The deformation of the Plio-Quaternary alluvial deposits as a marker of the Digne Nappe activity

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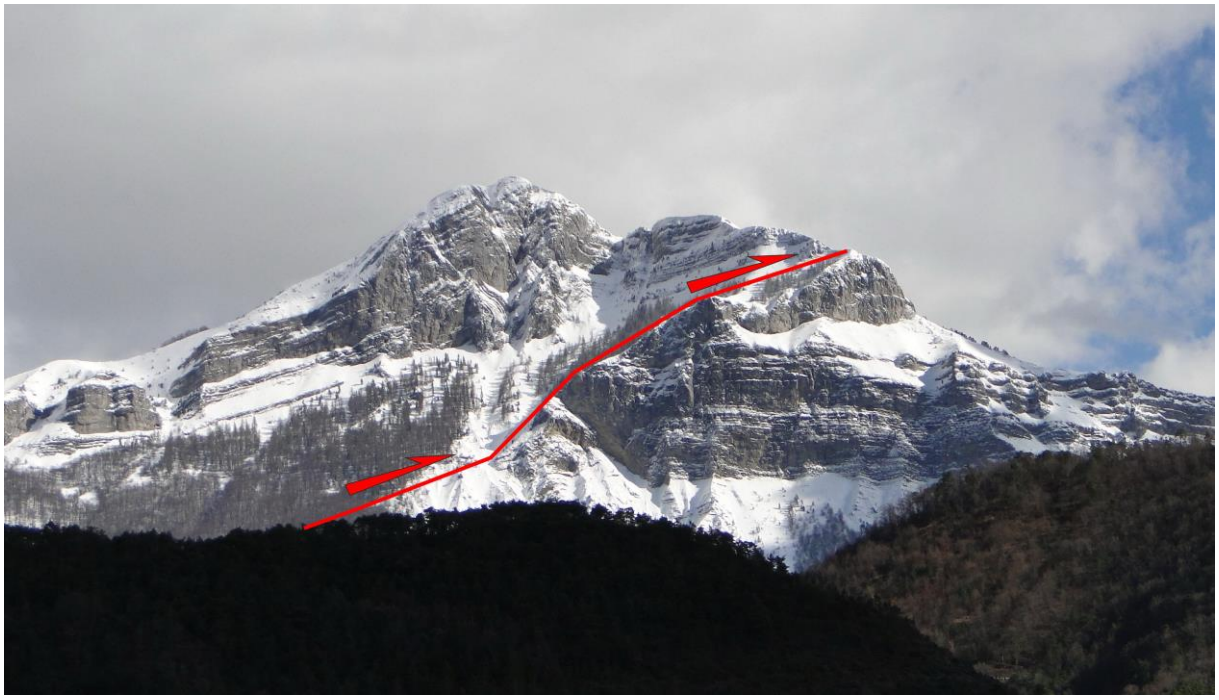


General presentation:

In low deformation rate areas the recognition of active deformation can be achieved by mapping old alluvial deposits. In the Southwestern Alps, the reconstruction of an ancient paleo-drainage network reveals the Quaternary slip of two fault strands on the hanging block of the Digne thrust nappe: the >20km-long Bès fault, the 9km-long St Benoît fault (Hippolyte et al., 2011; 2012).

