Landscape evolution of the Salagou valley

J. F. Dumont

Sound, colour and scene in an evolving landscape

The rivers which flow in these valleys ought rather to be called mountain torrents. Their inclination is very great, and their water the color of mud. The roar which the Maipu made, as it rushed over the rounded fragments was like that of the sea. Amidst the din of rushing waters, the noise from the stones, as they rattled one over another, was most distinctly audible, even from a distance… The sound spoke eloquently to the geologist…It was like thinking on time, where the minute that now glides past is irrecoverable. So was it with those stones; the ocean is their eternity, and each note of that wild music told of one more step towards their destiny. (p.318)
… Daily it is forced home on the mind of the geologist, that nothing, not even the wind that blows, is so unstable as the level of the crust of the earth. (p.323)

Charles Darwin
The voyage of the Beagle
Natural History Library Edition,
London 1962 (1860).

Abstract

The evolution of the Salagou valley is visualized through the reconstruction of the pre-volcanic surface (about 1,5 M BP [years ago]) and observation of terrace elements on the bottom surface of the valley during the Riss glacial period (130 000-200 000 BP). Elevation and surface dating allows the calculation of a mean vertical erosion rate ranging from 0.1 to 0.25 mm/year. The valley is framed by faults and structures that are inherited of the late Hercynian period, suggesting that the present evolution is partly the recuperation of past structural characteristics. An extrapolation of past evolution leads to a forecast of the capture of the Orb River by the Salagou River in the next 0.6 to 1.5 M years.

Foreword

Geology allows us to discover more about our natural environment at a low cost. To do this it is just necessary to open our eyes, with the help if possible of a magnifier and a hammer, to think about what we are looking at, and sometimes to have good shoes.

To look at landscape is certainly the best introduction to geology. Two situations from my early experience in geology come in my memory. “Look, draw what you see, and describe the landscape” our professor told us at the first class of geology in the University of Paris, in the Sierra de Demanda in Spain. The other record was with Professor Ellenberger in the Cabrières area, just south from the Salagou valley: “before to handle a rock sample look carefully what is its position is here in the landscape.” To look and draw because drawing stresses observation, and write the observations, because, if you cannot put a name, you cannot really understand what you have seen.

Below the blanket of soil and vegetation, the observation of the depths of the earth opens the fantastic book of the history of the earth. Page after page in this book uncovers the successive layers of what was once the surface of the earth, that is a former landscape. Sure, a bit of practice, knowledge and imagination is necessary to give birth to these old landscapes, but this is part of the common vision that a man can spiritually generates on earth, as Claude Levi-Strauss experienced it when walking along the shore of a Mesozoic sea in Languedoc.

Concluding a career mainly realized in field geology at the four corner of the world, that is for an European from Asia to America and from the bottom of ocean trench to some of the higher mountains, I retired to Octon. The place was not new for me, but just a resting place between two journeys, and a store for the numerous things collected during travels.

Geology has been for me a way of living more than a simple job. Look at landscapes, try to discover what stage of the earth’s history they represent, that is their previous state and what they are going to be, was an instinctive purpose of travel. The choice of Octon was just good fortune, but I soon understood that this valley includes some of the elements that makes this area an abstract of geological situations that goes beyond the limited area of the valley.

The following text is an invitation to leaf through some of the main pages of the landscape book of the Salagou valley. The oldest, but also easy to recognize and imagine, is the Permian landscape, as old as about 250 M years before present. The rock color and the Savannah conditions of some parts of the valley help significantly to revive these very old times.

But most of the text focuses on the understanding of the geological and morphological signatures of the Quaternary evolution of the valley. A tremendous benchmark is constituted by the volcanic lava flow that fossilized the valley bottom as it was 1.5 million years ago. Later the fluctuating climate during Quaternary glacial periods shaped specific terraces that remain now as suspended surfaces. As far as quantification of evolution helps to understand the real effect of phenomenonas through time, we calculate the erosion rate of the Salagou valley. Together with the present morphological pattern this helps to consider some possible evolution of the valley in a near geological perspective that is no longer than the past Quaternary.

Considered besides the numerous cases of geomorphologic evolution than I studied in my professional activity, the Salagou valley can be considered as a case study for the identification and calculation of erosion and landscape evolution processes.

In the following text we try to join the rigour of a scientific analysis with the clarity of exposition that is necessary to arise the interest of a non-specialist person, someone who just concerned with looking at landscapes. Bibliographical references are included mostly in scientific publications, that is by mentioning the name and date in the current text -which is good for an historical perception of knowledge acquisition- and pointing the complete reference in an annex. Also a

glossary quotes the usual definition of some specialized terms that are not specified in the text.

J. F. Dumont, February 2013, Octon

Contents

1 - Introduction

The landscape is defined usually as "the aspect of a country, or a picture representing it" (Davidson, 1910; Hornby, 1974; Larousse, 1988). For the traveler this is usually a combination of morphology, vegetation, and more frequently, human occupation (Birot, 1970; Winckell et al., 1977). Landscape looks frequently stable, if not permanent, until a sudden flood, a volcanic eruption, a large landslide, or just a harsh climate change occurs and reminds us that what we see is only representative of an evolving surface of the earth. Fortunately the evolution of natural sceneries results more frequently from slow processes, hardly perceived at human scale. But over long periods, a slow but unavoidable change of our landscapes is going on. The Salagou valley is exceptional scenery presenting geomorphologic benchmarks of the evolution of the landscape during the Quaternary, as well as forecast on the possible future of its continuing evolution. Thus the landscape appears to be not just an instant picture, but also an evolving theater, which stages come from the remote periods of the history of the earth.

2. Geographical background

The Salagou valley is sloping down eastward (Fig. 1), and occupied a low position in the Causses . The north side of the Salagou valley rises continuously up to the Causse (Escandorgue and Orb Mountains between Lunas and Lodève), and the south side stands against the Cabrières Mountains. The Salagou River is part of the Hérault hydrographic basin* (the words with* refers to the glossary at the end of the text). This river merges first with the Lergue River upstream from Rabieux (Fig. 1), which joins downstream the Hérault River. The head of the Salagou River and valley is located on the eastern slopes of the La Merquière Pass, on the hydrographic divide* between the Hérault and Orb basins.

