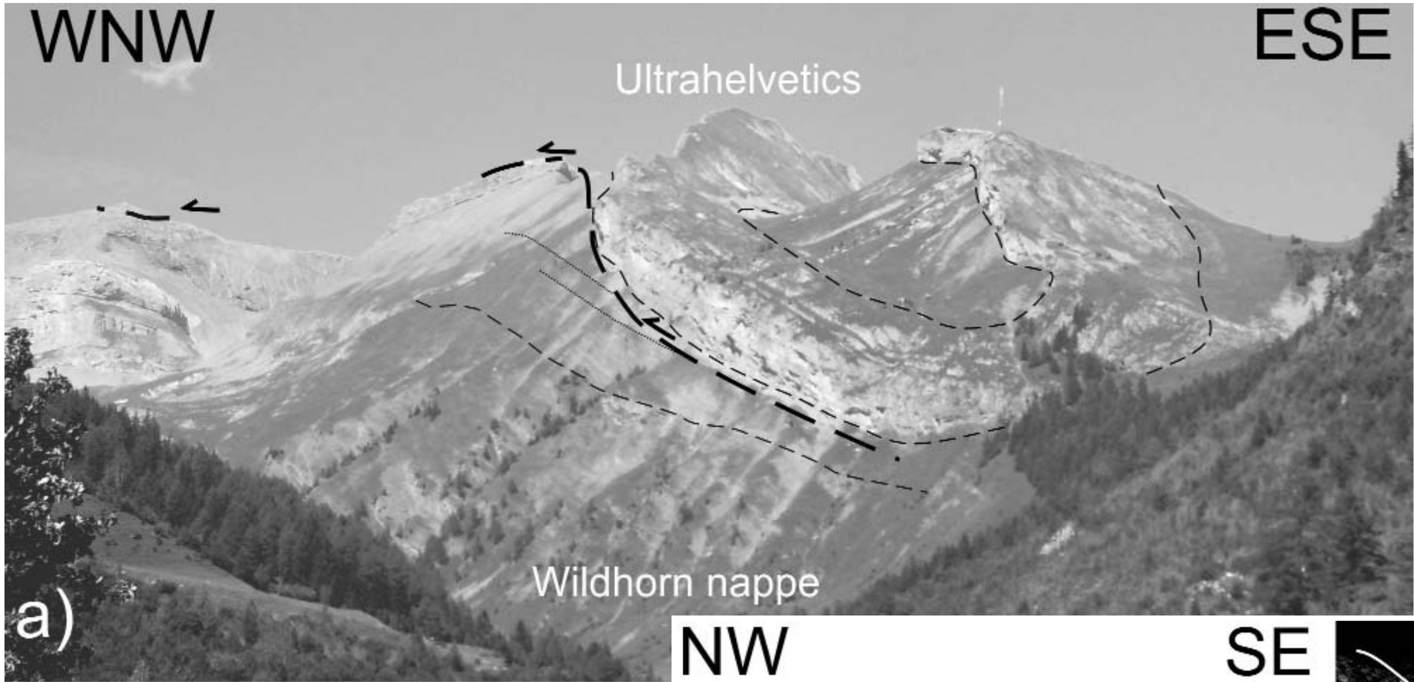
First day: nappe boundaries, syn-sedimentary structures and Neogene oblique-normal faults

The total path length of the first day is some 6.5 km, whereas the height difference is about 350 m but with some up and down. The highest point is 2766 m and the difficulty grade is medium. A few easy off-track deviations are included. From the bus station of Sion the cable car of Anzère can be reached by Post Bus. The uppermost cable car stop is Pas de Maimbré (Fig. 4a), from which you can observe the Ultrahelvetic basal thrust on the other side of the valley toward the NE (Fig. 4b, c).



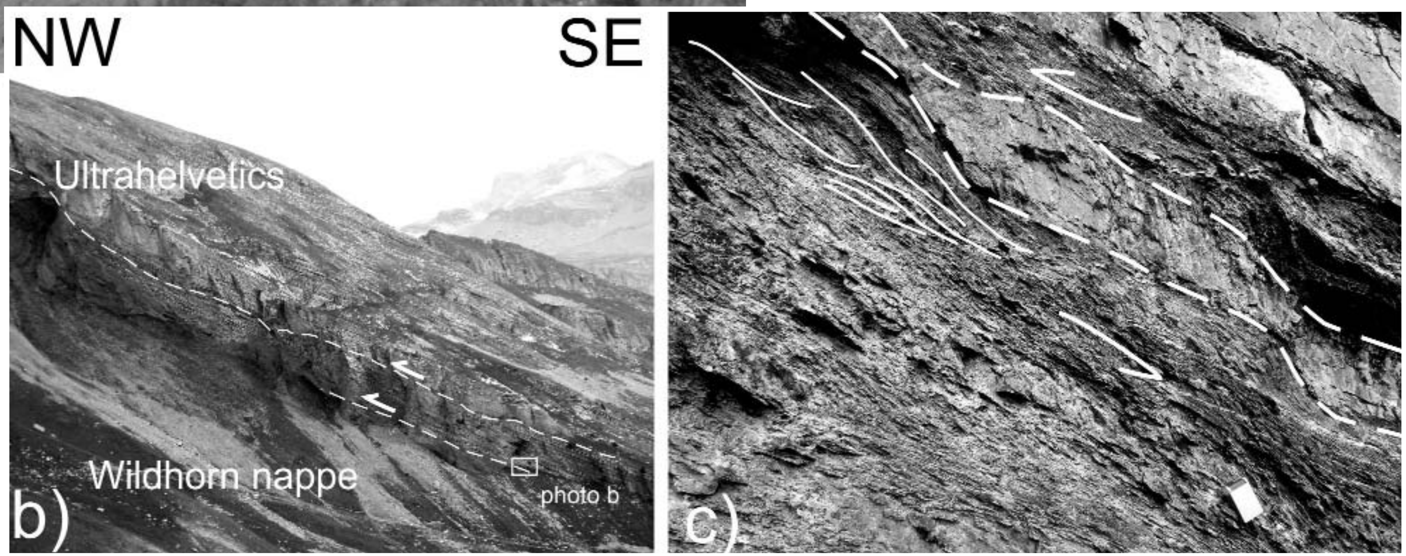


Fig. 4 - **a)** Chamossaire area, the Ultrahelvetic basal thrust ramps onto the Cretaceous succession of the Wildhorn Nappe; this package is later folded together in the Prabé syncline. **b)** and **c)** Detail of the thrust zone. Asymmetric boudinage affects the rocks close to the contact, giving top-to-the-NW sense of shear.

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STOP 1 - (46°18'54.03"N / 7°22'55.11"E) a panoramic overview of the Ultrahelvetic basal thrust

This Stop is a quick view of the tectonic ramp contact, which juxtaposes the Ultrahelvetic Quinten limestones over the Wildhorn Nappe (Fig. 4b, c). From here, we will walk on along the cross-section AB in Fig. 5 from the Prabé fold core to the Eaux Froides palaeo-fault.