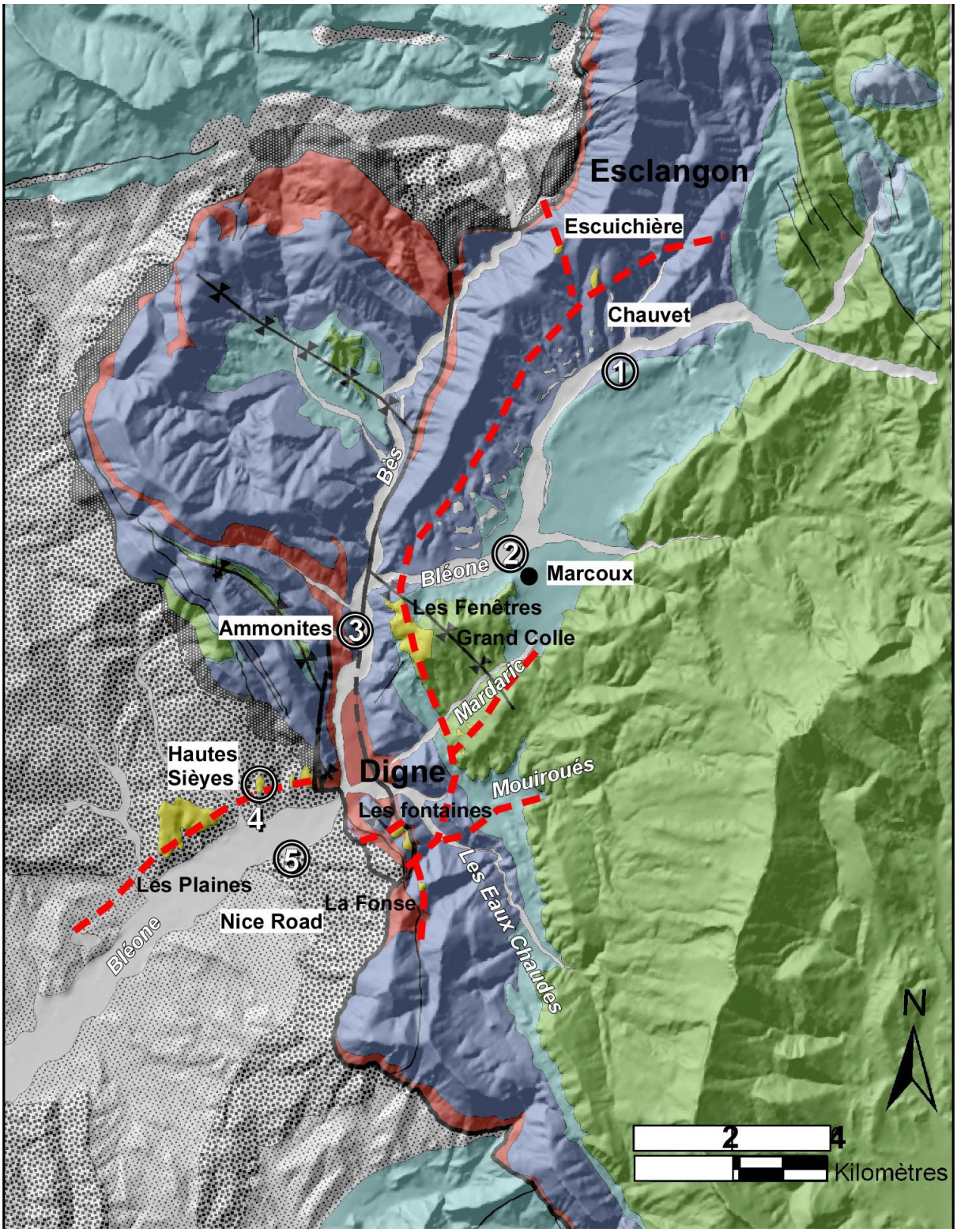
The Digne nappe, a thick Jurassic sedimentary sequence above a ductile decollement layer in the Triassic gypsum, is one of the most important thrust nappe in the external Alpine zones of France. At its front, Jorda et al. (1988; 1992) discovered striated pebbles and underthrusted alluvial deposits of supposed Early and Middle Pleistocene age. Clauzon (1999) proposed that these alluvial deposits are relicts of Pliocene formations infilling the Bléone Messinian canyon.

During the Messinian salinity crisis (5.9-5.3 Ma), the Mediterranean Sea underwent the strongest eustatic oscillation of his history (about 1500 m drop of sea level) that resulted in deep incision of the Mediterranean rivers including the Rhône and the Durance Rivers (Clauzon 1982; 1979; Clauzon et al., 1996). During the Early Pliocene (5.33 Ma), the Zanclean flooding of the Mediterranean sea also reached the canyons that were transformed into rias rapidly filled by marine sediments (Clauzon, 1979; 1982). In the Durance river, >145 m thick Pliocene sediments (89 m thick marine clays covered by 56 m thick alluvial deposit) infilling a paleo-canyon are known up to Mirabeau, 80 km downstream from Digne.

At Digne, the alluvial deposits infilling the paleo-valleys are presently 100 m thick at Rochassas, 90 m thick at La Bonnette, and might have been up to 200-300 m in the Grand Colle Mountain and ~126 m at l'Escuichière, which is compatible with the thickness of Pliocene-Early Quaternary conglomerate in the Valensole Basin: >270 m at Oraison.

The thick alluvial deposits outcropping at Digne represent the upstream part of the Pliocene-Quaternary infill of the Durance canyon and its tributaries. Based on pollen analysis, we estimate the age of the oldest alluvial deposits between 3.4 and 2.6 Ma (Late Pliocene). Most, or all of these alluvial deposits are therefore of Quaternary age. We explain the occurrence of thick alluvial deposits at Digne, and their young age, by the infill of the Valensole Basin that retrograded upstream in its tributaries.