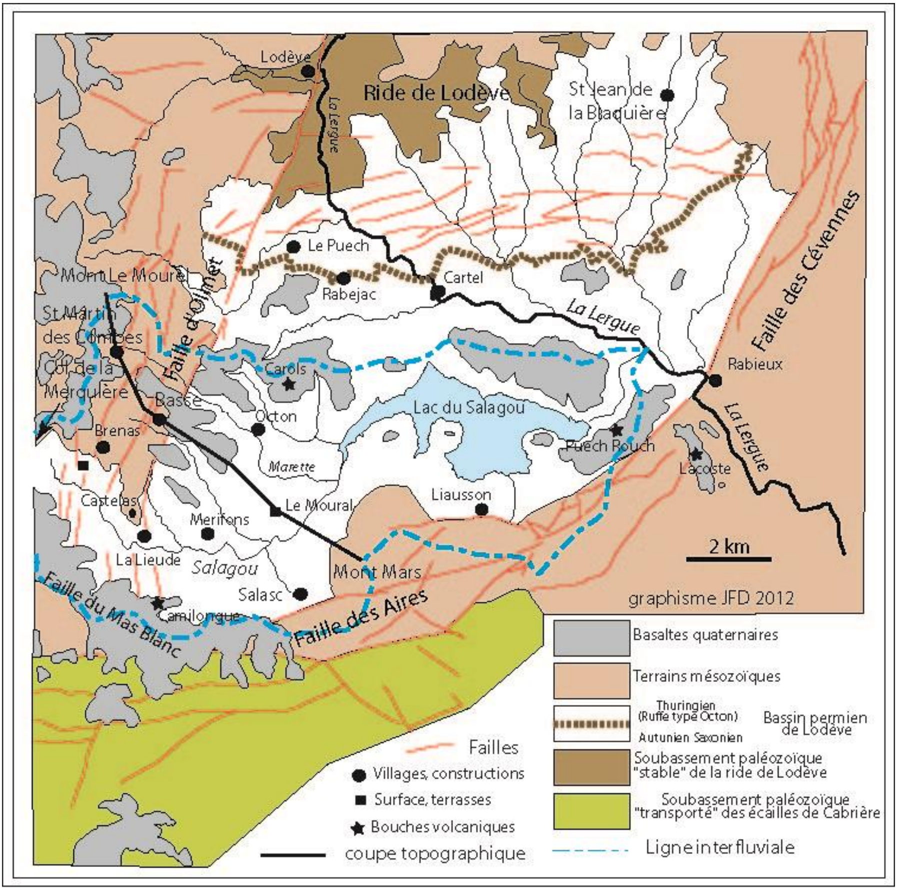

Fig. 1. Simplified Geological map of the Salagou valley. Redrawn and modified after Alabouvette et al. (1982). Schéma géologique de la vallée du Salagou et de ses alentours.

The Salagou valley is about 20 km long, extending downstream from the La Merquière Pass to the West at an elevation of 360 m a.s.l. (above sea level), down to the confluence with the Lergue River near Clermont l'Hérault at an elevation of 68 m a.s.l., giving a total difference in height of 292 m. The slope of the valley bottom presents an ordinary profile, decreasing progressively downstream (Fig. 2). However two irregularities presenting local higher slopes are observed along the profile line of the river : one in La Lieude where the Salagou valley crosses the Olmet fault* zone, and the other just before the confluence with the Lergue River. This lower slope irregularity suggests a higher downward erosion of the Lergue River valley that forces the Salagou River to increase its slope before to merge (Fig. 1 and 2). Since the 1970s the Salagou dam created a 7 km long lake, at an elevation of 137-140 m according to the water level of the lake.

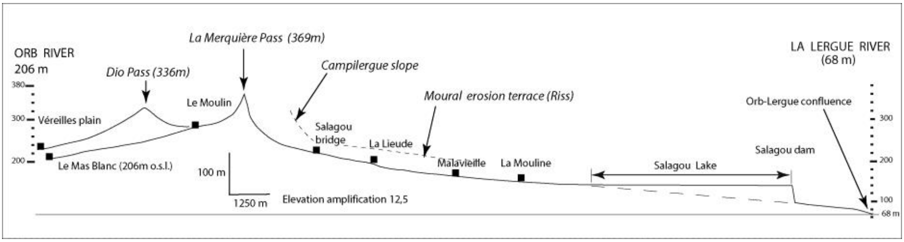

Fig. 2. Topographic profile from the Lergue to the Orb rivers through the La Merquière Pass, along the Salagou and Vernoubrel rivers.

The morphology of the Salagou valley shows two different parts. To the East and downstream from La Lieude, the valley is 3 to 4 km wide, and partly occupied by the Salagou Lake. The slope is relatively steady, with a mean value lower than 1%. In La Lieude, between the Castelas of Merifons (to the north) and the Camilongue Mountain (to the south) the valley presents a reduced width of less than 500 m. Westward from La Lieude the valley width increases again, but remains relatively narrow. The valley slope increases progressively (Fig. 2), with a mean value of about 2.2%, increasing upslope toward the La Merquière Pass.

Le Salagou valley if well known for the occurrence of the "ruffe", a massive to stratified reddish rock that is observed about all over the bottom of the valley and along the low to middle slopes. This is a hard clayey material looking like laterite*, and giving very contrasted landscapes of deeply eroded badlands* and about flat surfaces covered by grassland, that during the Mediterranean hot and dry summer recalls African savannah.

3. Geological background

The oldest rock outcropping in the Salagou valley is the ruffe, and date the Thuringian*, about 260-250 Ma before now (Ma = Millions of years; geological scale of the International Union for Geological Sciences) (Bousquet, 1997; Odin et al., 1986). Thuringien is the last stage of the Permian*, which is the last period of the Paleozoic era*. This is a very particular period of the history of the Earth: the Hercynian* cycle that lasted from 325 to 250 Ma before present is ending. During this period high mountains with topography probably over 4000m high and located in the Massif Central just upslope to the north from the Salagou valley, have been raised and partly eroded. The ruffe represents the last fill of a piedmont basin with material eroded from the Hercynian Massif Central, under probably with a very dry climate. For reasons that are still debated (desert conditions? huge volcanic eruptions? meteorite?), more than 90% of the living animal and plant species disappeared at the Paleozoic-Mesozoic transition that is between the Permian and Triassic.

The foothill basin of the ruffe extended originally over more than 30 km from the Graissessac region to the West to the Lodève region to the east (Bousquet, 1997). Filling of the basin began during the upper Carboniferous* 300 Ma ago with conglomerates and sandstones that are interbedded with coal levels. The climate was wet and hot, but turned dry and desert during the deposition of the ruffe by the end of Permian, 50 Ma later. Inside continental plates, the formation of new large geological structures is exceptional. This is also the case for the Salagou valley, which appears superimposed over previous structures of the Permian ruffe basin. More than 30 years ago Paul Edwin Potter (1978) pointed out that most of the large fluvial basins and estuaries are superimposed over long lasting and periodically reactivated geological structures. Another way to describe this idea is saying that the main geological structures that support the present landscapes have previously supported former landscapes, possibly different, but inside the same frame. For example the main faults that framed the Salagou valley (Olmet, Aires, Mas Blanc, Cévennes) are inherited from the Hercynian period, more than 250 million years ago (Horrenberger and Sirieys, 2000; Saint Martin, 1992).

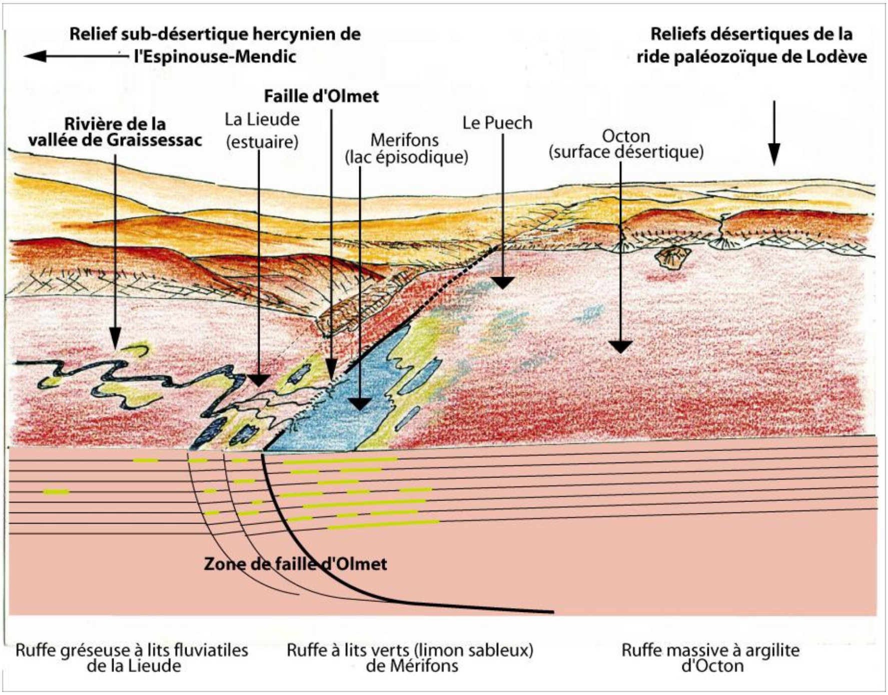

Fig 3. Figurative representation of the Permian basin during deposition of the ruffe. The basin was bounded longitudinally by the Olmet fault zone, which determined the position of the centre where temporary lake facies are observed (La Lieude-Merifons area). Desertic clay (playa facies) are observed to the east (Octon), and river sand lenses to the west.