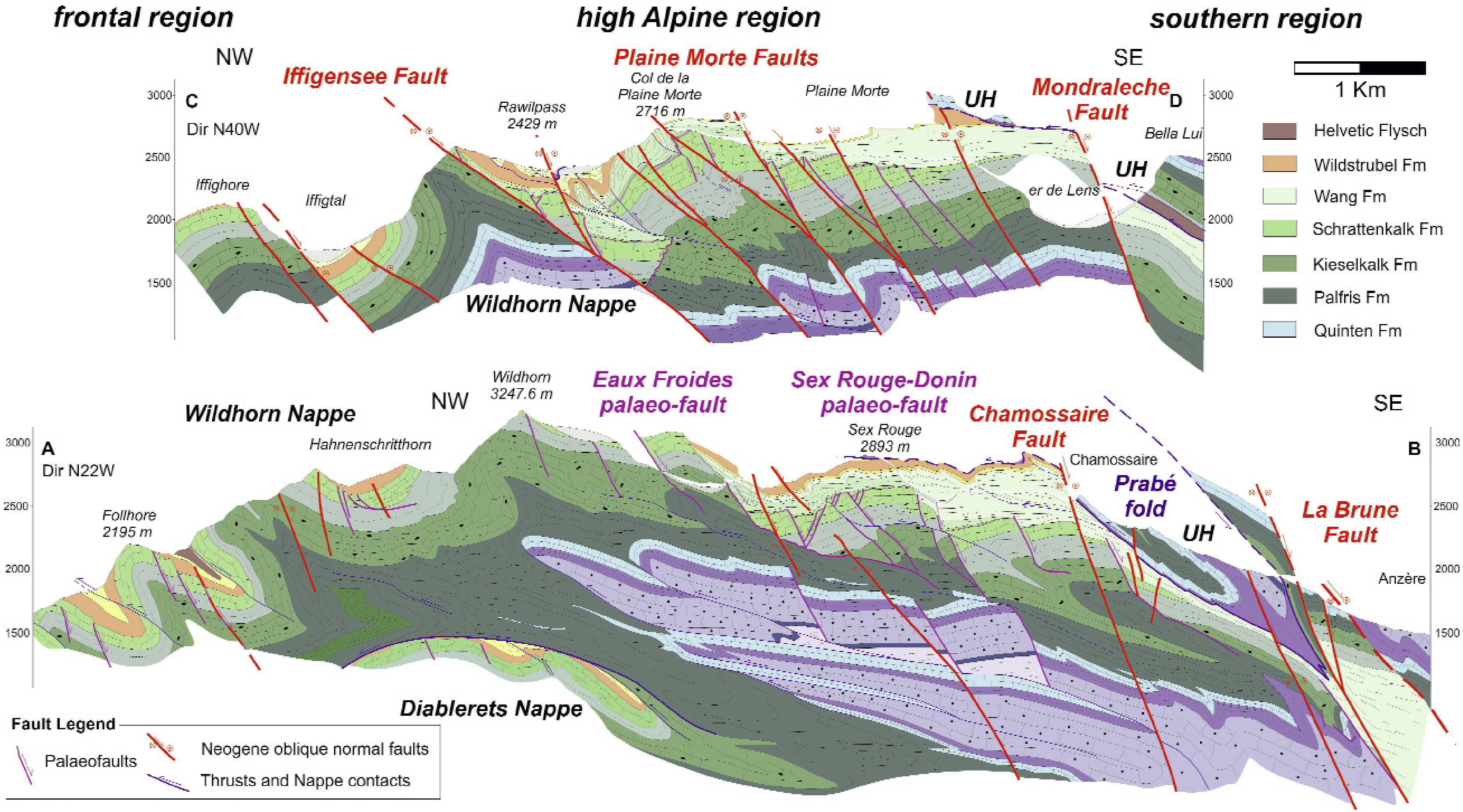

Fig. 5 - Geological profiles (modified after Cardello & Mancktelow 2014), the trace of which are indicated in Fig. 1. Most of the faults in red that crosscut folds and nappe boundaries belong to fault set 2), as shown in Fig. 1. Palaeofaults (purple lines) determine facies and thickness variation in the Upper Cretaceous series.

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STOP 2 - (46°19’5.77”N/7°22’49.88”E) the Chamossaire fault

The Chamossaire fault (Fig. 6a) is a well exposed EW-striking, steeply dipping oblique normal fault with an important dextral strike-slip component. The fault length is ca. 1.2 km and the displacement ca. 100 m. As seen from Fig. 6b, the footwall consists of: **1)** little deformed to veined limestones of the Tierwis Fm (Fig. 6b, zone a), which are crossed by sporadic, 2-3 cm thick veins of calcite immediately adjacent to the sharp contact with the fault core; **2)** fractured, veined and gradationally recrystallized limestones of the Schrattenkalk fm, which are progressively dragged into the fault core, **3)** marly limestones and marls of the Wang Fm that are affected by S/C structures close to the main slip surfaces. The fault core is 1-1.5 m thick and can be divided

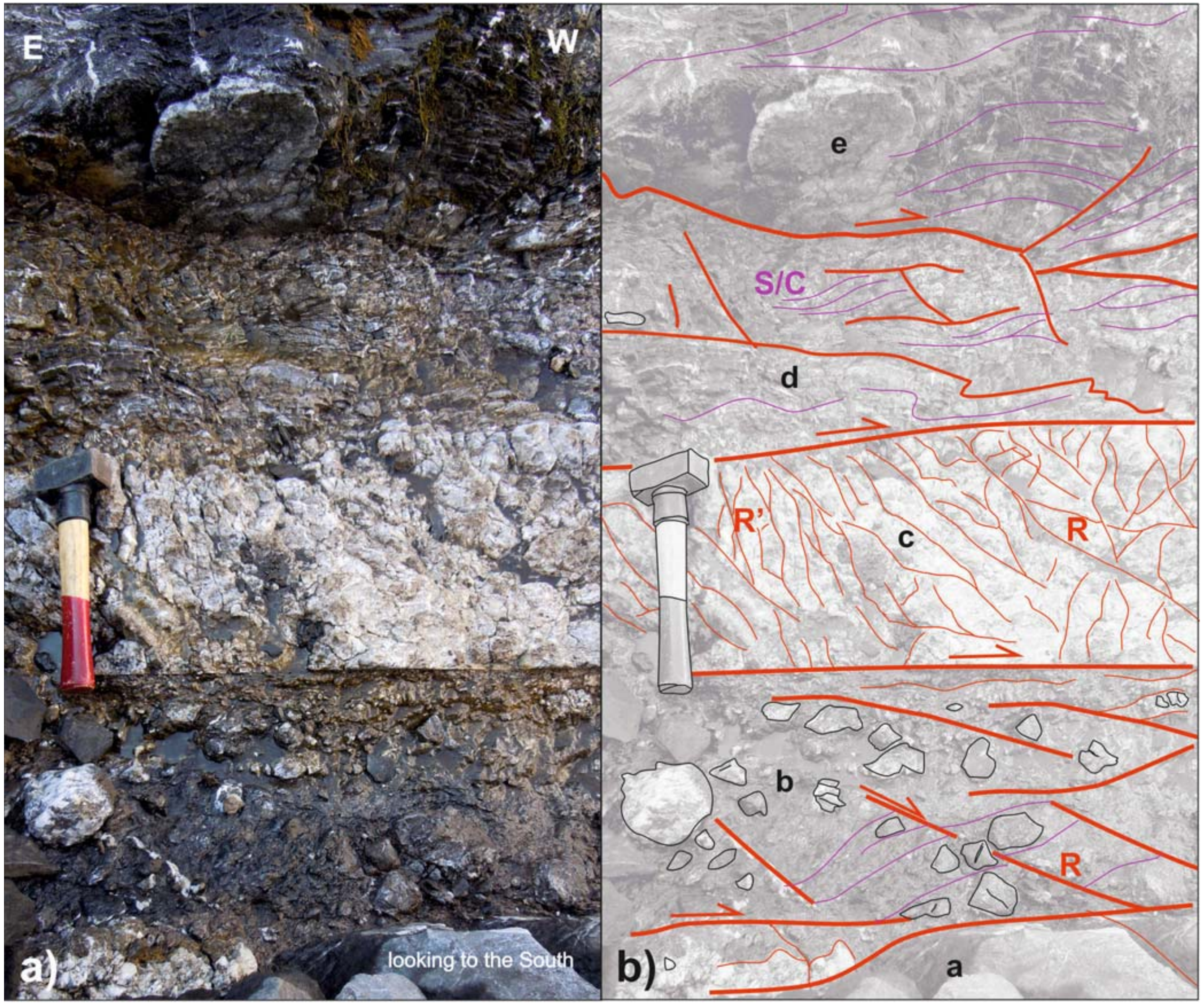

Fig. 6 - (modified after Cardello & Mancktelow, 2015). Chamossaire fault core (2310 m). **a)** Photograph; **b)** Interpretation: a) Fractured and veined Tierwis Fm (Lower Cretaceous marly limestones); b) Foliated and fractured cataclasite with clasts of Tierwis and Schrattenkalk fm; c) Fractured and recrystallized breccia of Schrattenkalk fm (Lower Cretaceous platform limestones); d) Riedel fractures and asymmetric folds in foliated cataclasite indicating dextral shear, with repeated faulting and more ductile shear; e) Foliated Wang Fm marls (Lower Maastrichtian).

