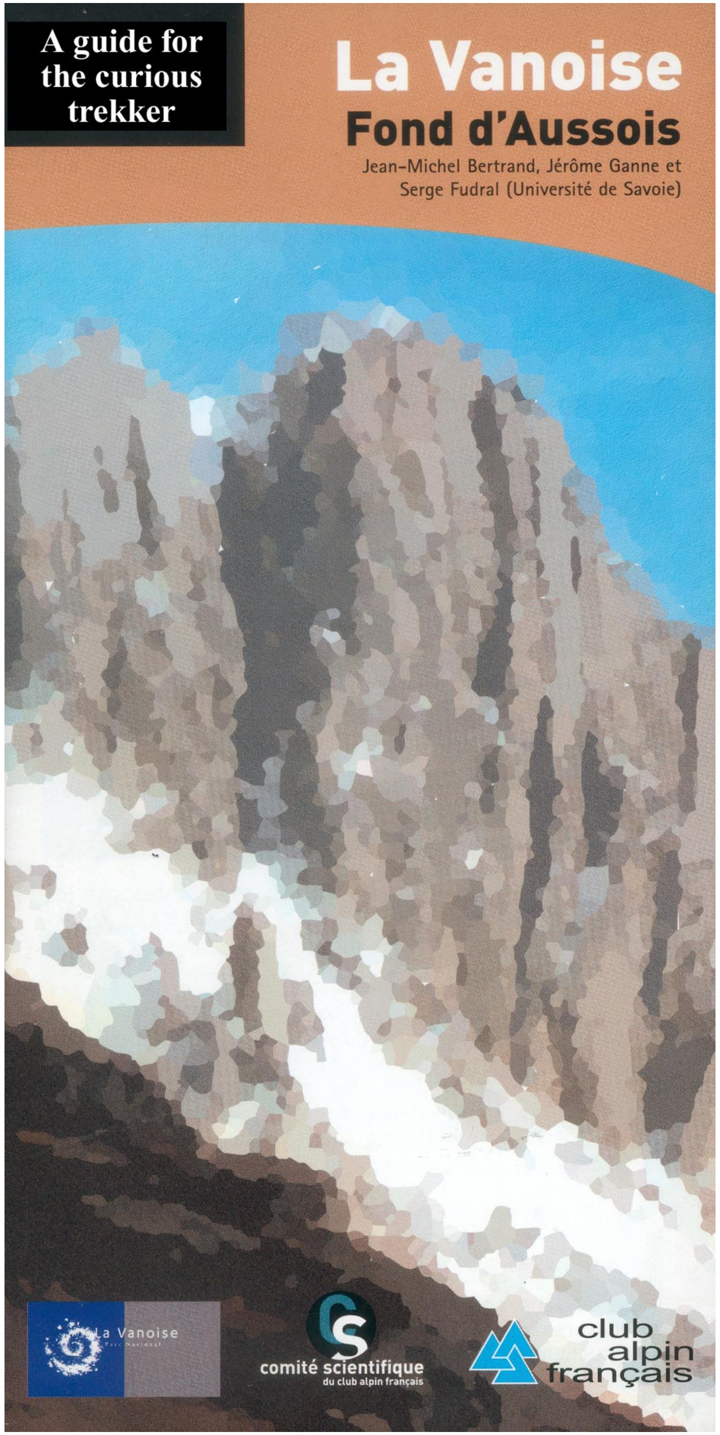


To walk in mountains and to be able to «read» the landscape is enjoying. When knowing some clues, it is easy to discover what are the successive stages of the dramatic geological changes that allowed the Alps to exist.

To know more ......

* ***Debelmas J. & Rampnoux J.P. (1994):*** Guide géologique du Parc National de la Vanoise, itinéraires de découverte. Editions du BRGM.

* ***Debelmas J. & Desmons J. (1997):*** Géologie de la Vanoise. Documents BRGM 266.

* ***Lemoine M., Barféty J.C., Cirio R. & Tricart P. (2000):*** De l'océan à la chaîne de montagne. Tectonique des plaques dans les Alpes. Gordon & Breach Science Publishers.