The word "ruffe" is frequently used as a general name for any reddish rock from the Lodève region. However the geologists who studied the Lodève region reserved the word "ruffe" for the massive reddish argillite* outcropping in the Octon-Cartels area that are

Photo 1. Typical ruffe sediment, made of massive argillite. Few and thin silt levels, frequently topped by desiccation fractures, represent temporary lake conditions.

stratigraphically located over the sandstone and conglomeratic level outcropping in Rabejac (Odin et al., 1987) (Fig. 1). This true ruffe is interpreted as flood plain and playa* sediment deposited under dry arid climate (Odin et al., 1987).

The deposition of more than 2000m thick ruffe results of tectonic subsidence* (Odin et al., 1987) controlled principally by the Aires and Mas Blanc faults (Fig. 1). The sedimentation rate is about 0.2 to 0.3mm/year, which can be interpreted as a tectonic subsidence rate because the continental basin that received the ruffe never registered a notable presence of free water such as a permanent lake, and lack of significant internal unconformities.

Some variations from the typical ruffe facies* are observed. West of Octon in the area of the Merifons Church, centimeter thick green layers of thin sandstone are intercalated in the reddish massive argillite, proving presence of temporary lakes. Farther west in the La Lieude area we observe, in addition to the reddish argillite and green layers, lenses of medium to coarse sandstone, clearly related to streams deposits from a paleo-drainage issued from the west (Odin et al., 1987; Odin et al., 1986; Saint Martin, 1992).

Photo 2. The ruffe facies in the area of Mérifons. Clear levels, of grey to green color, represent silt deposits of temporary lakes. When drying the bottom of the lake is covered by desiccation fractures.

Photo 3. The ruffe facies in the upper part of the Salagou valley, west from La Lieude. Lenses of thin to coarse sandstone represent river beds from wandering streams.

The ruffe is a hard and compact rock as long as it stays below the surface, but it begins to disintegrate into small, millimeter fragments, as soon as it is submitted to weathering. When carved in the ruffe the valley slopes of the Salagou valley present a concave shape, steepened upslope. This steepened upslope is due to the presence of a cover of hard rock protecting the ruffe from weathering and erosion. This protecting cover is constituted in some places by the thick Mesozoic cover (between Brenas and the La Merquière Pass, and west of Salasc in the Liausson area), and in the other places (Octon, Celles) by a relatively thin (10-50m) but extensive basaltic* lava flow, issued from the Escandorgue volcanic complex located some tens of kilometers to the north (Alabouvette et al., 1982; Gèze, 1979). The Escandorgue volcanic complex erupted between 2.5 and 1.5 Ma according to Alabouvette et al. (1982), or only around 1.5 Ma according more recent dating of Dautria et al. (2010). The locations of volcanic centers are indicated by breccias and scoria, such as in Camilongue, Carol and Puech-Rouch (Fig. 1). Near Lacoste a basaltic lava flow is located 30 to 40 m below the level of the main volcanic table, for which Alabouvette et al. (1982) suggest an age as young as 0.7 Ma. A similar situation is observed near Octon, in the Mas Hébrard.

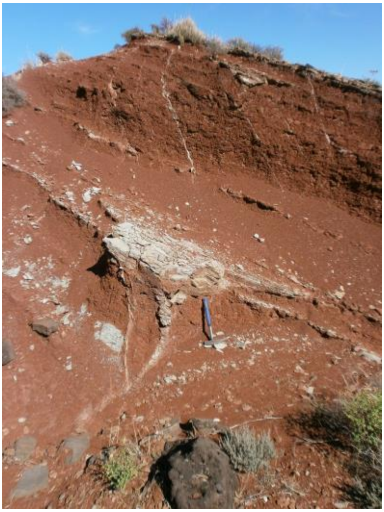

Photo 4 (left) and 5 (right) . Sedimentological evidence of the activity of the Olmet fault during Permian. These strange sedimentary structures show lake bottom sediments filling narrow fractures, repeated from time to time (left). They are interpreted as a rollover effect that stretch the terrain near an extension fault (here the Olmet fault). They are specifically located in a centre related to fault motion.

The sediment strata of the ruffe as well as about all the Permian terrain from the Lodève area, present a constant dip of 10-20° to the south. This corresponds to a structural tilt of the whole basin that began early in the Permian period, and is terminated by the Mesozoic transgression* (Saint Martin, 1992). This transgression began during the Triassic, with continental sediments lying with a stratigraphic* unconformity* on the ruffe, which corresponds to a gap of some millions of years after the end of the deposition of the ruffe. The tilt of the ruffe basin is geometrically accommodated along the south margin of the basin by a normal movement of the Mas Blanc and Aires faults (Saint Martin, 1992) (Fig. 1). This movement results of a N-S extension that occurred during the late Hercynian period (Horrenberger and Sirieys, 2000). The same fault line determines the present the south border of the Salagou valley.

The presence of faults is an important element of the Salagou valley. We observe on Fig. 1 than the area of occurrence of ruffe is delimited by a quadrilateral of faults, which are respectively the Cévennes fault to the east, the Olmet fault to the west, the Aires fault to the south, and a network of small E-W trending faults along the Lodève ridge to the north. We observe also than the Salagou valley is bounded to the south by the Aires fault and his extensions, to the east through the Cévennes fault and to the west towards the Mas Blanc fault. As stated before this fault line belongs to Hercynian structures, and has been part of the structures of the ruffe basin. Later during the Mesozoic this fault zone participated to the formation of a structural submarine high forming the reef barrier of Mourèze carbonates (Alabouvette et al., 1982; Gèze, 1979; Horrenberger and Sirieys, 2000; Saint Martin, 1992).

The other important fault for the Salagou valley is the Olmet fault (Fig. 1) (Alabouvette et al., 1982; Gèze, 1979). The Olmet fault is probably better defined as a fault zone of one to two kilometers width, trending N-S to NNE-SSE, parallel to the southern segment of the Cévennes fault (Horrenberger and Sirieys, 2000). The Olmet fault zone is underlined by intrusions of basaltic rock cutting across the strata of ruffe. These intrusions are principally observed as dikes trending roughly N-S, nearly parallel to the Olmet fault. Some of them such as in La Roque and near the Merifon's Castelas are associated with volcanic necks*. As frequently observed in volcanic systems (Beccaluva et al., 1983) volcanic centers and necks are frequently located near cross-cutting main faults: in the Salagou valley the volcanic center of Camilongue is located where the Olmet fault intersect the Aires fault, and that of Puech Rouch at the junction between the Aires fault with the southern segment of the Cévennes fault (Fig. 1). This situation gives account of a tectonic activity of these faults during the Quaternary*.

Around La Roque and on the borders of the Merifon's Castelas we observe a dense fracture* system trending perpendicular or highly oblique to the trend of the volcanic dikes. These fractures are 2-3 cm thick, filled partially or totally with calcite. This calcite fill pre-dates the intrusion of the volcanic dikes*. The calcite fill is supposed to come by dissolution transport and recrystallization from the Mesozoic cover where carbonates are abundant in some formations. This suggests activity of the Olmet fault during Jurassic or Cretaceous times.