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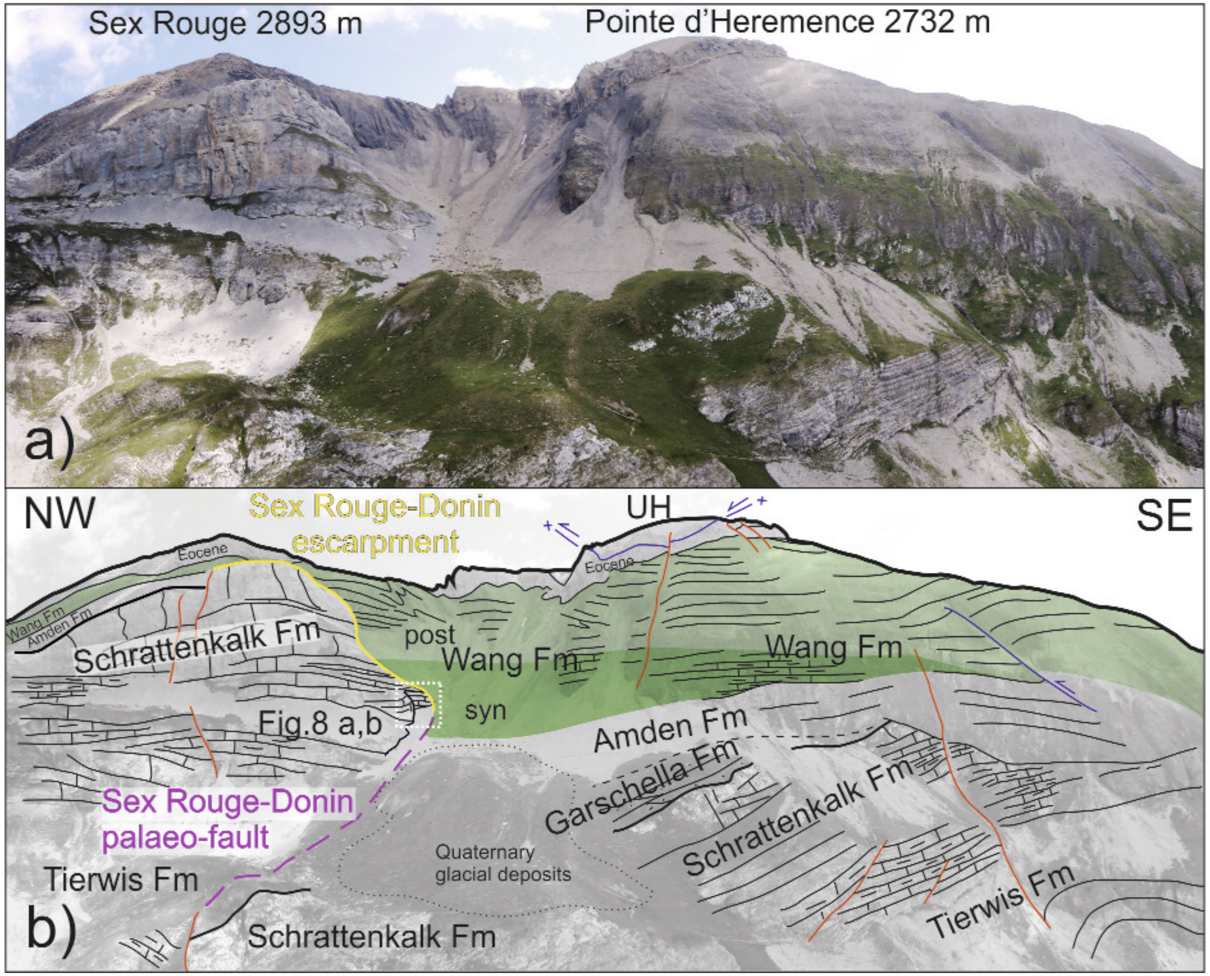

into 4 zones characterized by different structure and therefore rheological behaviour during the fault activity. The folding of Riedel fractures and discrete slip surfaces within the fault core shows that plastic creep played an important role even for generally brittle conditions. The sense of shear implied by the "ductile" structures is in agreement with the kinematic indicators on the main slip surface, indicating a consistent geometric and kinematic regime during continued movement along the Chamossaire fault.

Fig. 7 - (modified after Cardello & Mancktelow 2014). Sex Rouge south: growth fault. The Eocene deposits lie unconformably on the Wang Fm. Yellow line: palaeoescarpment. The Wang Fm passively recovers the relief by increasing sedimentation rate on the hanging wall of the no-longer active faults.

STOP 3 - (46°19'40.60"N/7°22'40.09"E) the Sex Rouge-Donin palaeo-fault

Here the Lower Cretaceous platform to ramp deposits are progressively onlapped by the Upper Cretaceous sequence, which is composed of Turonian to Campanian Amden Fm marls and the early Maastrichtian Wang Fm. This palaeo-escarpment setting is characterized by slumps and angular unconformities, related to a growth-fault structure formed during the late Cretaceous (Fig. 7). In Figure 8a, a detail of the contact between Schrattenkalk fm (Urgonian limestones) and Wang Fm marls is given. This contact is marked by patchy breccias (Fig. 8b) that are interposed between the two units, with an age that probably dates back to the earliest Maastrichtian.

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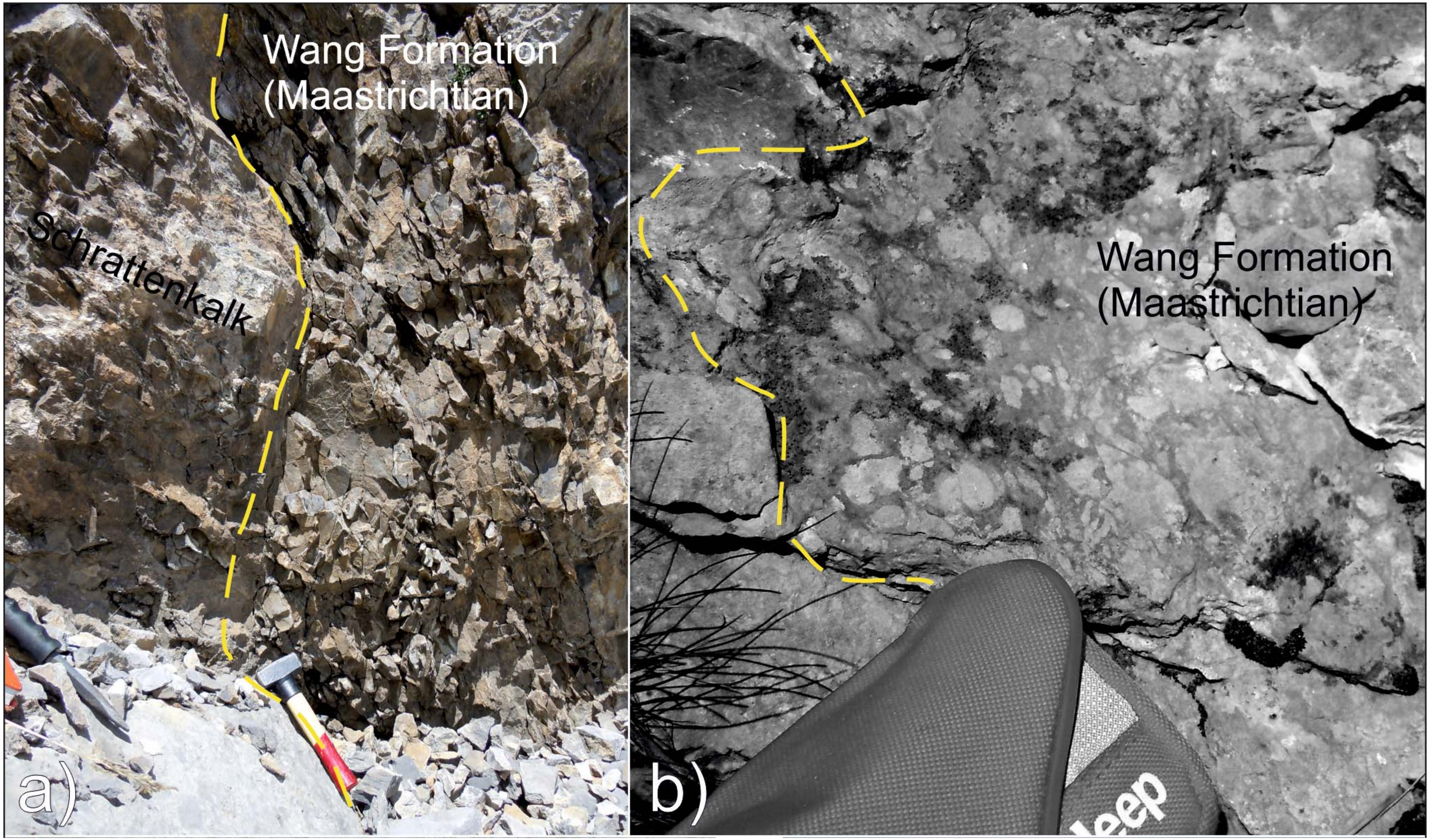

Fig. 8 - Details of escarpments. a) and b) Southern slope of Sex Rouge (see Fig. 7 for panoramic location). **a)** Step-like geometry of the escarpment (yellow line). The surface is silicified. **b)** Syn-sedimentary breccia preserved in the flatter parts of the escarpment underlying the onlapping deposits.