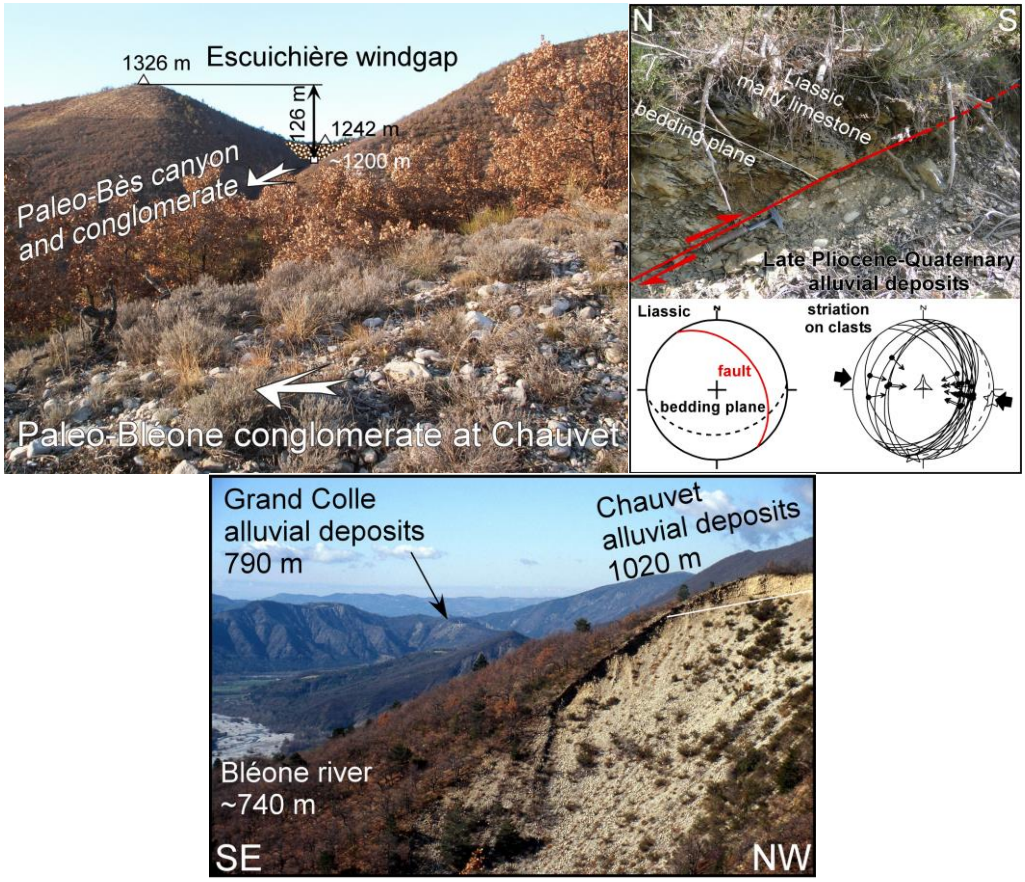
During this field trip we will see that portions of the Late Pliocene-Quaternary paleo-valleys have been uplifted, tilted, underthrusted and cut by strike-slip faults. Along the Bès fault and St Benoît fault, the alluvial infill of the paleo-valleys shows striated pebbles and secondary faults. Fault slip measurements indicate strike-slip to reverse movements and ENE-WSW compression, in agreement with the dextral-reverse slip of the two main faults.



Shaded relief map of the southwestern Alps with location of the stops.
The Digne nappe is the eastern part of the Digne nappe-Castellane arc thrust system. It is thrusted over the Valensole Neogene foreland basin in gray.

Stop 1: Uplifted Bléone and Bès paleovalleys at Chauvet and L'Escuichière

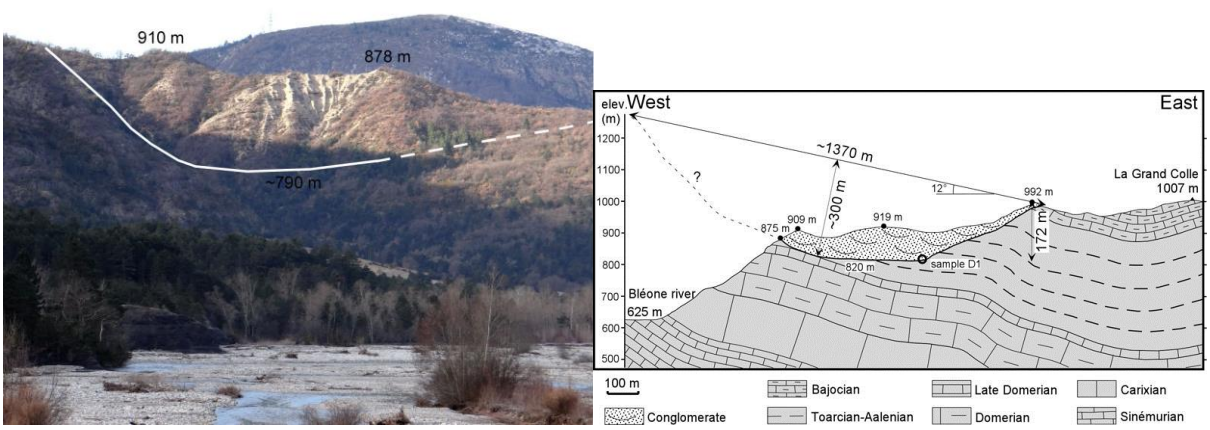
The thalweg of the paleo-Bès at l'Escuichière, at 1200 m elevation, is 460 m above the modern Bès River. If we compare this relative elevation with those of La Bonnette (+ 115 m) in the foreland basin, we infer that the paleo-canyon was uplifted of about 345 m at l'Escuichière. This is the major local uplift observed in the studied paleo-canyons. It shows that the Barles nappe anticline continued to form after the Pliocene infill of the canyons.