* ***Marthaler M. (2001):*** Le Cervin est il africain? Une histoire géologique entre les Alpes et notre planète. Editions Loisirs et Pédagogie, Lausanne.

****Mattauer M. (2001):*** Ce que disent les pierres. Bibliothèque «Pour la Science».

Translated from a booklet published jointly by the Club Alpin Français and the Parc National de la Vanoise (2003)

club alpin français

Fédération des clubs alpins français
24, avenue de Laumière - 75019 Paris - Tel: (33) 1 53 72 87 13
e-mail: editions.com@clubalpin.com

Geology of Vanoise

From sample to outcrop and lansdcape scale, we will try to understand the large scale geometrical organisation of rock masses in the Fond d'Aussois area when walking along G.R. paths across the large glacial cirque.

Preliminary remarks:

- All the rocks from Vanoise have suffered intense **deformation (1)** and **metamorphism (2)** that are responsible for their foliated appearance.

- The chronological scale of the past geological times (given in Ma = million years), as evidenced in the Fond d'Aussois rocks, is as following:

1. The Paleozoic Era (542-251 Ma) is represented by **micaschists (3)** of the pre-Alpine **basement (4)**, about 500 Ma old, and by the Permian (299-251 Ma) conglomerates (5);
2. During the Mesozoic Era (251-65 Ma) sediments were deposited. They are from bottom to top: (a) white and pale green quartzites (6), limestones, dolomites and gypsum of the Triassic (251-199 Ma); (b) banded limestone of the Lower Jurassic (=Liassic: 199-175 Ma); black and green marbles of Middle to Upper Jurassic (Dogger and Malm: 175-145 Ma) and from Cretaceous to Lower Tertiary (145-45 Ma).
3. There is almost no rocks deposited during the Cenozoic Era (Tertiary= 65-1.80 Ma) in the Aussois region. It is the time when the Alps were formed.
4. The huge Quaternary glaciers and indlandsis (from1.65 Ma) are responsible for the landscape that we observe today and especially the old moraines and the shape of the Aussois cirque ??.

Dent Parrachée and Grand Chatelard

(1) deformation = fracturing, breaking, folding, stretching or flattening (schistosity) of the rocks at all scales. When several deformation episodes affected a rock unit, they are chronologically numbered: Fold F1, F2....., Schistosity S1, S2........
(2) metamorphism = increasing temperature and pressure during the burial of sediments lead to the appearence of new minerals by solid-state re-crystallization of the pre-existing minerals and to their foliated organisation (= schistosity and foliation).
(3) micaschist = a foliated mica-rich metamorphic rock.
(4) basement = remnants of an ancient eroded mountain belt on top of which new sediments were deposited. The basement of the Alps is a 300 Ma-old mountain belt, the Hercynian (or Variscan) belt.
(5) conglomerate = a sedimentary rocks constituted by rounded pebbles of all sizes in a matrix of sandstone or grit.
(6) quartzite = a re-crystallized sedimentary rock constituted almost exclusively by quartz.

Following the paths....

1. From Plan d'Amont lake to Fond d'Aussois refuge.

From the parking area to the refuge (and above toward the Aussois Pass), we will walk on **basement (4)** rocks well exposed along the path above the dam before arriving at the Sétéria bridge.

Rocks are green and grey **micaschists (3)** with numerous quartz veins. The alternation of the two rock types is the result of large scale folds with parallel flanks **(F1 folds)** indicated on the map but impossible to observe in the landscape.

Figure 1 - F2 fold that refolds the main S1 schistosity in the SW cliff of Roche Chevrière.

The main schistosity **(S1)** is outlined by tiny micas and was formed at the same time than the folds. This first schistosity was folded again by more open folds (F2 folds) that may be observed in some cliffs **(figure 1)**. F2 folds may be associated with a near-horizontal **S2** schistosity.