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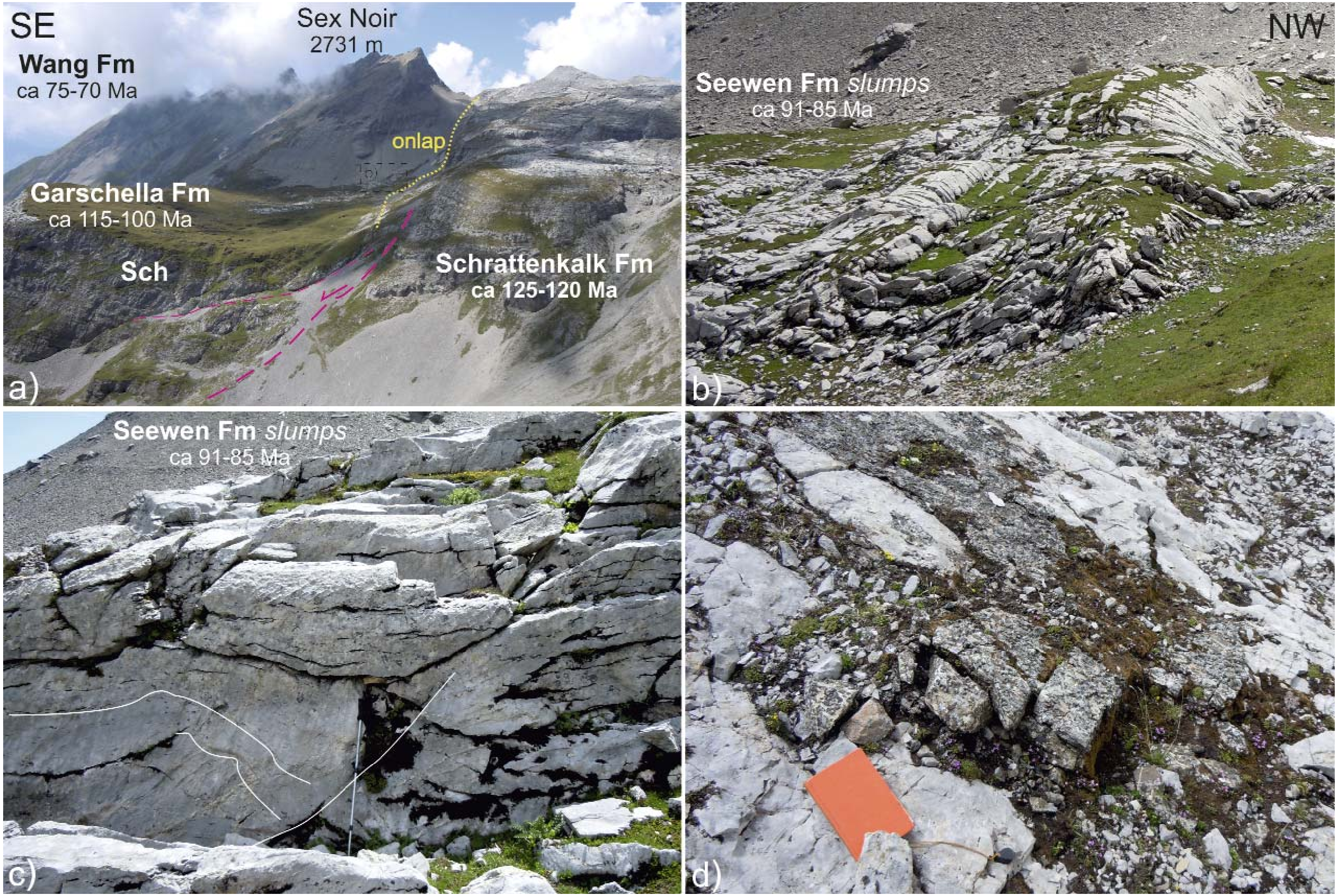

Fig. 9 - Sex Noir-Donin region. **a)** Palaeo-fault and related palaeo-escarpment crop out with **b)** slumps within the Seewen Fm. **c)** Detail of b), whose shape indicates soft-sediment deformation and gliding towards the depo-centre. **d)** Encrusted Schrattenkalk fm.

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STOP 4 - (46°19'51.00"N/7°22'19.22"E) half-graben structures

On the way to Stop 4, looking to the west of the valley, you can observe the Sex Noir-Donin region, which is rich in palaeographic features (Fig. 8a-c). At a height of ca. 2640 m, encrusted Urgonian limestones rich in rudists are topped by a reduced series of pelagic limestones and marls (Fig. 9d). According to our reconstructions (Fig. 10), this Stop is exactly on the southern shoulder of a half-graben, whose reduced stratigraphic thickness is due to a lateral slump of the Seewen Fm deposits, followed by hardground formation (Fig. 9d).

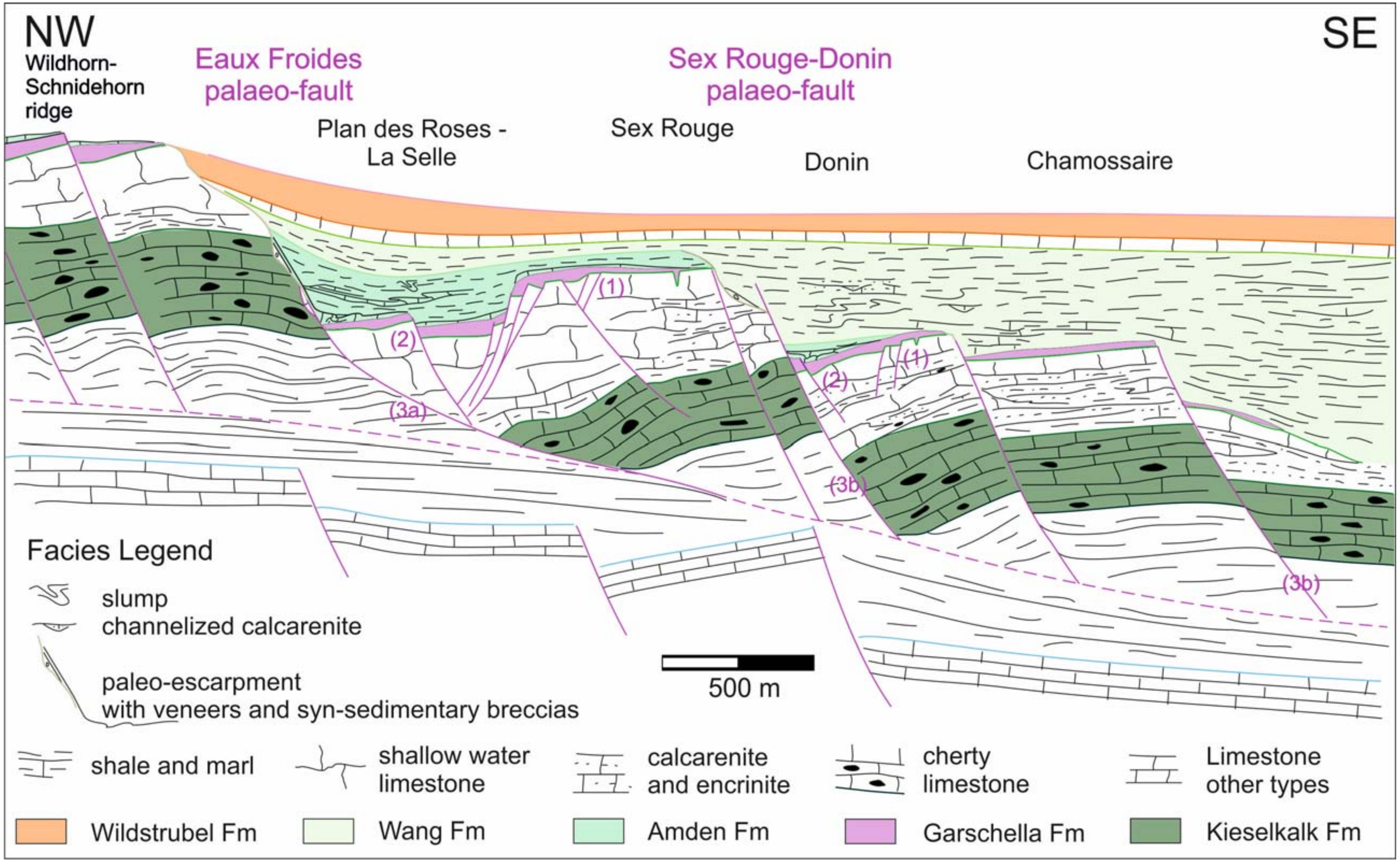

Fig. 10 - Cartoon summarizing the sedimentary facies and fault distribution based on profile AB in Figure 5 (Cardello & Mancktelow 2014). Numbers in brackets are **(1)** small-, **(2)**, moderate-, and **(3)** large-scale faults. Fault set **(3a)** was active in the Turonian-Santonian, whereas **(3b)** was active in the early Maastrichtian.

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STOP 5 - (46°19'52.08"N/7°22'17.34"E) latest Aptian syn-sedimentary dykes

A series of NE-striking Garschella dykes and related structures, such as small scale faults and open fractures, dismember the top of the Schrattenkalk fm (Fig. 11). A graben a few decimeters across dissects the encrusted top of the Schrattenkalk fm. This is then directly covered by the Seewen Fm, which also occurs as an infilling of a few dykes oriented parallel to the Garschella related material. (Lunch break is forecast at this Stop).

Fig. 11 - Small-scale graben within Schrattenkalk fm, filled in by deposits of the Garschella Fm (Brisi member, latest Aptian) and topped by Seewen Fm (Cenomanian-Turonian).

STOP 6 - (46°19'56.94"N/7°22'9.63"E) an example of a Neogene fault

On top of the Seewen Fm and Schrattenkalk fm, an en-echelon arrangement of Neogene faults can be observed, cross-cutting the pre-existing Cretaceous syn-sedimentary faults and later fold-and-thrust structures. Some of these faults record the transition from ductile to brittle behaviour (Fig. 12).

STOP 7 - (46°19'57.98"N/7°21'57.60"E) Turonian slumps within Campanian marls

Slumps of calcareous re-sediments, which occur within the Campanian marls of the Amden Fm. (Fig. 13). Similarly to what was observed by Villars (1989) more to the east, the re-sedimented Seewen-type limestone is Turonian in age. Slumps are internally quite folded.