All the volcanic structures such as dikes and necks, together with the calcite fill of the other older fractures, constitute a framework giving more resistance to the ruffe in this area. Possibly also the calcite fill of fractures favored local cementing of the ruffe, as well as volcanic intrusions induced local heating and cooking of the clay content of the ruffe. The result is that ruffe in the area of the Castelas's headland and Olmet fault zone resists better to weathering and erosion than in other areas of the Salagou valley, giving locally sub-vertical scarps up to 10 m high.

Photo 6. Dense fracture zone of the Olmet fault zone. Fractures are filled with calcite, and appear as white wall that resist erosion, and gives a morphologic scarp.

Photo 7. Calcitized fracture giving a sharp crest out from the soft ruffe argilite. Olmet fault zone, near La Roque.

Photo 8. Calcitized fractures that stop against the basalt dike, and thus predates the volcanic activity. The ruffe describes a roll of hardened argilite on the border of the dike basalt, probably due to heating. Together with calcitization this gives the ruffe more resistant to weathering along the Olmet fault zone.

4 - The Salagou valley just before the Quaternary volcanic activity

In several places the slopes of the Salagou valley are topped by low dip surfaces, called locally "plans" or "planas" (Plan de Basse, Plan de Carol, Planas du Mas Bas), culminating at elevation ranging between 375 and 400 m. These morphological surfaces correspond to a relatively thin basaltic cover 10 to 50m thick, issued from the Escandorgue volcanic complex. This lava flow cover filled preferentially the topographic lowlands of the previous morphology. Joining together the different planas it is possible to reconstruct the Salagou valley as it was during the early Quaternary when the Escandorgue volcanic complex erupted.

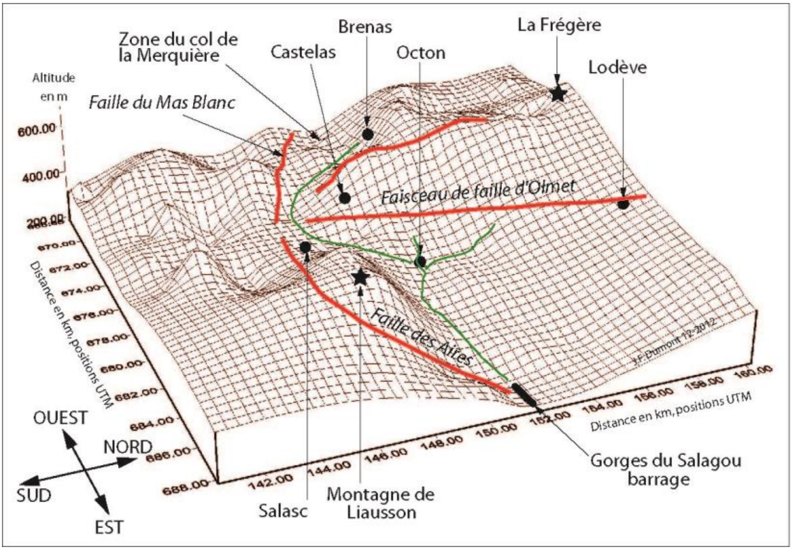

Fig. 3. 3D perspective of the pre-volcanic surface of the Salagou valley realized with Surfer, using about 200 points from the basal level of the basaltic flow identified on the geologic map (Alabouvette et al., 1982; Bogdanoff et al., 1984).

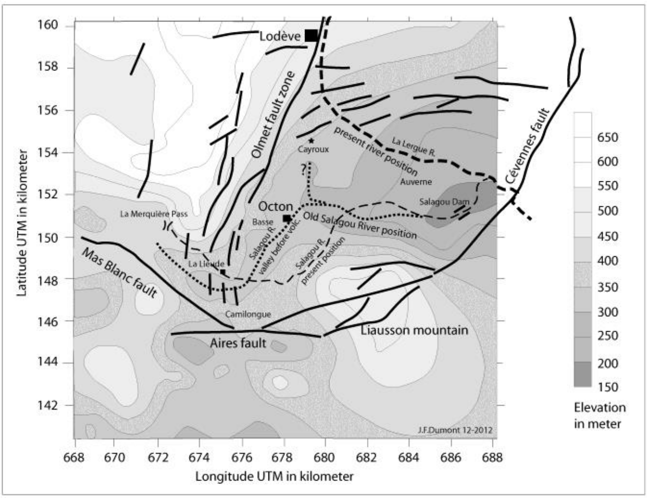

Fig. 4. Cartographic representation of the 3D vue presented fig. 3. The position of faults is taken from the geologic map (Alabouvette et al., 1982; Bogdanoff et al., 1984).

However, only an incomplete thickness of the volcanic cover is preserved due to recent erosion. Sowe considered for this reconstruction the elevation of the base of the volcanic cover as it can be determined and measured on the geological map of the area at a scale of 1/50 000° with a margin of error of about +- 5m (Alabouvette et al 1982; Bogdanof et al., 1984). The geographic position and elevation of about 200 points were registered, choosing positions as scattered as possible. In the eastern part of the area of this study, such as south of Lodève where there is no volcanic cover, we considered the top elevation of hills, to which we added arbitrary 20m to account for the erosion than occurred since then (Fig. 3 and 4). This arbitrary correction is based on a maximum erosion rate calculated by Séranne et al. (2002) for the Hérault valley, which is probably higher than the erosion rate in the Lodève region for two reasons: we consider here the hilltops where erosion is less than in the valley bottoms, and Paleozoic schists are more resistant to erosion than Mesozoic limestones. The points determined in geographic position and elevation were processed with Surfer in order to restore the pre-volcanic topographic surface. The result is presented in 3D view on figure 3 as well as a contour line map on figure 4. On the 3D view (Fig. 3) the Salagou valley presents a wide, smooth, and continuous northern slope extending east of a line joining Octon to Lodève. This regular slope ends to the west on the prominent relief of the Brenas-La frégère area (Fig. 3), extending westward toward Montbringues and Mont Caussil (not on the figure). The foot of this relief toward Octon underlines the Olmet fault, and we can observe that the Castelas's headland was not clearly determined at that time. Downstream from La Lieude (Fig. 4) the bottom of the valley follows the border of the Olmet fault. North of Octon the Salagou valley merges with a secondary drainage coming from the Cayroux area to the north, and located slightly eastward from the present Révérignès brook. Then the valley bottom turns abruptly east-southeast, joining a line more or less similar to the present position of the Salagou valley. Upstream from La Lieude the upper Salagou valley was not clearly determined, and the La Merquière pass was an area of smooth morphology with an uncertain drainage: one tendency of this drainage is directed toward the

Salagou valley -to be developed later-, and another is directed to the south, down slope from the Causse, across the Aire fault.

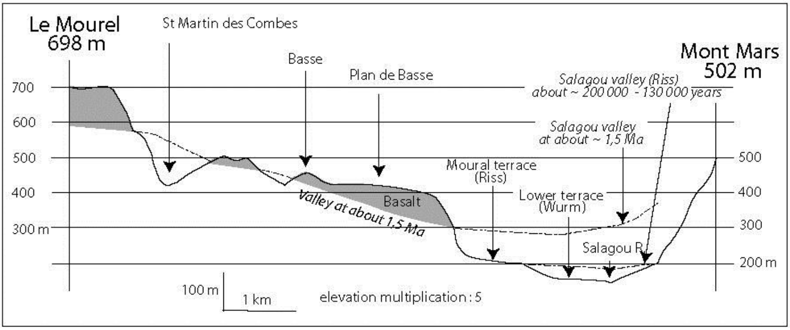

Fig. 7. West-East topographic of the Salagou valley, see location on fig. 1.