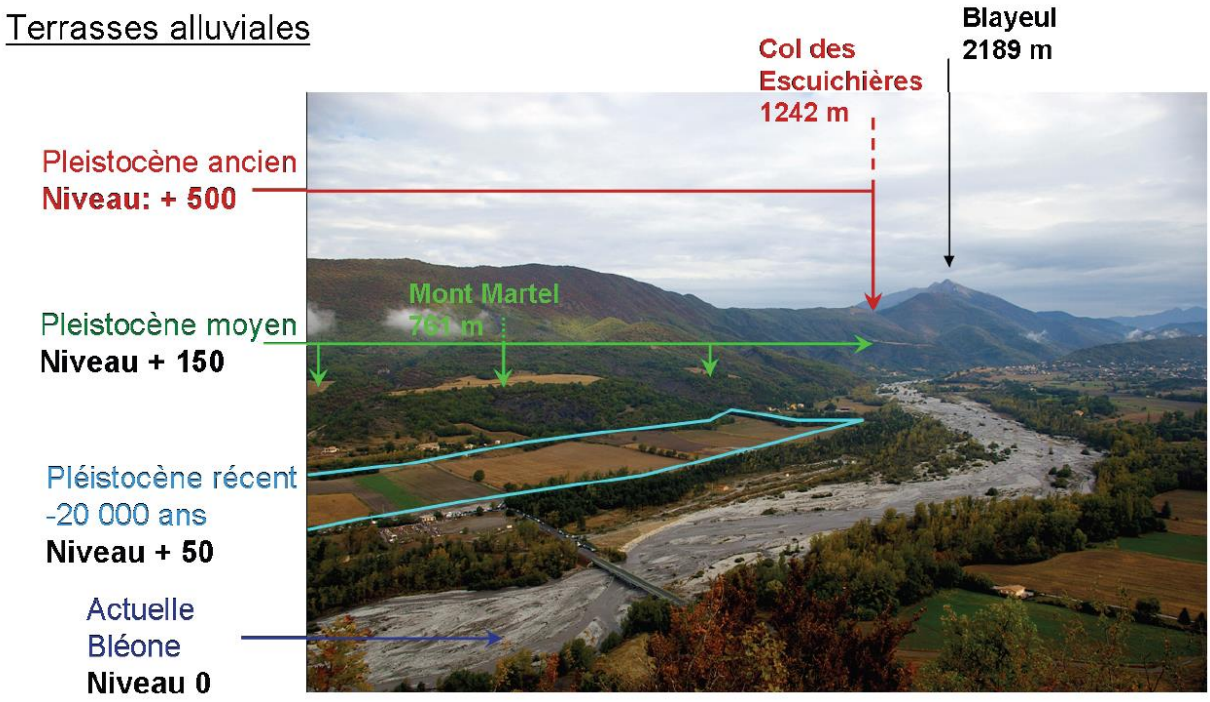
Uplifted and faulted alluvial deposits at l'escuichière and Chauvet.
Schmidt's diagram shows fault planes with striation measured in the conglomerate and computed paleostress axes (Angelier, 1990).

Stops 2: Tilted Bléone paleo-valley

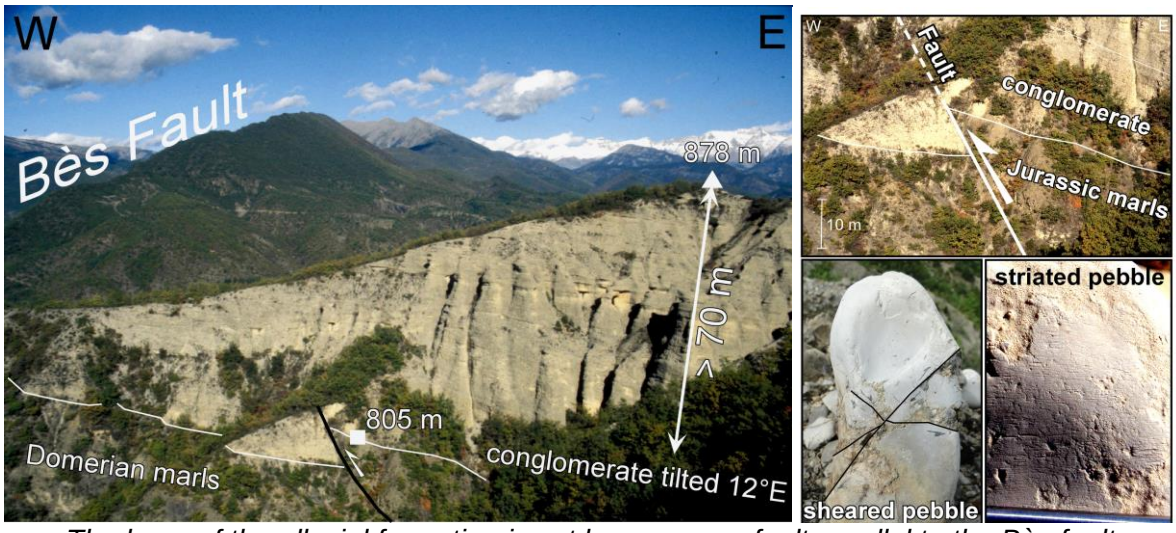
In the Grand Colle Mountain, the thick alluvial deposits are well visible in a cliff. The conglomerate dips 12° toward the east.