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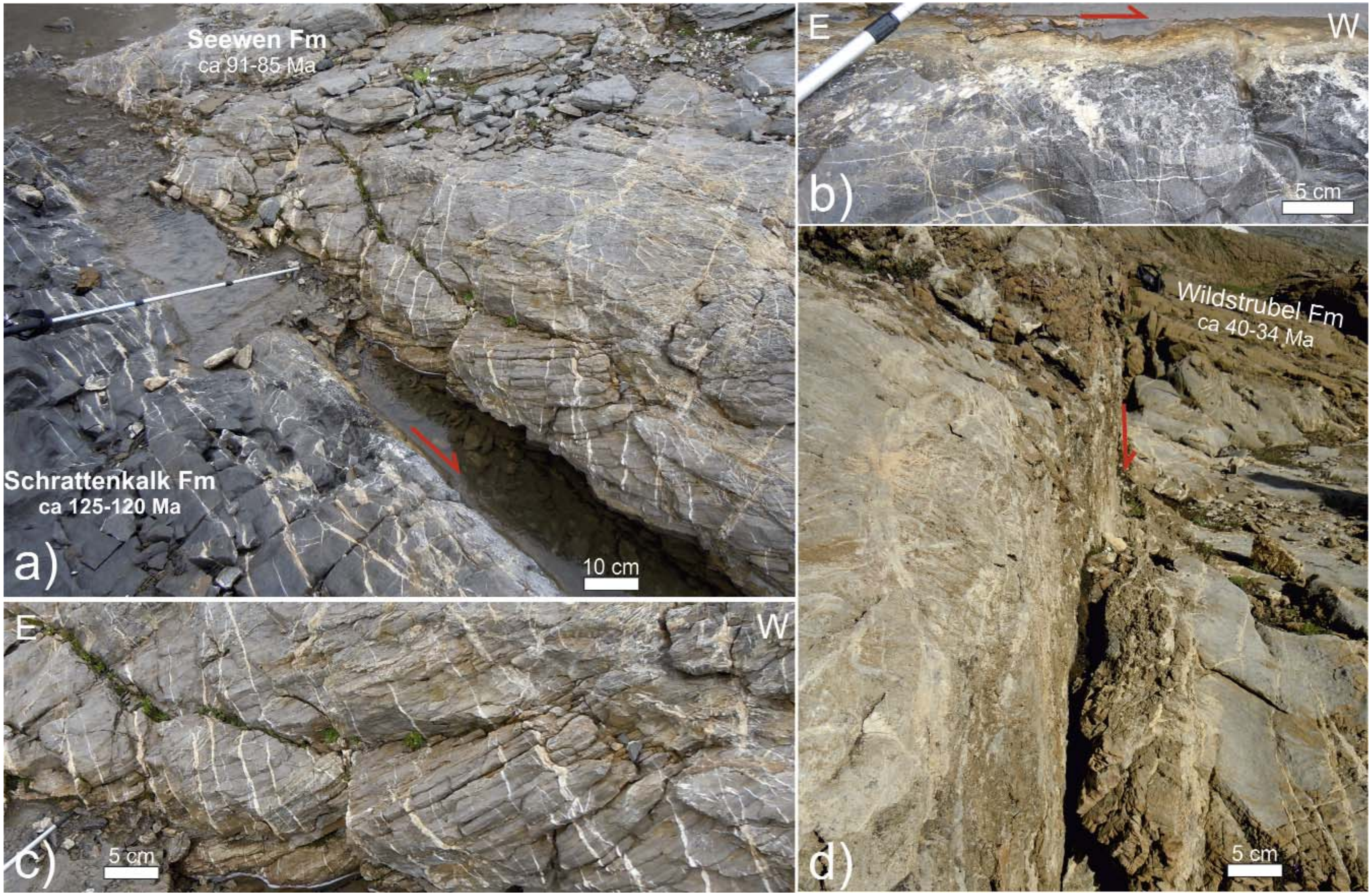

Fig. 12 - Examples of deformation associated with the Neogene faults. **a)** Sex Rouge eastern plateau, 2619 meters. Fault plane dips 172-63, slickenlines 240-05; **b)** Detail of Schrattenkalk fm, with recrystallized and sheared cataclasite; **c)** Foliation related to the fault develops in the Seewen Fm wheareas the Schrattenkalk fm is affected by sheared veins and new calcite mineralization on the fault planes and finally by late fractures; **d)** Throughgoing fault and associated deformation within the Nummulitenkalk and the Wildstrubel Fm.

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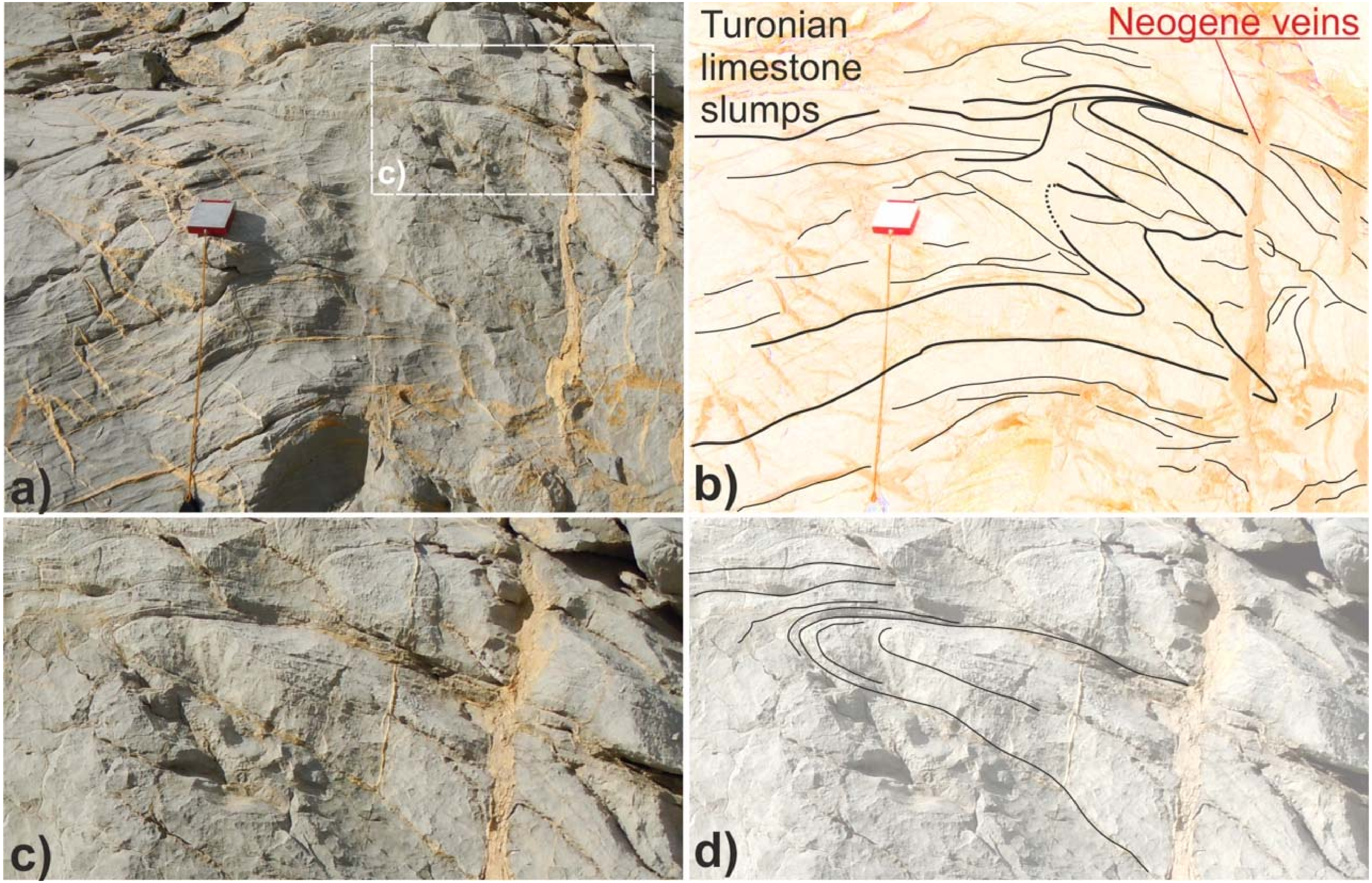

Fig. 13 - **a-b)** Slump deposits that are later cross-cut by Neogene veins (orange) and bedding-parallel pressure solution planes due to compaction. Black lines mark bedding and pressure solution planes. **c-d)** Close-up of tight fold produced after soft-sediment deformation.

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STOP 8 - (46°20'5.15"N/7°21'37.03"E) a panoramic view of the syn-sedimentary structures

At this Stop there is the limit between the palaeo-fault and -escarpment related to the Eaux Froides syn-sedimentary fault, which accommodates nearly 0.5 km displacement and is determined clearly in the stratigraphic record Fig. 14.