Observing the Dent Parrachée panorama from the path along the dam **(figure 2)**, we will try to understand the large scale geometry of the massif. The left side of the panorama shows the basement (Am = green micaschists; Cl = grey micaschists). On the right the green mica-bearing quartzites of **Permo-Triassic (7)** (PTr = ca. 250 Ma and the white quartzites of the Lower Triassic (Tq, about 240 Ma) forms also the Grand Chatelard buttress. Here the Permo-Triassic and Triassic sedimentary rocks were deposited directly upon the basement **(normal contact - see 8).**

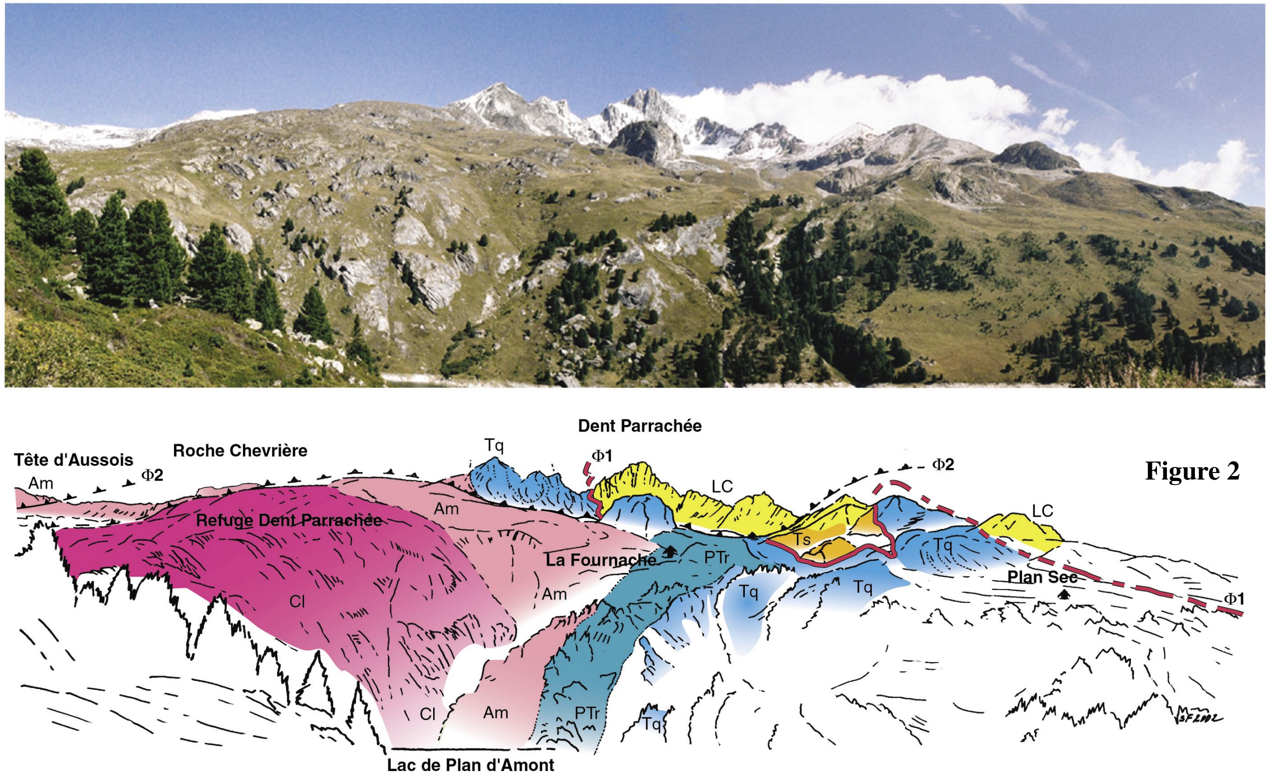


Figure 2

In the background, in between the Dent Parrachée and the Faculta passes, the geometry is less simple. Dolomites and limestones from the Upper Triassic (Ts), Liassic (LC) and Cretaceous do not lie «normally» above the underlying rock units. They form a **nappe (8)** the contact of which (called **ϕ1**), probably near horizontal when formed, is now folded by a F2 fold. Everything was subsequently displaced along a large scale **shear zone (9)** **ϕ2**. All these structures are sketched on the map and cross-section **(figure 3)**.