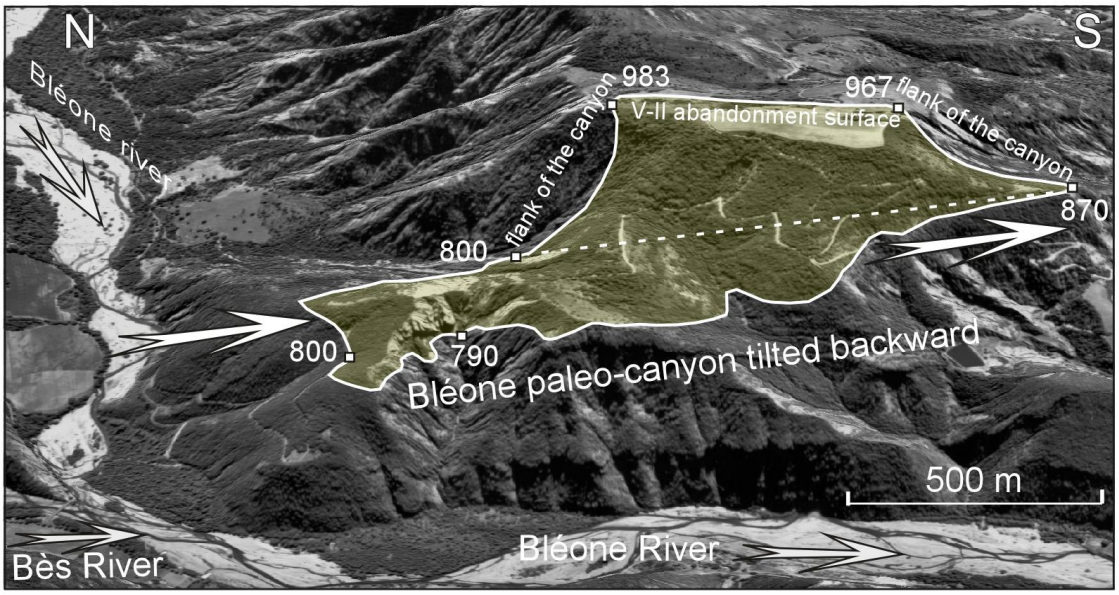
We can also have an outlook at the successive and stepped alluvial terraces of the Bléone river, from Lower Pleistocene (+500 m above the current riverbed) to Upper Pleistocene (+50 m) and Holocene alluvial channel. This testifies the active incision (at the geological scale) and the regional uplift of the Préalpes.



Stop 3a: The Bléone paleo-valley tilted by the Bès fault



The base of the alluvial formation is cut by a reverse fault parallel to the Bès fault.

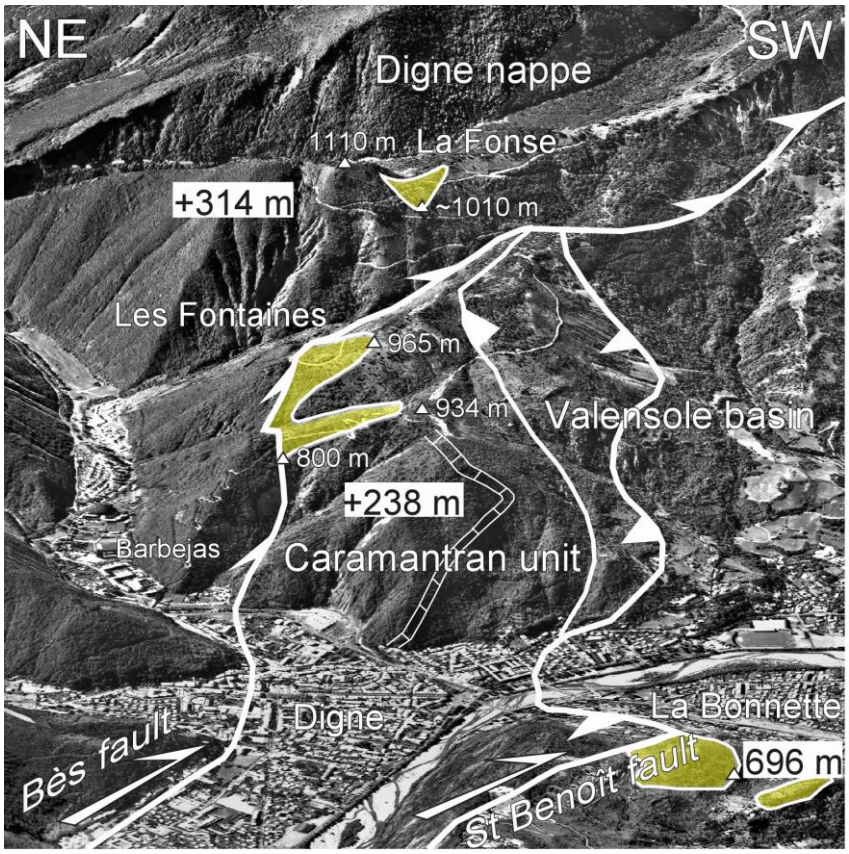


At La Grand Colle, the conglomerate was at least 172 m thick. Imbricate pebbles show that the river was flowing to the south as shown by the orientation of the eastern flank of the canyon.

In the flow direction, the elevation of the base of the paleo-canyon rises from 790 m to 870 m. It shows that, after its sedimentary infilling, the canyon was tilted longitudinally of about 4° to the NNW. Note that the tilted thalweg dips to the North whereas the river was flowing toward the south.

<u>Stop 3b: Ammonites layer:</u> A paleo-canyon underthrusted (Les Fontaines-Caramantran)

Immediately south of Digne, at Les Fontaines, the geological map indicates a little outcrop of conglomerates overthrusted by the Digne nappe (Gigot, 1973). Jorda et al. (1988) described this section starting with 30 m of conglomerates with striated clasts, covered by about 10 m of sandy loams with plant leaves. Based on the absence of subtropical species, they interpreted these plant macroremains as corresponding to a temperate climatic phase of the Late Pliocene or Early Pleistocene.