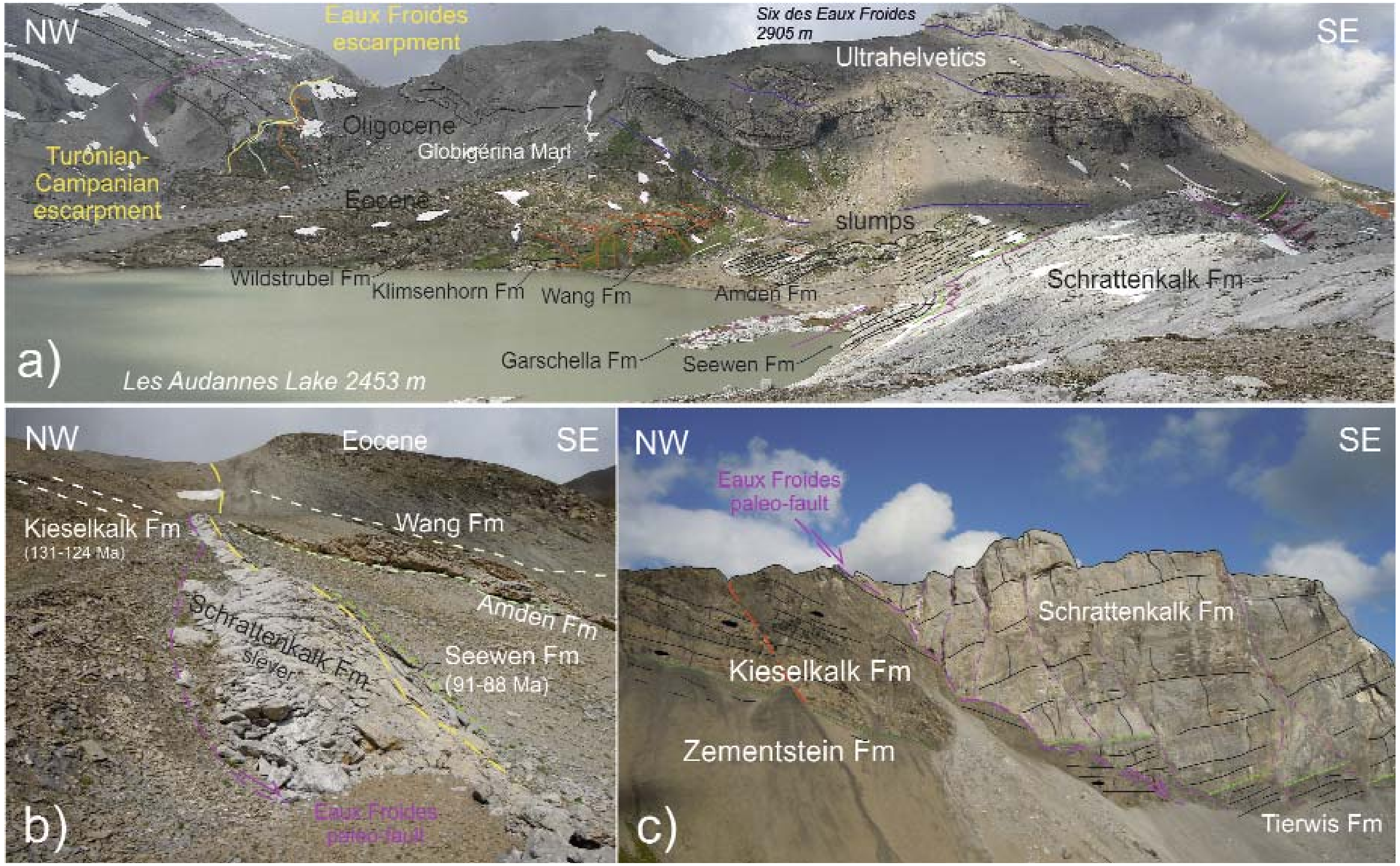

Fig. 14 - **a)** Eaux Froides palaeofault structure with related palaeo-escarpment (Cardello and Mancktelow 2014). **b)** Slice of Schrattenkalk preserved in the footwall of the fault. A thin veneer of Seewen Fm onlaps and subsequently covers this slice, which is then onlapped by the Amden Fm and the rest of the Tertiary succession. **c)** Fault geometry in the westernmost outcrops shows that the original structure is wavy and probably modified by later deformation.

STOP 9 - (46°20'20.50"N/7°22'25.35"E) Neogene vein sets

On the way to the hut, en-echelon veins occur associated with faults, with theirnumber and arrangement depending on the lithology in which they are developed. Within Tertiary sandstones, kink bands can be observed. At about 17h, you should arrive at the Cabannes des Audannes (46°20'36.25"N/7°23'2.74"E, height 2500 m).

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Second day: a closer look at the Cretaceous syn-sedimentary fault system

The total path length of this second day is some 7.5 km. Height difference is about 900 m downhill but with some up and down along the path, whose difficulty is medium. Some minor and quite easy out-of-path views are planned on the calcareous plateau southeast of the hut. The highest point is 2665 m. We suggest you to leave from Les Audannes hut (circa 2500 m) at 8:30 in the direction of the palaeo-escarpment, marked by the yellow dotted line in Figure 12.

STOP 10 - (46°20′57.51″N/7°23′11.25″E) the escarpment; a stratigraphic contact

At this Stop, syn-sedimentary breccia covered by a veneer of Seewen Fm and later onlapped by the Late Cretaceous to Tertiary sequence can be observed (Fig. 15).

STOP 11 - (46°21′5.56″N/7°23′15.65″E) palaeo-escarpment culmination

Palaeo-escarpment at the 2665 m culmination and a panoramic view over the Rawil pass region and the Tseuzier Lake, where the Neogene nappe-related structures are evident (Fig. 16). After this point, the way downhill to the bus stop will mostly be along the Cretaceous structures.

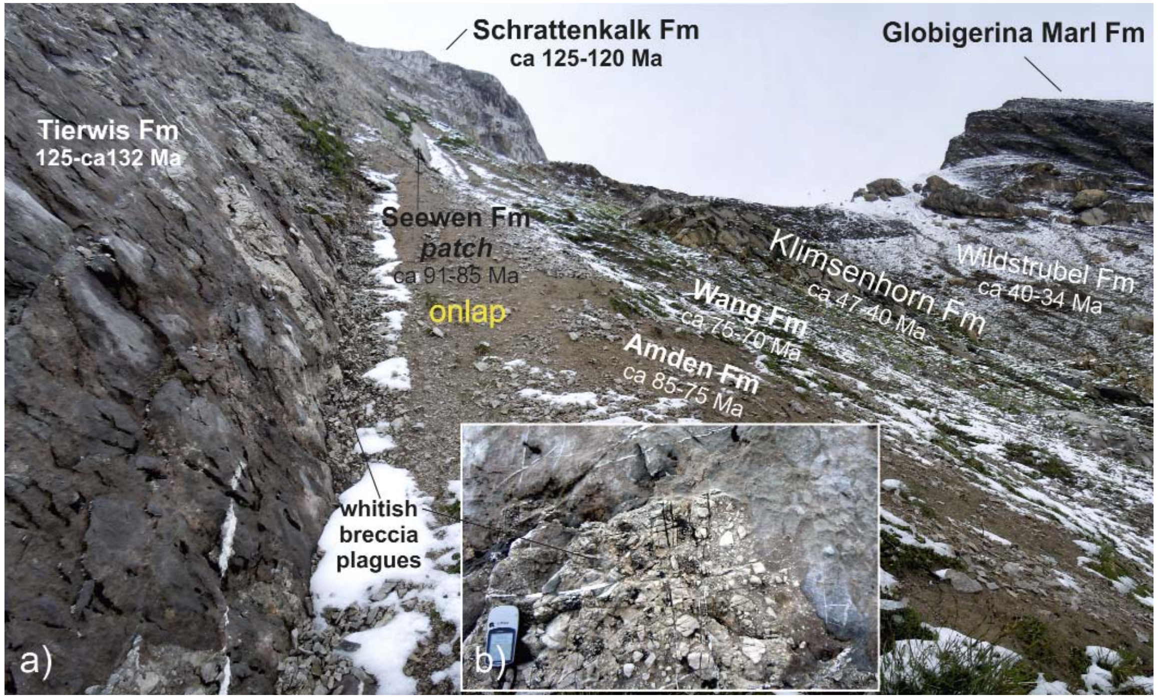

Fig. 15 - **a)** Detail of escarpment at Col des Eaux Froides looking to the NE. Two generations of breccia are at the contact between the Lower Cretaceous series in the footwall (left) and the Upper Cretaceous – Tertiary sequence in the hanging wall (right). A thin level of pelagic limestones (Seewen Fm) discontinuously covers the escarpment, which is later onlapped by the Amden, Wang, and the Tertiary Klimsenhorn, Wildstrubel and Globigerina Marl Fms. **b)** Detail of whitish syn-sedimentary Albian breccia.