(9) Permo-Triassic = close to the basement contact, the bottom of the sedimentary cover is constituted by impure green quartzites containing numerous micas and small pebbles of pink quartz. The age of this formation is intermediate between Permian and Triassic and, in the Pointe de l'Echelle ridge, similar rocks are intercalated between Permian conglomerates and Triassic white quartzites.

(10) nappe = a complex mass of rocks that has been displaced and lies now upon an other rock mass from which it was initially far away. The bottom of a nappe constitutes what is called an **abnormal or tectonic contact** (quoted $\phi 1$, $\phi 2$ ....with respect to their relative chronology). On the contrary, a **normal contact** respects the normal chronology of the geological succession.

(11) shear zone = a displacement plane located inside a rock mass or at the bottom of a nappe (= tectonic contact) and where the deformation is concentrated and all the rocks are sheared. When the deformation is very strong the rocks are transformed into **mylonites**, crushed and laminated rocks showing often brecciated textures (re-cemented broken pieces of rock)

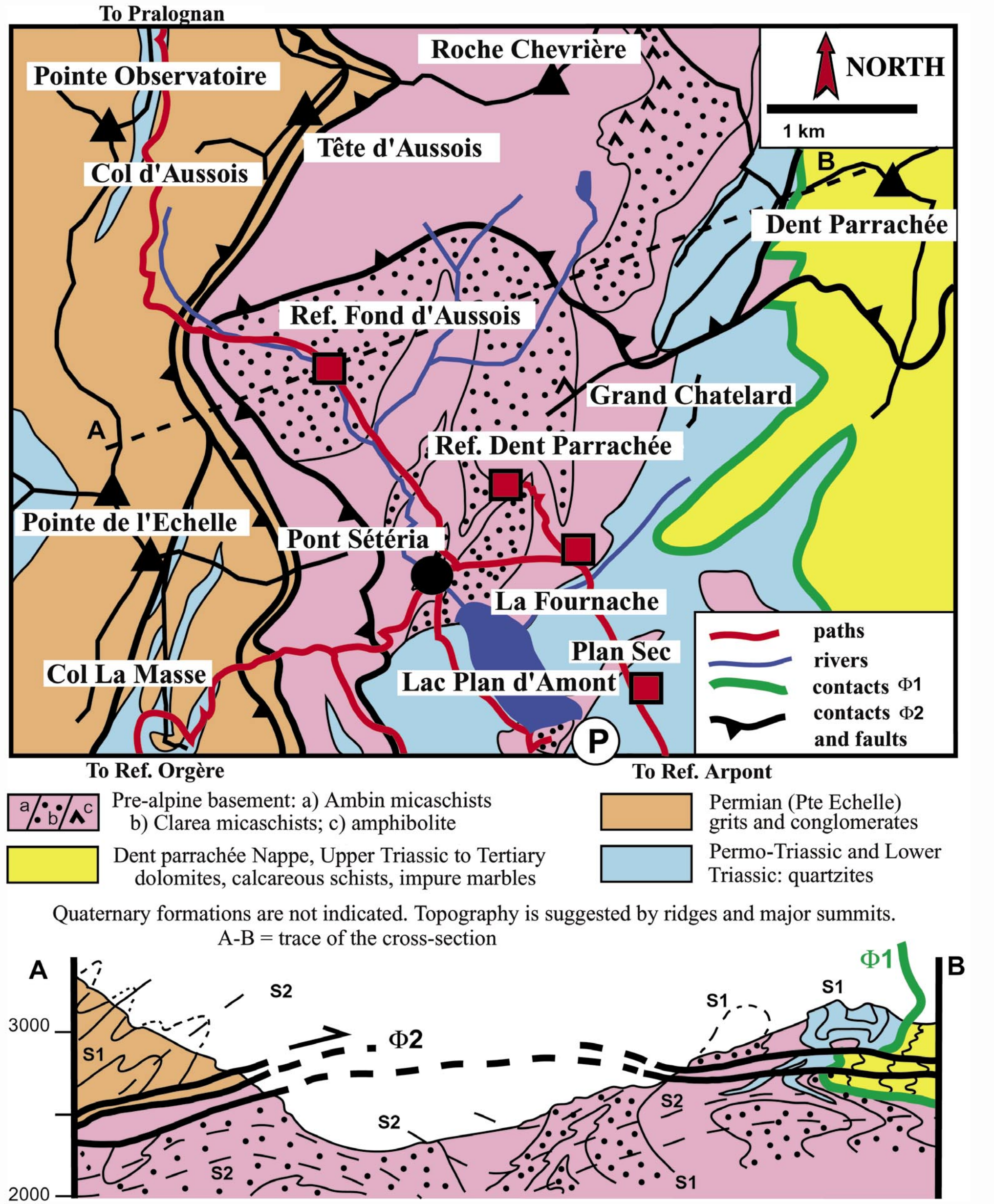


Figure 3

2. From Sétéria bridge to the Col de la Masse

Figure 4 - Green micaschists with quartz veins, observed south of the Col de la Masse path (2455 m). Shear planes are outlined with the corresponding movement direction (toward East).

Walking up toward the Col de la Masse, the basement's green micaschists are more and more deformed **(figure 4)**. Deformation is maximum when reaching two major **tectonic contacts** located near the base of the Pointe de l'Echelle upper cliff. The lowermost contact is the same that was indicated on the other side of the valley, below the Dent Parrachée **(see geological sketch -figure 3 - and figure 5)**: It is thus a $\phi 2$ contact that cross-cut older structures. The upper tectonic contact is similar and may be followed far to the North in the Pralognan region. Even if formed simultaneously, the two contacts are not equivalent: displacement along the lower contact may be estimated precisely (about 200 m toward East) whereas the upper contact is a major contact at the scale of the Vanoise massif with a very large displacement (probably several km). These tectonic contacts were formed 45-30 Ma ago.

Above the upper $\phi 2$ contact, Permian sandstones, grits and conglomerates outcrop in steep cliffs. They are less deformed than the underlying micaschists and their original sedimentary features are often well-preserved. During the alpine deformation, sandstones, quartz-rich grits and conglomerates behaved more rigidly than the basement micaschists.