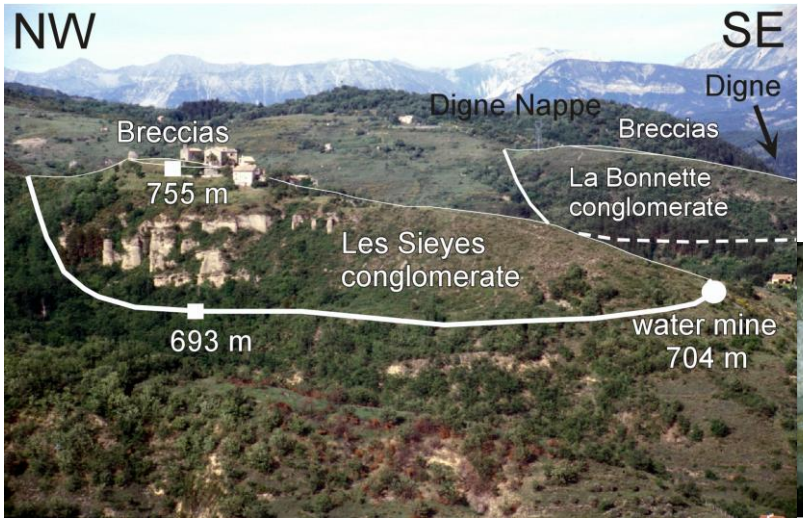


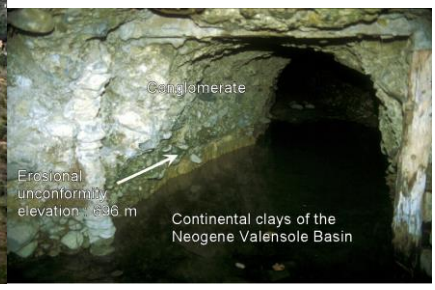
This unit has a larger extension (Caramantran area) and corresponds to a segment of the Bléone paleo-valley that has been tilted, uplifted and trusted by the Digne nappe along the Bès fault strand.

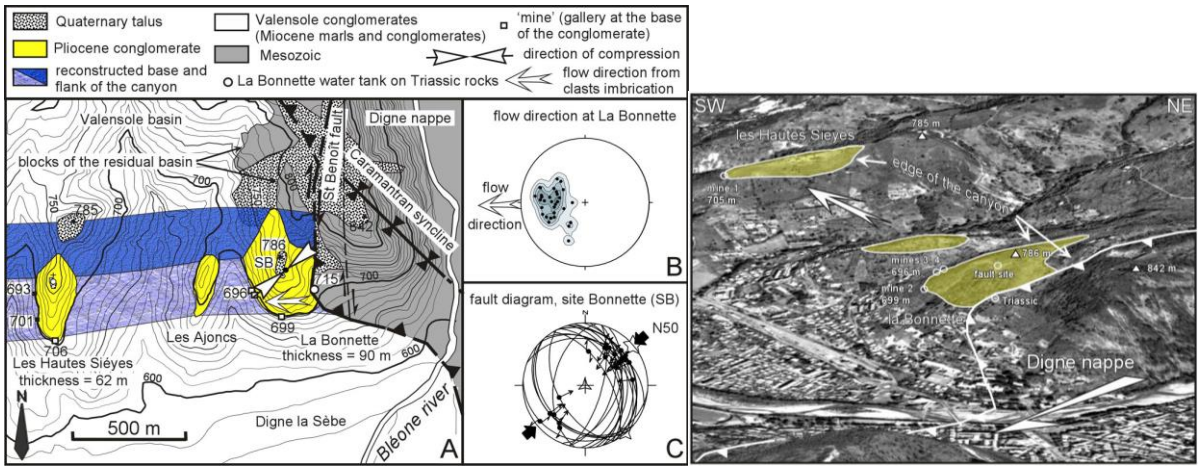
On the Digne thrust nappe the thalweg of La Fonse paleo-river was uplifted at 1010 m in agreement with the high elevation of the mountains.

The Caramantran tectonic slice is thrusted over the Valensole Basin along the St. Benoît fault.