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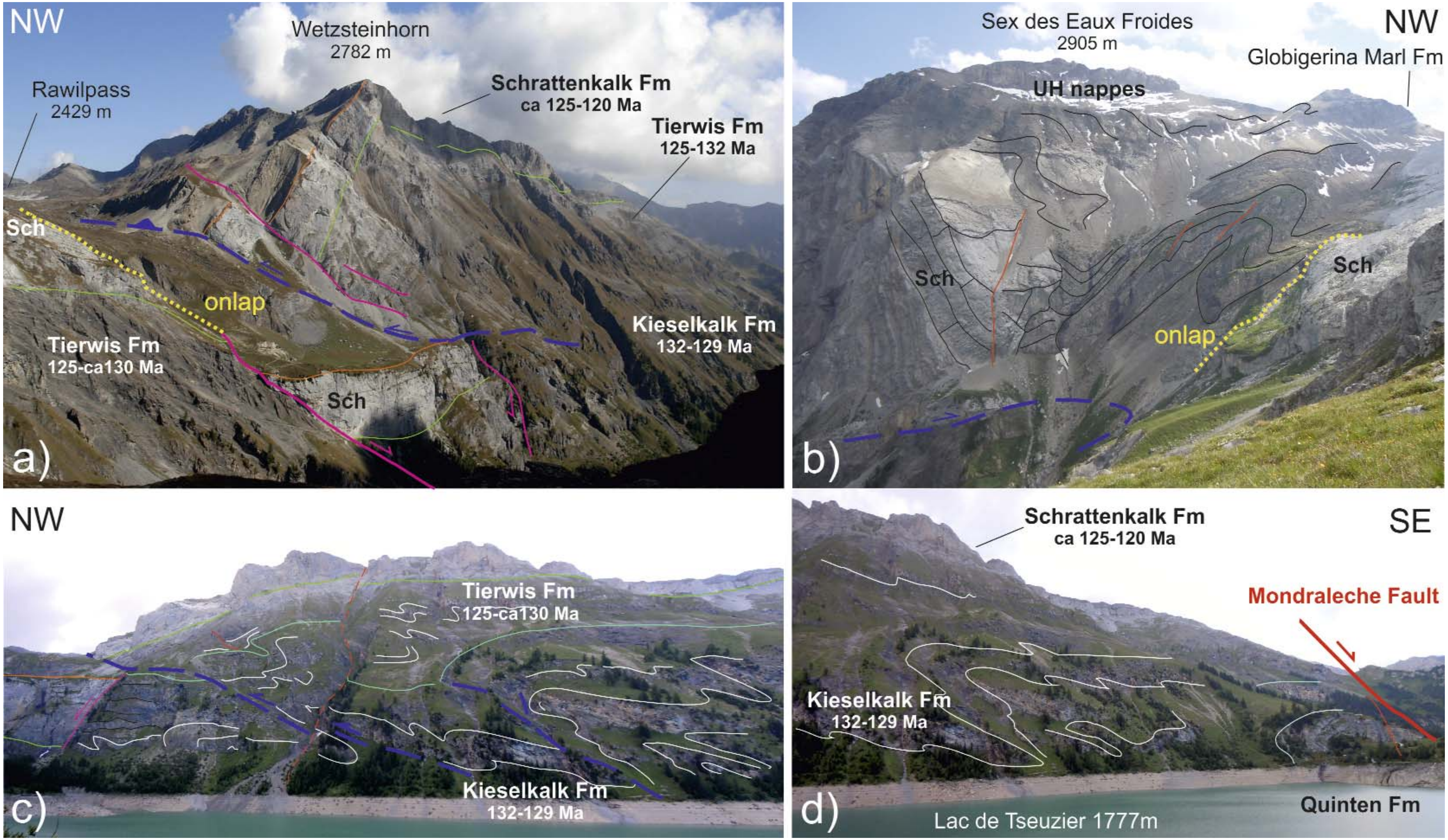

Fig. 16 - Panoramic view of the Tseuzier Lake and valley. **a)** Thrusts crosscut the inherited Cretaceous structures (i.e., graben in the hanging wall of the main palaeofault (in violet)). During folding these structures **b)** were buttressed against the palaeo-escarpment (dotted yellow line). **c, d)** top-to-the-NW nappe-emplacement related folds and thrusts within the Kieselkalk Fm later crosscut by late normal faults (red lines; e.g., Mondraleche fault), which dip to the SSE.

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Fig. 17 - Detail of Col des Eaux Froides and its palaeo-escarpment. Picture is taken from the opposite side of the valley looking to the SW. This erosive surface is defined by promontories and embayments that shape the Schrattenkalk fm (on the right), which is later onlapped by the Upper Cretaceous and Tertiary succession.

STOP 12 - (46°20'48.84"N/7°23'24.04"E) palaeo-escarpment and buttressing

Similarly to what is shown in Fig 14b, the interference between the inherited Cretaceous structures and the nappe geometries is evident. At this Stop, we are right in the syncline in the hanging wall of the Eaux Froides palaeofault. Both the Wildhorn and the Ultrahelvetic nappes are folded together against the palaeo-escarpment, generating a buttressing structure (Figs. 14, 16, 17). This is further evidence that these palaeofaults preceded nappe formation.

STOP 13 - (46°20'41.86"N/7°23'27.97"E) slumps

A further Stop in the late Cretaceous slumps on the eastern shore of the Audannes Lake (Fig. 18).

STOP 14 - (46°20'37.64"N/7°23'56.62"E) a way-back trip through the Cretaceous series

A domino-like structure occurs dissecting the Lower Cretaceous series (Fig. 19). Schrattenkalk fm beds are covered by a reduced and discontinuous stratigraphic series, whose thickness and facies changes according to the small- to moderate-scale faults. Similarly to what was observed the day before, the top of the Schrattenkalk fm is affected by silica and Fe-rich encrustations at the top of the Lower Cretaceous series.

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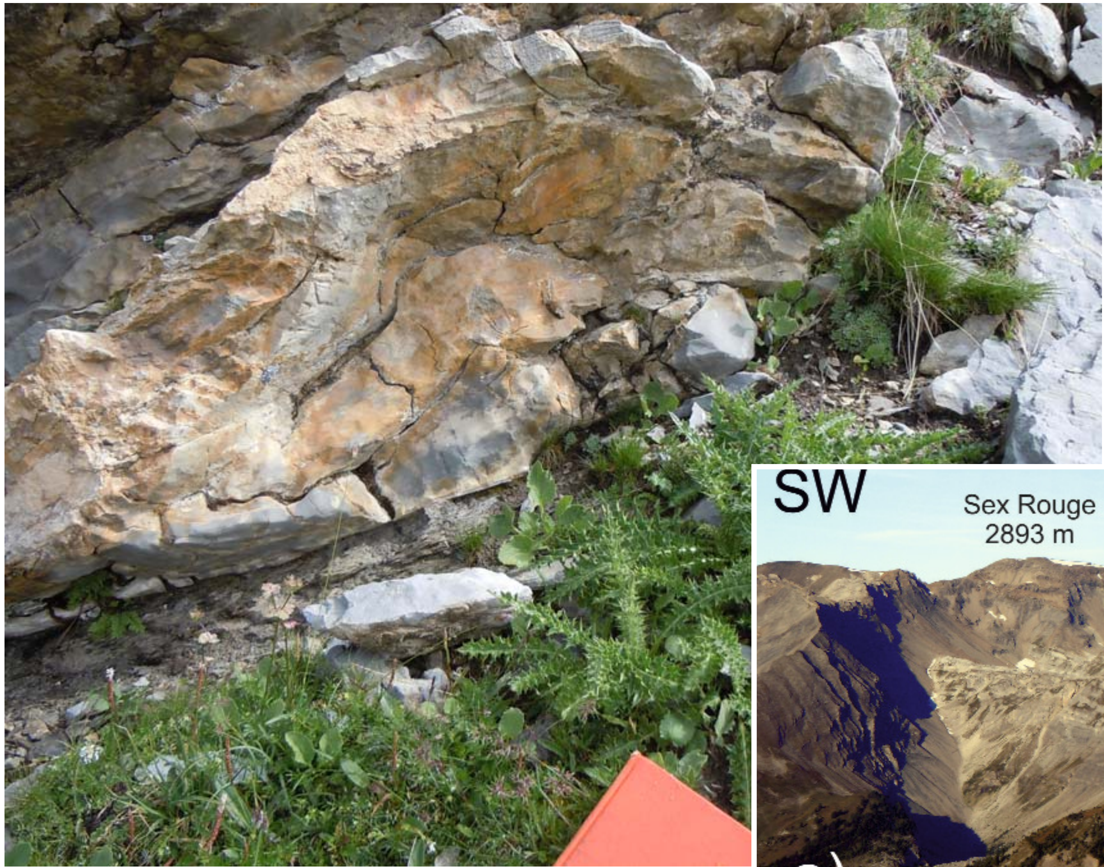

Fig. 18 - Detail of slump in the re-sedimented Seewen Fm type deposits within the Amden Fm. Gravity related gliding of these pelagic limestone was probably triggered by instability related to excessive steepness of the palaeo-escarpments.