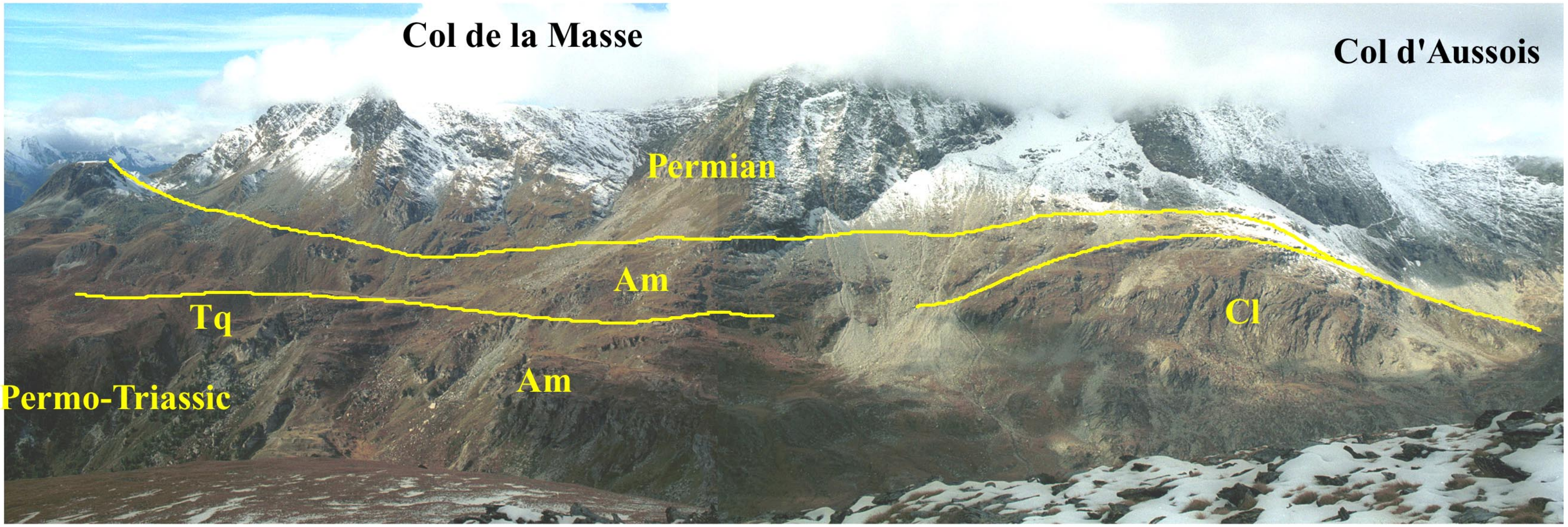


Figure 5 - Panorama of the Pointe de l'Echelle ridge (view from the refuge Dent Parrachée). (1) Permian sandstones, grits and conglomerates outcrop in the snow-covered area; (2) the shelf at medium height corresponds to the $\phi 2$ tectonic contacts; (3) the basement (Am and Cl) outcrops at the bottom, together with Triassic quartzites (Tq). Below the $\phi 2$ tectonic contact, the S1 schistosity of the basement is very steep **(see also figure 6)**.

3. On the path between the Fond d'Aussois refuge and Col d'Aussois.

Basement micaschists outcrop close to the Fond d'Aussois refuge and may be seen up to 2430 m on the path leading to the Col d'Aussois. At this place **mylonites (see 11)** outline the two ϕ2 tectonic contacts that are here coalescent. Below the mylonites, the **S1** schistosity in the grey micaschists (basement) is rotated to the vertical **(figure 6)** whilst the contact itself is almost flat-lying. Toward Col d'Aussois, the path climbs in alternating Permian grits and conglomerates where sedimentary features are often preserved **(figure 7)**.