Stop 4 : Fault-truncated paleo-canyon : La Bonnette-Les Hautes Siéyes

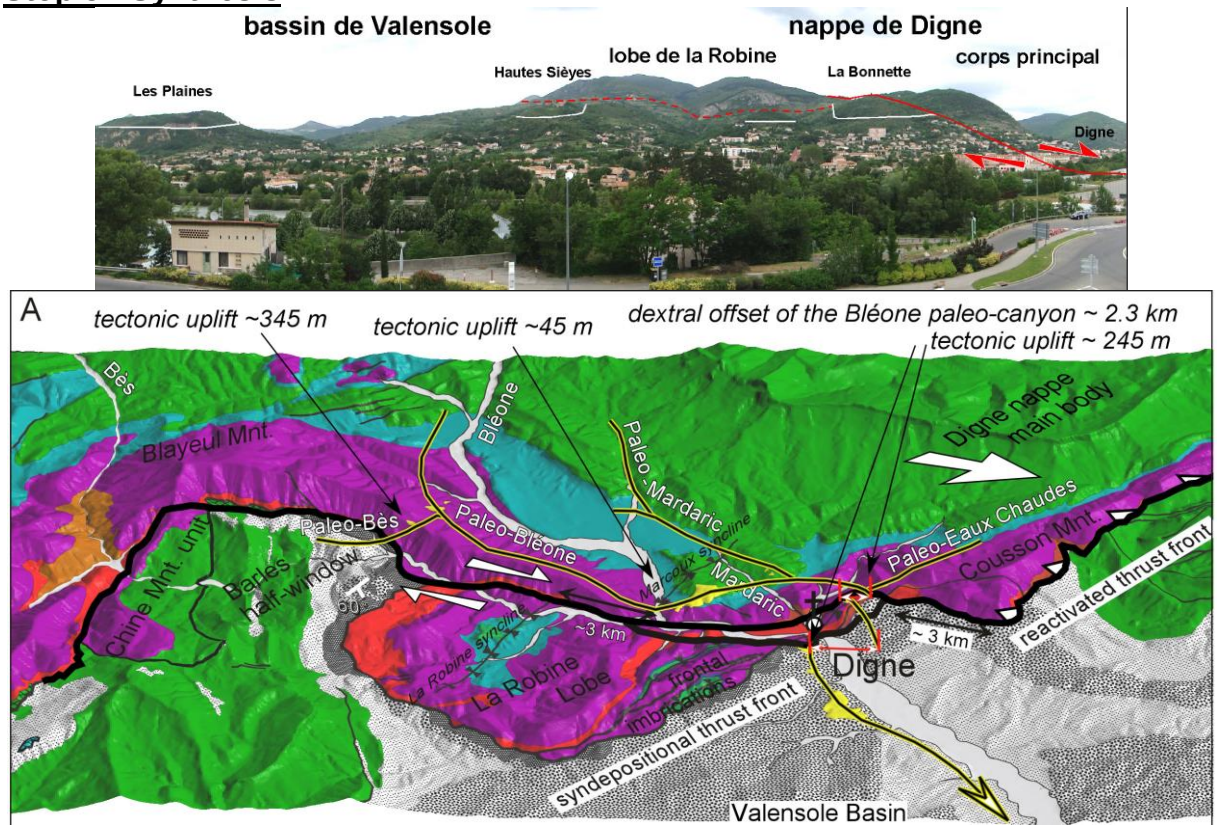






At Les Sieyes the alluvial deposits are 62 m thick. At La Bonnette, the geological map shows a 50 m thick 'ancient terrace', but the real thickness is 90 m. Imbricate pebbles indicate flow from the east, where now we find the Digne nappe. The paleo-valley was truncated by the Digne thrust along the St. Benoît fault strand. Close to this fault we found striated cobbles with reverse-dextral slips on N-S trending surfaces reflecting the reverse dextral slip along the main fault.

Stop 5 : Synthesis



The strike-slip separation of the Bléone paleo-valley is about 2.3 km. It confirms that the front of the Digne nappe is an oblique ramp of the South-verging thrust system of the 'Arc de Castellane'. This nappe moved toward the SSW. The displacement of the Digne nappe is contemporaneous with its folding in the Barles nappe anticline (half-window) as shown by the 345 m uplift at l'Escuichière. The magnitude of the nappe displacement was 2.3 km to the SSW in less than 3.4 Ma, which indicates a slip rate >0.7 mm/yr. and an uplift rate up to 0.1 mm/yr. at l'Escuichière pass.

Age of the alluvial deposits

J.-P. Suc analyzed the pollen assemblages from two clay samples from the base of the Bléone paleo-canyon.

We know from $\delta^{18}O$ records in the Mediterranean Sea that the last 5 Ma were a transition from the Messinian warm climate to the fluctuating Pleistocene cooler climate. In Europe, the Lower Pliocene was warmer and moister than the Upper Miocene. A first cooling event is recorded at 3.4 Ma and corresponds to a significant opening of the vegetation in relation with the TB 3.4-3.5 cycle sea level fall. Starting with a second cooling event at 2.58, rapid climatic variations (glacials: open vegetations; interglacials: warm-temperate forests) and sea level fluctuations characterize the Quaternary.

Sample D1 is from the **base** of the Grand Colle **canyon** at 800 m elevation **(stop 2)**. **Sample D2** is from the base of Les Plaines conglomerate in the Valensole Basin, at 690 m elevation **(stop 5).**The two samples are rich in pollen grains. They contain the same taxa, which supports the correlation between the outcrops in the Valensole Basin and those in the Digne nappe.

The pollen assemblage is dominated by herbs (Asteraceae with Cichorioideae and *Centaurea*, Malvaceae, Dipsacaceae as *Scabiosa* and *Knautia*, Poaceae, *Linum*, *Convolvulus*, etc.). Arboreal pollen grains are not frequent but include high-altitude elements like firs (*Abies*) and spruces (*Picea*) and mid-altitude elements such as cedars (*Cedrus*), *Tsuga* and *Cathaya* attesting for a significant elevation environment. The presence of *Cathaya*, *Tsuga* and *Cedrus* without any Taxodiaceae pollen is indicative of the Late Pliocene and Early Pleistocene in the Northwestern Mediterranean region (Suc et al., 1995b; Suc & Popescu, 2005). In addition, *prevalence of pollen of herbas favours a climatic episode younger than the cooling at* 3.4 Ma while the absence of *Artemisia (*widespread during the earliest glacial events at 2.6 Ma) allows proposing an age between 3.4 and 2.6 Ma (Piacenzian). This age is consistent with the age proposed for the plant macroremain of Les Fontaines site (Jorda et al., 1988) situated stratigraphically above our samples.