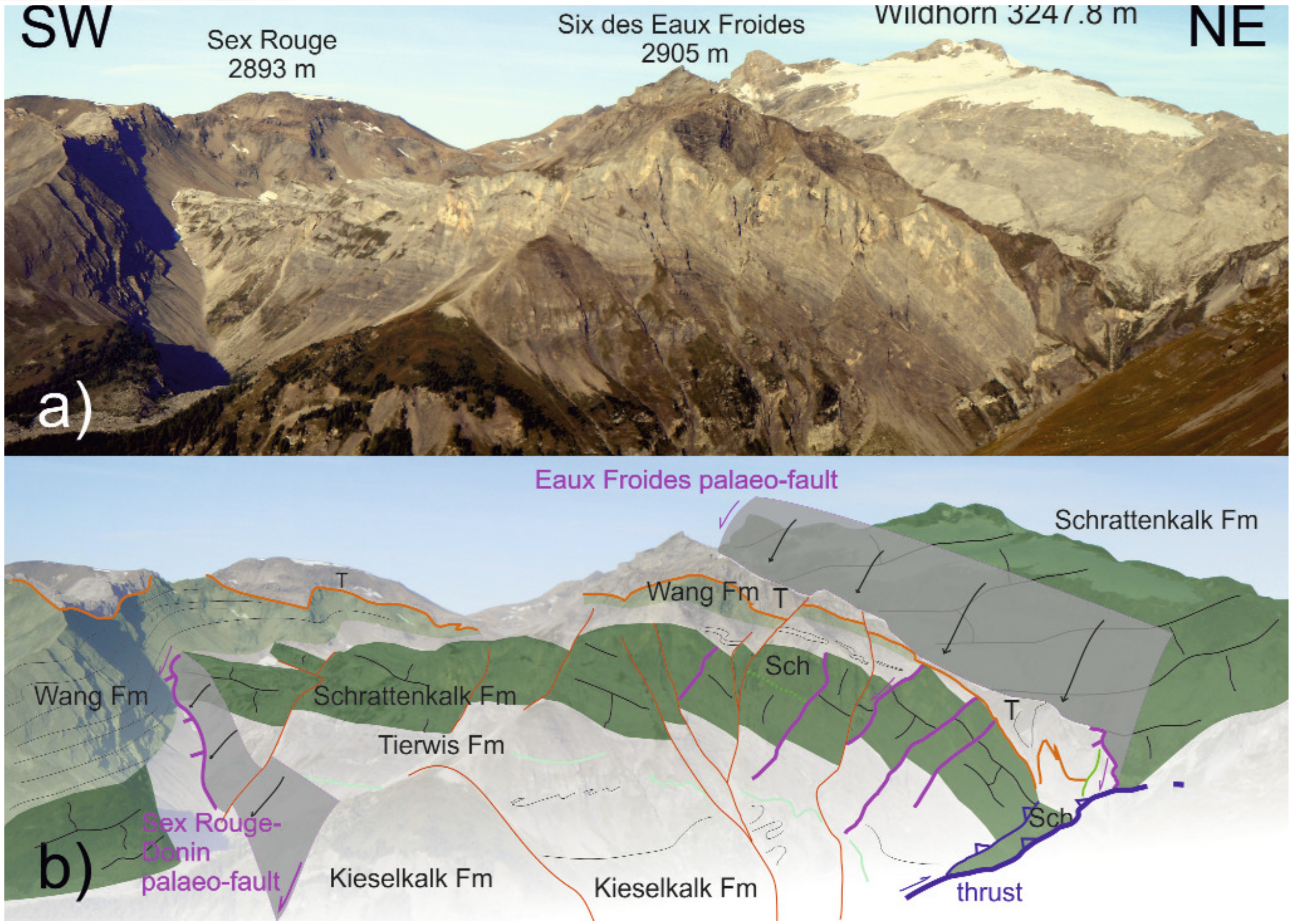

Fig. 19 - (modified from Cardello & Mancktelow, 2014). The Cretaceous succession between the two major palaeofaults is formed by a rollover anticline, broken by a syn-sedimentary domino-like structure, later crosscut by the thrust trajectories. Red thin lines are late Neogene faults.

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STOP 15 - (46°20’7.12”N/7°23’7.79”E) palaeo-geographic Maastrichtian evidences

A close look at a step of the Sex Rouges-Donin palaeofault that was completely sealed during the sedimentation of the Wang Fm in the early Maastrichtian (Fig. 20).

After this Stop, the bus stop can be reached to take the way back to Sion (Fig. 1, Stop 16 - 46°19’57.31”N/7°26’14.63”E).

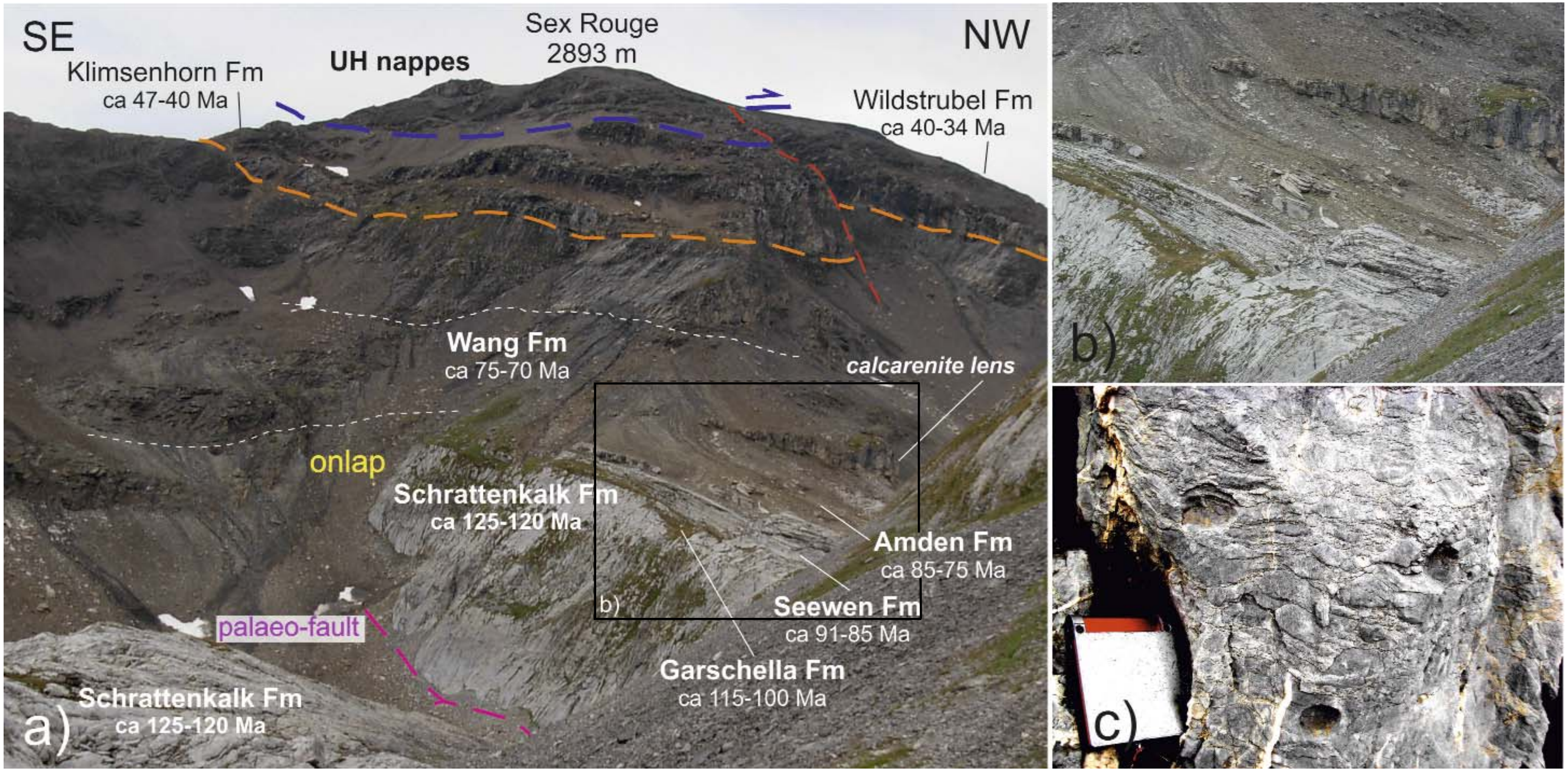

Fig. 20 - **a)** Moderate scale paleofault sealed during the late Cretaceous. **b)** Detail of the Upper Cretaceous succession. Away from the edge of the normal fault, re-sediments are thicker and lenses of calcarenites occur. **c)** A patch of pebbly mudstone of Seewen Fm type limestone along the palaeo-escarpment surface.

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The Wildhorn Nappe structure from Cretaceous to Neogene time

8th – 9th August 2015
summer excursion organized by
Giovanni Luca Cardello & Neil Mancktelow

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