Figure 6 - Vertical S1 schistosity of the grey micaschists located below the main ϕ2 tectonic contact (alt: 2430 m)

Figure 7 - Permian conglomerates above the same contact (alt 2430 m). Small stream on the right of the Col d'Aussois path.

4. On the path between Fond d'Aussois refuge and Dent Parrachée refuge.

On the way to the Dent Parrachée refuge the contact between the grey (Cl) and green (Am) micaschists of the basement is well exposed at about 2480 m - 100 m on the left of the path, at the bottom of the discontinuous cliff **(figure 8)**. Grey micaschists and green micaschists (S1 schistosity) are deformed together by **F2 folds**. **S2** schistosity is best developed in green micaschists. The refuge itself is built on a beautiful outcrop of grey micashists.

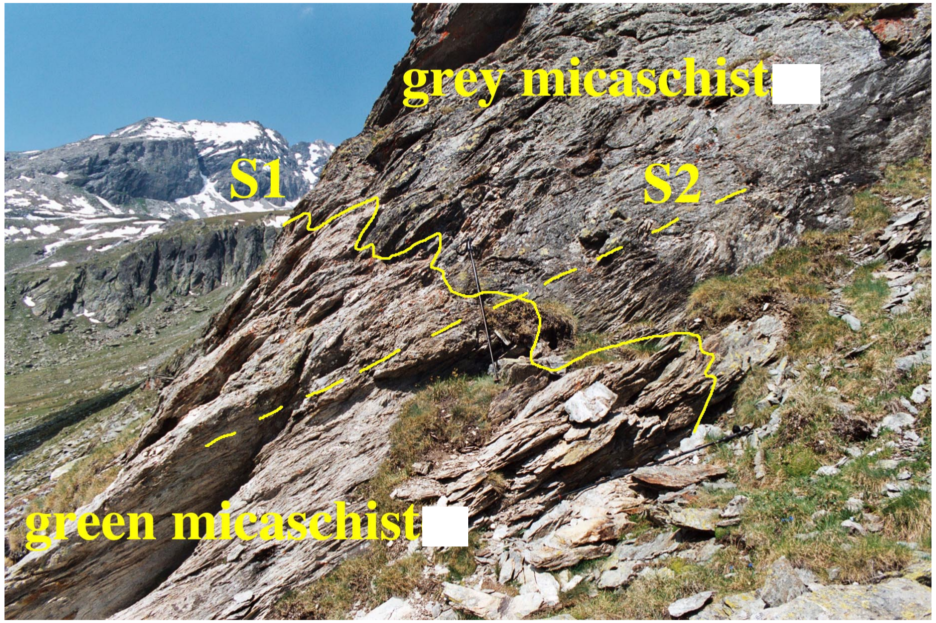


Figure 8 - Folded (F) contact between grey micaschists (Cl) and green micaschists (Am).