The Salagou valley that predates the volcanic episode is framed inside a structural polygon determined by the NE-SW trending Cévennes fault to the east, the NNE-SSE trending Olmet fault to the west, the E-W trending fault zone of the Lodève ridge to the north, and the W-E trending Aires fault to the south. The Aires fault is a transition segment joining two major faults, the Cévennes fault to the northeast and the Mas Blanc fault to the west. The Salagou valley as it is observed now occupied a more restricted space relative to the early drainage described by the pre-volcanic surface. The lava flow layer will introduce a drastic change in the evolution of the morphology of the valley that will be analyzed through the erosion surfaces inside the Salagou valley.

5. The Salagou valley just after the quaternary volcanic episode

Basaltic lava flows down along thalwegs, valley slopes and valley bottoms, and thus will fill preferentially topographic lows. After this deposition the volcanic cover will represent a differential protection against erosion, more effective in the previous lows because the lava cover is thick, and less effective in the previous relief elevations where the volcanic cover is thin or lack. When the erosion will be active again, we will observe some local relief inversion with respect to the previous morphology: the valley bottom and lows where erosion is reduced will appear progressively as morphological high points , and the former hill top that lack of volcanic cover will be eroded more easily and changed for new low areas.

As stated by Alabouvette et al. (1987), this phenomenon of relief inversion applies more specifically for secondary and relatively small valleys, but not for the Salagou valley in general. There are two spectacular examples of this phenomenon : the Lignous valley (former high and present valley) relatively to the Plan de Basse (former valley and present high), and similarly the Toucou valley relatively to the Plan de Carols and the slope toward the Mas Hébrard. In the first case this phenomenon is evidenced in a rock section on the border of the road by two levels of lava flow, separated by sedimentary layers from a topographic low, temporary lake or valley bottom. In the second case we observe along the slope from Mas Hébrard to Carols a lava flow at an elevation of 250m, that is 50m below the lower level of the main flow. However the main volcanic centers that erupted and formed relief during the volcanic activity remain as high topography in the present morphology : among them are the Carols, Puech Rouch, Camilongue, and the most important of all, the Escandorgue volcanic outlet farther north. It appears that the position of these volcanic centers has had a significant effect on the present morphology, contributing to divide the wide pre-volcanic Salagou valley in two parts. The eastern part lacking olava flow protection (Lodève-Le Bosc) will be eroded more actively, but the western part including the Salagou valley will develop a more intricate morphology of local relief inversion and resistant uplands (the "plans") separated by deep thalweg and valley entrenched in the ruffe. In the area of the Olmet fault, the intrusions of basalt dikes and volcanic necks improved the resistance to erosion together with the calcite cementing of fractures, and this protection help to the formation of the Castelas headland along the Olmet fault zone.

6 - The Salagou valley during the last glacial periods

Along the low slopes of the Salagou valley several elements of nearly flat terraces* are observed. They constitute generally preferential areas for the production of cereals (in the upper part of the valley) or vineyards. Along the slope of the La Merquière pass (Photo 1), as well as below Brenas (Photo 2), these terraces are relatively small (some hundred meters in size) and separated by incised thalwegs and badlands*.

East from the Castelas headland, in the areas of Merifons and Octon, the elements of terraces are more extensive, represented typically by the Plan de Moural (Photo 3). The Plan de Moural has an elevation of about 200 to 210m o.s.l., that is 50 to 60m over the bottom of the Salagou valley. Either in the upper or lower part of the Salagou valley, the mosaic elements of terraces presents continuity of elevation from one to the other. This suggests that they are part of a previous continuous terrace, and were later separated in several elements by erosion. However some scattered elements of terraces suggest that other period of terrace formation may have existed, but lack of importance and continuity to be considered here.

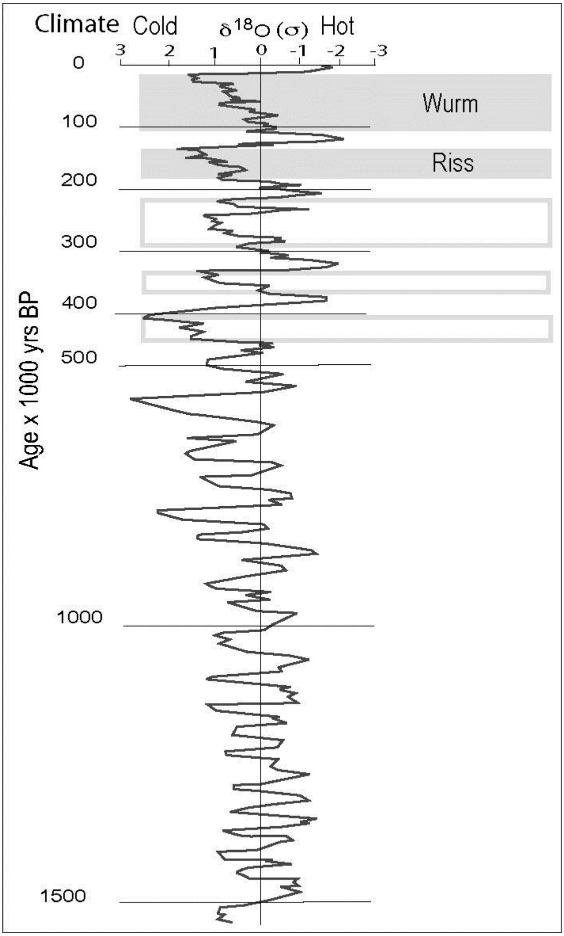

Fig. 6. Climate variation during the Quaternary, interpreted from the oxygene isotope. The grey zones -Riss and Wurm- represent the two last glacial periods. Observe that climate variations are more important since about 600 000 years before present. Curve redrawn from Burbank and Anderson, 2001.

The terraces are erosion* surface discordant over the ruffe. The top of the terrace is a thin level (some decimeters) of soil including rock fragments of various sizes issued from the volcanic cover of basalt, as well as from the Mesozoic cover of sandstone or limestone according to the place, that have been transported downslope over the erosion surface. On the geological map (Alabouvette et al. 1982) the Moural terrace is interpreted as a morphological inheritance from the Riss glacial period, formed about 130 000 to 200 000 years before present (Riser, 1999). We speak here of the period, and that does not mean the presence of ice cap, but just a climate slightly cooler than during the interglacial periods, such as the present period. This cooler climate was possibly associated with more regular precipitation allowing the formation of more regular slopes. There is no striking element to indicate what was the Languedoc climate during glacial periods of Quaternary. However during the last cool period of the history, called the "Little Ice Age"*, that lasted from about 1450 to 1850, climate in south of France was generally characterized by rainy summers (Le Roy Ladurie, 1983), favorable to the formation and preservation of a grass cover able to protect the surface from erosion. Low terraces observed below the Moural terrace are interpreted by Alabouvette et al. (1982) as related to the last glacial period (Wurm). This glacial period that just predates the present time was a relatively long and fluctuating period that lasted nearly 100 000 years, from about 110 000 years to 10 000 years before present.

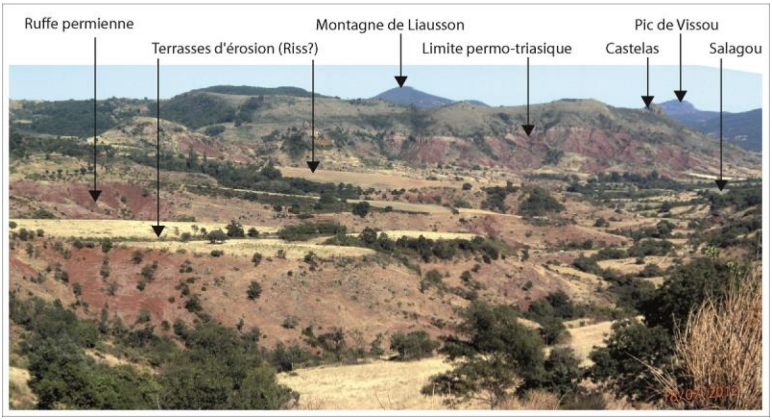

Photo 9. Erosion terraces from the upper part of the Salagou valley, below La Merquière Pass. The closer terrace elements correspond to the area called Redondel, with a low edge 30m over the bottom of the Salagou valley.