With the exception of local alluvial fans of up to 1 Ma, the uppermost dated formation of the Valensole Basin is the Ségriès travertine, which contains a fauna attributed to the Saint Vallier mammal biozone (MN 17) close to 2 Ma (Dubar et al., 1978). The Valensole-II abandonment surface (the Valensole Plateau) is therefore dated at around 2 Ma (Clauzon et al., 1990), which is in agreement with the age of the top of the canyons at Les Fontaines (Jorda *et al*., 1988).

The age of the paleo-canyon infill at Digne appears to be constrained **between 3.4 and 2 Ma.** This Pliocene to Early Quaternary age is in agreement with the age of the infill of Messinian canyons around the Mediterranean Basin, but at Digne the Zanclean clays are missing, thus the deposits are younger.

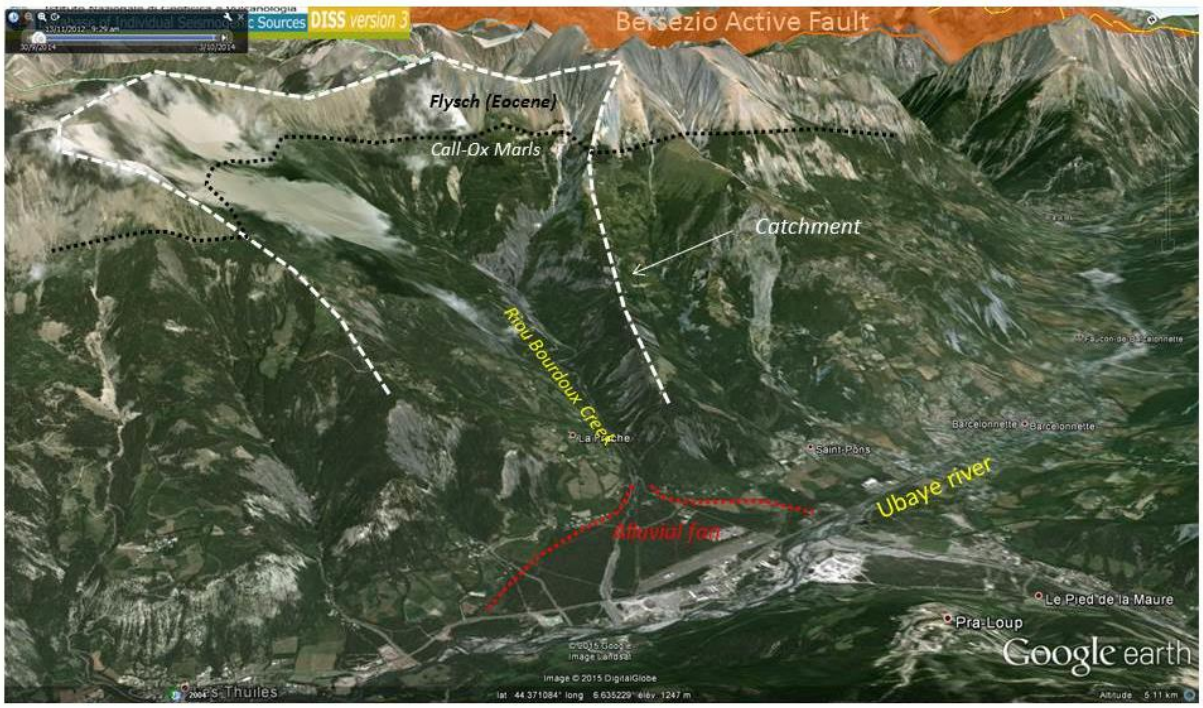
Stop 6 : Riou Boudoux alluvial fan (Barcelonnette)

See Delsigne et al. (2001) for more information

The Riou Bourdoux is certainly the most famous torrent of the Ubaye Valley. Its famous and frequent floods caused it to be referred to as the “monster” of the Ubaye Valley. Its catchment covers the Eocene Flysch (above 2200 m asl) and the Callovo-Oxfordian marls, these latter being prone to incision, gravitational sliding and debris-flows triggering. This is the main explanation to this large alluvial fan.

The Restoration of Mountain Lands Department undertook its adjustment in 1866. During the “pioneering days” (1866-1914), Prosper Demontzey and his successors implemented an ambitious program of reforestation and restoration of the grass cover, associated with the building of 2000 sills and dams in the channel. During the first and the second world wars, the program was stopped and the works were damaged. Since 1950,

renovation and reinforcements have been implemented on a continuous basis so as to maintain an acceptable level of safety. In spite of these improvements, there is still a risk of a major debris flow occurring due to the instability of the slopes. The area is still vulnerable, with recent facilities such as the local airport, industrial and business estate.



Google Earth view of the Riou Bourdoux alluvial fan and its catchment

The alluvial fan in 1878

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