(11) shear zone = a displacement plane located inside a rock mass or at the bottom of a nappe (= tectonic contact) and where the deformation is concentrated and all the rocks are sheared. When the deformation is very strong the rocks are transformed into **mylonites**, crushed and laminated rocks showing re-cemented broken pieces of rock.

5. Above the Dent Parrachée refuge, toward the Fournache comb and the Col de la Dent Parrachée.

When leaving the refuge we will find, above the basement micaschists, Triassic quartzites that form the Grand Chatelard and the Esché ridge. The comb located in between Grand Chatelard and the ridge corresponds to the ϕ2 tectonic contact quoted on **figure 2**. In the gully below the Col de la Dent Parrachée, the observed tectonic contact, outlined by «cargneules» is the main ϕ1 contact at the bottom of the Dent Parrachée nappe, here vertical because it was refolded by large F2 folds **(figure 9)**. Close to the «Col», this contact separates Triassic quartzites (NW of the pass) from the Liassic banded limestones that form the bulk of the Dent Parrachée nappe (SW of the pass). In the pass' gully, the yellow rocks are cargneules, a mixture of gypsum and dolomites with an alveolar texture, that outline the tectonic contact.

Figure 9 - Col de la Dent Parrachée: yellow «cargneules» outline the ϕ1 tectonic contact between the Triassic cover and the Dent Parrachée nappe.

How geologists interpret field observations

What we observe in Vanoise is the result of the convergence and collision of two plates. A reminder of basic knowledge:

Our **planet EARTH** owns a thin and rigid envelope called **«lithosphere»** that forms less than 2% of the earth's radius. From surface to depth, the lithosphere comprises a light **«crust»** with an average density of 2.7 and the upper part of the heavy **«mantle»** with an average density of 3.2. Lithosphere has a fragile behaviour and may break easily into **«plates»** that are moving back and forth according to time. The Earth evolution consists in four stages that are operating periodically through time, with some variance, since the 4.5 Ga of the Earth's life:

1 - Where the plates are moving apart - across **«oceanic ridges»** - juvenile oceanic crust, thinner and heavier that the continental crust, is continuously generated, directly from melting of the underlying mantle.

2 - As the Earth'volume is proved to be constant, the above growth zones should be compensated somewhere else by convergent zones where a part of the oceanic crust disapears. Thus, the opening of the Atlantic ocean since Jurassic (199 Ma) was compensated by the closure of the ancient alpine ocean. Such disapearance occurs in the oceanic trough where, due to the «**subduction»**, a plate may plunge under its neighbour. In these places a dense oceanic lithosphere is going down, beneath another less dense plate that may be either oceanic or continental.

3 - When the whole of oceanic lithosphere is consumed by subduction two continental plates may collide. If **«collision»** is going on further, a part of a continental lithosphere may be also subducted.

4 - Such a situation is highly unstable because of gravity differences and leads rapidly to the upwelling - also called **«exhumation»** of a part of the content of the subduction zone - oceanic crust + deep sea sediments + pieces of dragged continental crust. It is in that case that a **«collisional mountain belt»** like the Alps is formed.

In the Alps, the corresponding chronology is as follows:

1 - At about 200 million years, the **alpine ocean** opens after the breaking apart of a huge continental plate grouping, at that time, Europe and Africa.

2 - At about 90 Ma, the alpine ocean is **subducted** beneath the African continent.

3 - **Collision** between the two continents starts at about 45 Ma and a part of Europe is plunging beneath Africa (now resting deep below the Po plain).