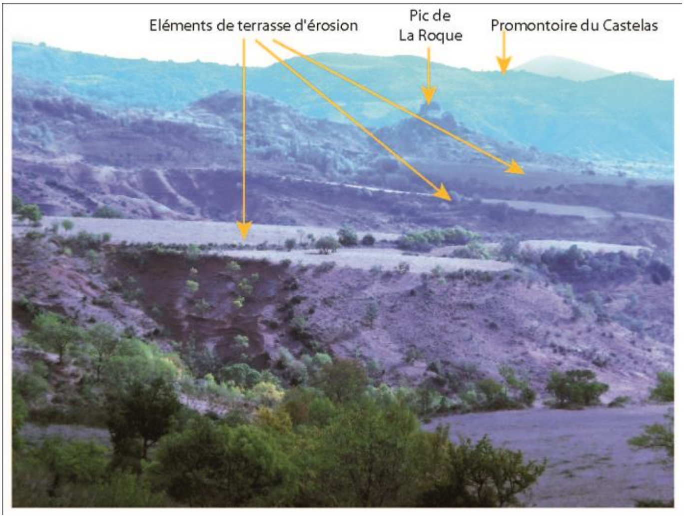

Photo 10. Erosion terrace elements observed between the La Roque neck and the Castelas headland, below Brenas. Note the continuity of the surface from a terrace element to another.

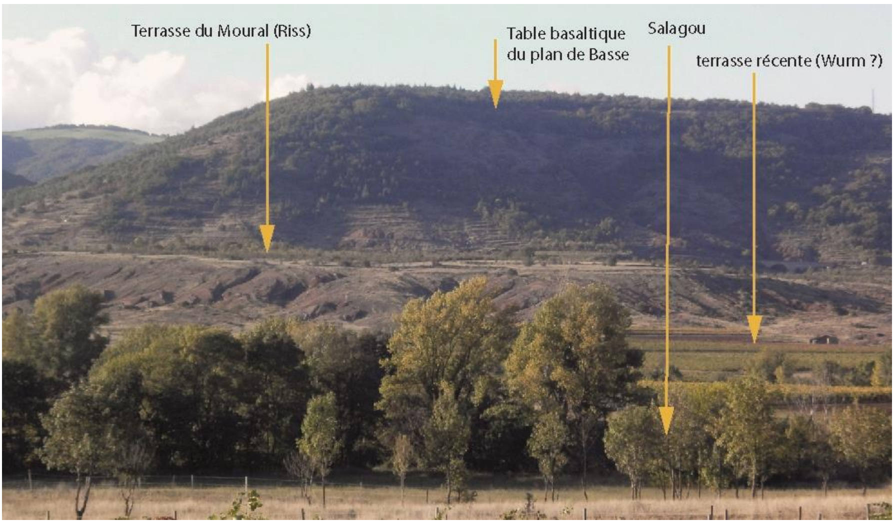

Photo 11. The Moural terrace looking eastward from Salasc. From photo 1 to photo 3, progressing eastward and downslope the Salagou valley, the elements of erosion terraces are more and more wide.

7 - Measurement of erosion rate of the Salagou valley

The rate of erosion of a valley is theoretically easy to calculate: the depth of the valley divided by the age of the top border of the valley gives the result.

In practice the first element is easy to determine with an altimeter or on a precise topographic map. The age of the top border surface depends on the contrary on more complex elements involving the geological history of the area. In the case of the Salagou valley we are lucky, because we have at least two top border surfaces for which an age is estimated with a relatively good precision at geological scale. The first and higher is the pre-volcanic surface which pre dates 2.5-1.5 Ma, and the other is the Moural terrace formed during the Riss glacial period that lasted from 200 000 to 130 000 years BP. A third and lower terrace related to the recent Wurm glacial period would provide an additional element for the calculation, however the wide time range of this glacial period and the reducederosion since that time results in an elevated margin of error.

Dating of the volcanic episode of the Escandorgue provided ages of 1.5-2.5 Ma according to Alabouvette et al. (1982), and an age of 1.5 Ma according to Dautria et al. (2010). The volcanic activity has probably been relatively short, because lava flows are not numerous, that gives probably more relevancy to the age provided by Dautria et al. (2010). We can thus consider the age of the surface below the lava flows to be close to the age of the volcanic activity. For the depth of the valley we used the difference of elevation between the Plan de Basse (350 m) and the bed of the Salagou River (134 m) located just down slope the Plan, that is a valley erosion of 207 m. The calculation gives a vertical erosion rate ranging from 0.14mm/year considering an age of 1.5 Ma for the pre-volcanic surface, and 0.08 mm/year considering 2.5 Ma. As an approximation we can consider a mean erosion rate of

0.11±0.03 mm/year, however the higher rate of 0.14mm/year is probably more realistic.

In the case of the Moural terrace, the low edge of the surface has an elevation of 200 m, that is 50 m above the riverbed of the Salagou River in the same area. However a correction must be applied because the Moural terrace presents a low slope of 2.5%, and his low edge where the elevation can be measured is located 1km away from the bottom of the Salagou valley. Taking account the terrace slope the erosion of the valley since the formation of the terrace during the Riss period can be estimated to about 30 m. The Riss glacial period lasted from about 200 000 years BP to 130 000 years BP (Riser, 1999). The calculation gives two extremes values of erosion rate considering either the beginning or the ending of the glacial period, that is 1.15 mm/year considering 200 000 years, and 0.23 mm/year considering 130 000 years. The mean erosion rate (more relevant here than in the previous case) would be about 0.18±0.05 mm/year. Another calculation considering the erosion terrace observed on the slopes of the La Merquière Pass, near Campilergues, gives an erosion rate ranging from 0.12 to 0.25 mm/year, due to the error margin on both elevation and terrace age.

8. Discussion on the calculated erosion rate

Three points are to be considered: 1 - the homogeneity of the calculated erosion rate, 2 - the effect of the volcanic cover on erosion process, and 3 - the relevancy of the erosion rate in term of landscape evolution.

The results of calculation are relatively homogeneous, ranging from 0.1 to 0.25 mm/year that is in an order of 1 to 2.5. In the detail the erosion rate calculated for the recent period (since the Riss period) is higher than the one calculated for a longer period. since the deposition of the volcanic episode. The mean erosion rates are respectively 0.18±0.05 mm/year and 0.11±0.03 mm/year. but considering the age of

1.5 Ma for the volcanic activity (Dautria et al. 2010). the differences are reduced. respectively 0.18±0.05 mm/year and about 0.14mm/year.

The second point considers that the volcanic cover protects from erosion the previous depressions and generates a relief inversion. This suggests a delay in the erosion process that can explain a lower mean erosion rate. But once the border of the volcanic cover has been exposed to erosion, it is easily demolished and falls on the slope of the ruffe. However the protection realized by the remaining peaces of the volcanic cover and giving the various "plans" (Basse. Carols) has not been yet eroded, and has favored the formation of a differentiated topography.

The last point is addressed to the importance and relevancy of the measured erosion rate. The value appears very low, not perceptible at human scale and representing only few centimeters over a century. Nevertheless, as for any geological process, it is necessary to consider large space and time periods. In order to get an idea of the practical effect of such erosion, we can consider than an erosion rate of only 0.1 mm/year corresponds to the extraction of 1 dm^3 ??? of rock for each square metre of land located near the bottom of the Salagou valley. This is also equivalent to 100 m^3 for 1 km^2. This estimation is considered only near the bottom of the valley, but not in the high relief, which lost elevation at a lower rate.

9 - Will the Salagou capture the Orb River ?

During the long time process of erosion of a mountain, the drainage network extends upslope, more or less fast according to climate and precipitation condition, the type of rock submitted to erosion, and the geological structures. It results from all these conditions than in a determined region adjacent rivers can increase in length at different rate. During this process a faster increasing drainage can reach and divert another one: this process is called a river capture (Bishop, 1995; Schumm et al., 2000). This is a very common phenomenon, occurring generally during the early stages of formation of a drainage network. Later in time it can move the divide line between two river basins. We have observed the development of the Salagou River upslope toward the La Merqière Pass, which is the divide line between the Orb and Salagou-Hérault river basins. The question now is can the Salagou River continue increasing its length, and La Merqière pass constitute moving basin divide between the Orb and Hérault hydrographic basins ?

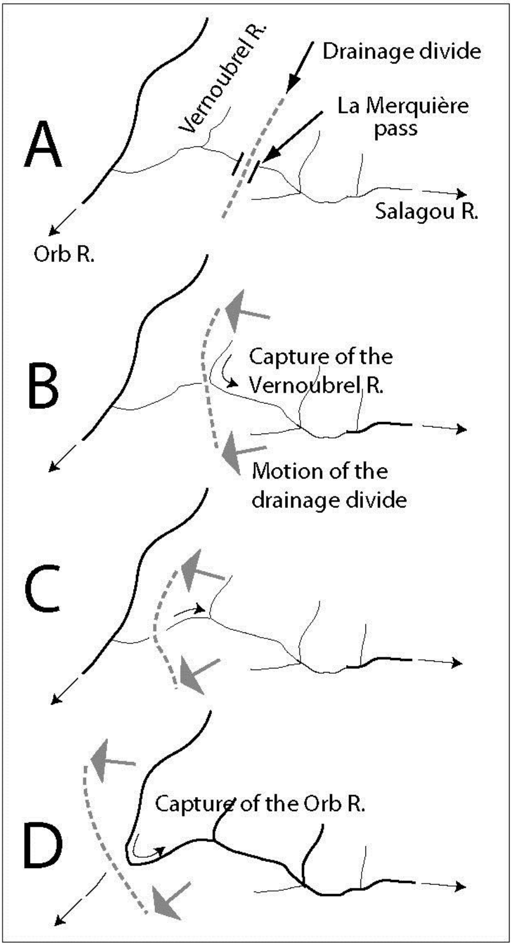

Fig. 8. Schema of a river capture. using the case of the Salagou and Orb rivers. Faster erosion of the Salagou valley pushes forward the drainage divide. capturing successively the Vernoubrel and Orb rivers.

During the Quaternary the Salagou River increased upslope preferentially westward for two main reasons. The first is that a northward extension is difficult because of the steep border of the Causse, and in this direction the hard basement of the Lodève metamorphic ridge. The other reason is due to structures: the erosion increases faster westward because of the presence of the ruffe, that stands in a W-E trending basin, limited southward by the Mas Blanc and Aires faults. A topographic section from the Orb River to the Lergue, through the Vernoubrel River, the La Merquière Pass and the Salagou River, show that the river bed of the Orb (214 m a.s.l. at Mas Blanc) stands 146 m higher than the Salagou River at its confluene with the Lergue River (68 m a.s.l. at the confluence). The faster vertical erosion of the Lergue and Salagou may be related to the less consolidated terrains: the Orb River crosses metamorphic schist of the Hercynian basement, which is more resistant to erosion than ruffe. Regarding the elevation differences and the erosion capacities of respective terrains, there is no reason to think that the westward increase of the Salagou River will stop. The suggested scenario will be the following: the La Merquière Pass, now at an elevation of 369 m a.s.l., will be progressively eroded. the upper Vernoubrel River captured. and the upslope erosion progressively reach the Orb River bed probably in Mas Blanc, the capture point of the Orb River by the Salagou River. No time prediction can be made for this capture, but some estimation can be hypothesized. Considering a vertical erosion rate of 0.1 mm/year for the river bed of the Salagou, the La Merquière Pass will be eroded down to the level of the Orb River in Mas Blanc in no more than 1.5 Ma. Another estimation can be made considering that the mean rate of longitudinal upslope increase of the Salagou River during quaternary is about 1.3 cm/year (20km in about 1.5 Ma). This gives a possible capture as soon as in 0.6 Ma, and a predicted capture of the Orb by the Salagou between 0.6 and 1.5 Ma in the future.

10. Discussion on landscape evolution and conclusion

Geology has a figurative dimension allowing the reconstruction of past landscapes, using the successive states of occurrence of rocks and structures in a determined region (Jonin, 2006; Michel, 1986), and analyzed intellectually by Claude Levy-Strauss (1993, p60-61). In most cases the landscape reconstruction is figured out through the study of the successive surfaces that shaped the region, which may be exposed in the present morphology as mosaic elements of old surfaces or planar contact between different types of rock.

Previous detailed studies from the Cévennes region (eastern part of the Hérault hydrographic basin) show that the landscape evolution has been slow, and realized during several identified stages (Séranne et al. 2002). These authors show that the main trends of the present drainage network is inherited from the morphologic slope developed 20 Ma ago between the old Massif Central (to the north) and the new opening Golfe du Lion (located between Marseilles and Perpignan). Most of the Cévennes relief was realized 5 Ma ago by an uplift of up to 700 m in the southern part of the Cévennes Fault, in the area where is located the ruffe basin. The present morphologys result from the drainage incision realized later than 5 Ma. In the area of the upper Hérault River Séranne et al. (2002) calculated a vertical erosion rate of the Hérault valley of less than 0,04 mm/year in the Mesozoic limestone cover. The ruffe is much more easily eroded than limestone, a higher erosion rate can be expected in the Salagou valley.

In the Salagou valley we can reconstruct more or less completely the morphology of the valley during two particular times. However to reconstruct completely the visible landscape at these times we lack of precision on the biological cover. A vegetation cover more continuous than the present one can only be expected during the formation the Riss terrace, but precise data are lacking.

Despite itss limited size, the Salagou valley is well inserted into the main structures of the area, and makes stand out their importance and permanency through geological times???. The valley extends along the south border of the Mas Blanc-Aires fault, which was previously part of the structure of the Permian ruffe basin. We can observe here than from a time to another the same structures conditioned the landscape, and only climate, vegetation cover and faunal occupation changed drastically.

We now try to quantify the presently ongoing erosion process. These measurements are indicative, and should certainly be précised by other measurements in more places because the effect of erosion is discontinuous and can change sensibly in scale, place and time. We got vertical erosion rate of the bottom of the valley ranging from 0.1 to 0.25 mm/year. These values are not surprising, and remain in the range of erosion calculated in other areas in France (to compare with similar climate zone) : for example 0.11 mm/year for the Meurthe and Moselle river valley (Cordier et al., 2004). 0.04 mm/year for the upper Hérault River valley on limestone (Séranne et al. 2002).