4 - **Exhumation** of the Internal part of the Alps (including Vanoise) occurs shortly - at last at 32 Ma. By contrast, in the westernmost part of the Alps, consequences of the collision and exhumation occur later, starting at about 25 Ma, and leading to a westward and upward extrusion of the External Crystallines (Mont Blanc and Belledonne massifs - a genuine part of continental Europe that was never subducted) and to the folding of the Subalpine massifs (Bauges, Charteuse, Vercors.....).

Our history is not completed: active seismic areas and continuous uplift of the External Crystallines (nowadays about 2 mm/year) are still related to the building of the Alpine mountain belt.

ALPS are still ALIVE

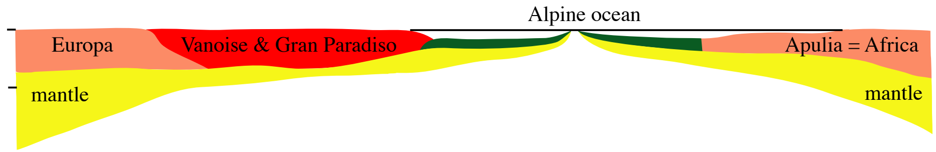
What happened in Vanoise?

Vanoise is part of the Internal Alps, initially located close to the plate boundaries. The stratigraphy registered in Vanoise (age and types of Mesozoic sediments not detailed here) indicates that it represented either the western edge of the lost alpine ocean or an independant micro-continent initially located in between Europe and Africa. The setting of the ancient Vanoise may be compared with the today setting of Corsica and Sardinia that are both bounded on each side by oceanic crust.

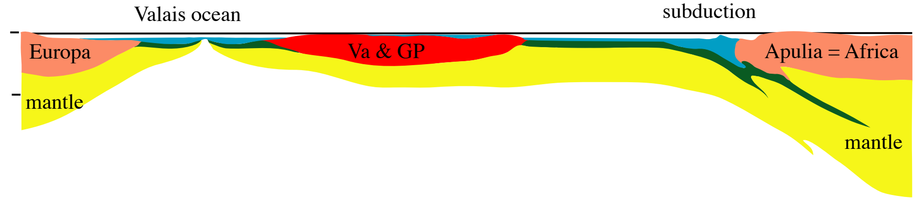
Before the Vanoise rocks being exposed at the earth's surface, they have been deeply buried in the subduction zone (down to more than 50 km) where they were submitted to a peculiar type of metamorphism characterised by minerals stable at high pressure and low temperature.

To conclude, the sketches of figure 10 are designed to visualise the journey toward the deeps and the coming back to Earth surface of a small piece of continental crust that corresponds to our Vanoise.

1 - Jurassic, ca. 165 Ma -> Alpine ocean is opening (in green: oceanic crust).



2 - Cretaceous, ca. 110-100 Ma -> subduction of the Alpine ocean and opening of a (small) Valais ocean. Vanoise and Gran Paradiso are isolated as a micro-continent (in blue: oceanic and platform Mesozoic sediments.



3 - Eocene, between 54-36 Ma -> Vanoise and Gran Paradiso are dragged into the subduction zone (Alpine + Valaisan).

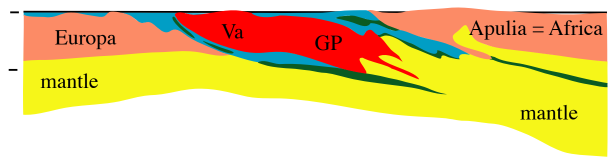
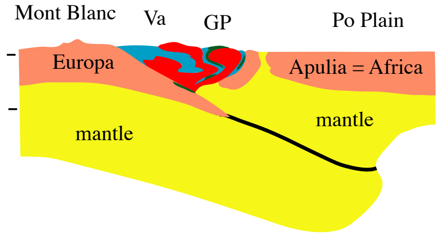


Figure 10

4 - Today, after exhumation initiated 35 Ma ago, convergence is still going on.



Sketches adapted from G. Stampfli, 1993

The genesis of the Alps is a long story. In Vanoise, everything was completed at about 35 Ma. This is not the case in the western part of the belt where Mont Blanc and Belledonne are exhumated only since 25 Ma .... and are still uplifting.