The idea of erosion is one of the basic concepts of geology. The idea that erosion reduces mountains slowly but definitively, and the eroded material is transported by the turbid water of rivers is commonly accepted, and comes from Greek antiquity. However it has been forgotten during the middle age and renew only with Renaissance???. The Mediterranean side of Languedoc, with accessible mountains slopping down to the coastal plain, a poor vegetation cover showing the rock skeleton of the earth, and precipitation charging rivers with colored sediments, has early been used as a testing area for geological concepts. During the 17th century the civil engineer Henri Gautier (1660-1737) observed and measured the sediment charge of Languedoc rivers, and got the idea of a long-time history of earth, that he estimated to more than 35000 years, probably in time for fear of the church (Ellenberger, 1994, p. 155). Some tenth years later in 1776 Antoine de Genssane estimated the vertical erosion of eastern Pyrenees to 10 inch/century, that is about 2.7 mm/year (ASNAT, 2012; Ellenberger, 1994, p.38). Regarding the knowledge and the instruments of that time, this result is incredibly close to the reality. We know now that the rate of mountain erosion measured at the top is not representative, because numerous phenomena such as active tectonics and hydrostatic adjustments can raise the top while the erosion of deep valley is going on (Babault et al.. 2009).

However for the common landscape observer not particularly sensible to geology, it is difficult to figure out the successive landscapes that have succeeded through time in a place, which are very different in remote geological times, but are progressively closer to the present landscape when entering Quaternary and prehistoric period. Seldom is a landscape it perfectly coherent with the present time, and very frequently the accustomed observer can detect scars of an ongoing transformation, such as badlands, mosaic elements of dissected terraces and surfaces, as observed in the Salagou valley. In frequent cases human activities and constructed surfaces, embankments of roads and rivers give the wrong impression that landscape is stable, under control. Unfortunately one day sudden and sometimes extreme events come and this demonstrates that landscape evolution never stops: a landslide triggered by extreme precipitation, a flood shifting a riverbed, a river capture, and in some particular regions an earthquakes or a tsunamis (Dumont et al, 2006). Also some side effects of erosion and transport are sometimes transferred from a place to another. Stabilizing erosion in valleys by constructing successive dams in mountainous regions, as it has been made in most areas of the world during the XXth century, stops most of the sediment transport to estuaries and coasts, triggering the accelerated coastal erosion observed in present time (Woodroffe, 2002, p.482).

The extrapolation to the future of observed erosion phenomena in the Salagou valley suggests a possible capture of the Orb River by the Salagou River. This is only now a tendency, however such a phenomenon occurs frequently in geological time) and constitutes a common rule of drainage network evolution (Bishop. 1995). River captures have been previously described in Minervois (western Languedoc) (Genna and Capdeville, 2007), in relation to slow deformations of the Montagne Noire (Larue, 2007). In the Hérault hydrographic basin Wienin (1986) describes the capture of the Dourbie by the Hérault, which moved the divide line between the Hérault and Tarn basins. In the case of the Salagou River we observe that the basin structure determined by the Mas Blanc-Aires fault constitutes a guide for the westward extension of the valley, with a tendency to reconstruct the previous late Carboniferous-Permian valley of Graissessac-Lodève. However this fault line is sealed by the quaternary volcanic activity, and seems presently inactive.

For most people the effect of a very low value phenomenon is difficult to realize, and a 0.1 or 0.2mm/year erosion rate may appear as a negligible element. However, at a time of great preoccupation for the preservation of our planet, thinking about the long-term effect of these slow rate processes is probably a better position than to neglect them.

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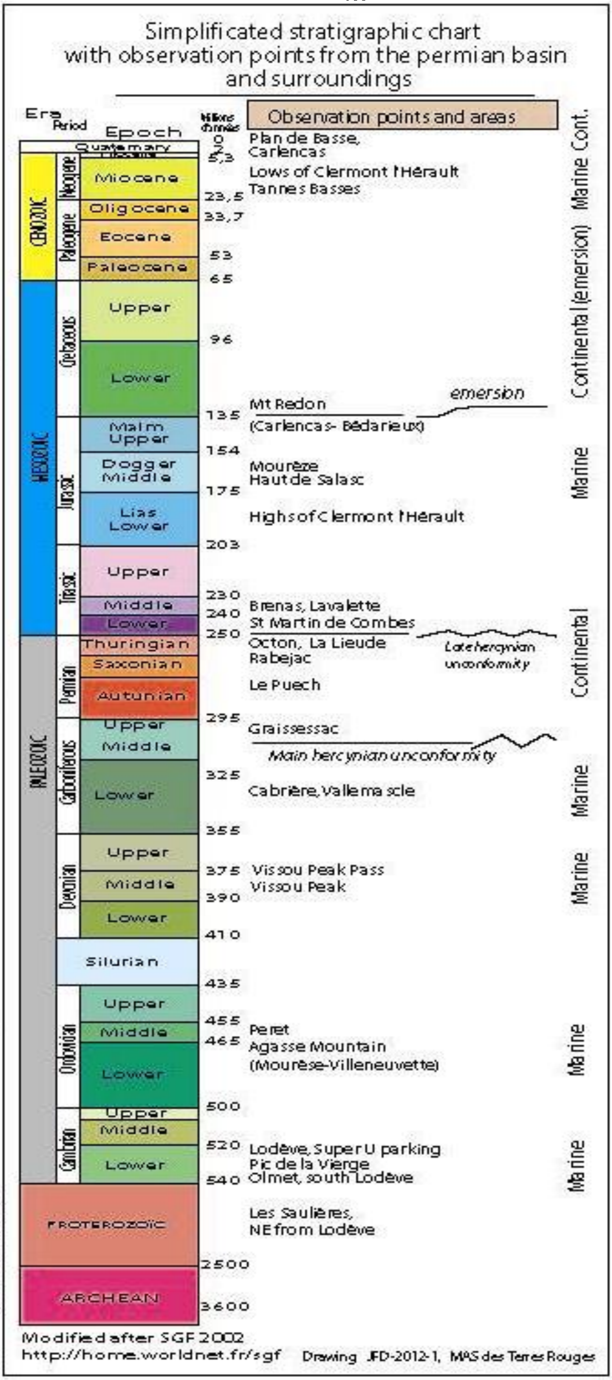
12 - Glossary

Realized using Foucault and Raoult (1985), Bates and Jackson (1980) and Allaby and Allaby (1991).

- **Argillite** : a sedimentary rock that does not split easily, formed from consolidated clay.
- **Badlands** : extensive tracts of heavily eroded, uncultivable land with little vegetation.
- **Basalt** : a dark, fine-grained volcanic rock that sometimes displays a columnar structure, but locally intrusive as dikes. It is typically composed largely of plagioclase with pyroxene and olivine.
- **Capture of river or stream :** the natural diversion of the headwater of one stream into the channel of another stream having greater erosion activity and flowing at a lower level.
- **Carboniferous** : a period or system of the Paleozoic era ranging from about 345-355 to 280-295 million years ago. In Languedoc the main Hercynian deformations occurred during the lower Carboniferous, and are sealed by the late Carboniferous, but extended until Permian.
- **Continental margin** : border of a continent comprising the ocean floor that is between the shoreline and the abyssal ocean floor.
- **Dike** : a tabular igneous intrusion that cuts across the bedding or foliation of the country rock.
- **Drainage basin** : A region or area bounded by a drainage divide and occupied by a drainage system.
- **Drainage divide** : Separation line between two adjacent drainage basins.
- **Erosion surface or terrace :** a land surface shaped and subdued by the action of erosion, especially by running water.
- **Facies** : The character of a rock expressed by its formation, composition, and fossil content.

- **Fault :** a fracture or a zone of fractures along which there has been displacement of the sides relative to one another parallel to the fracture, making a discontinuity of strata on either side of the fracture.
- **Fracture** : a general term for any break in a rock whether or not it causes displacement.
- **Hercynian orogeny** : late Paleozoic orogenic era of Europe extending through Carboniferous and Permian.
- **Hydrographic basin** : the drainage basin of a stream.
- **Hydrographic divide** : Separation line between two hydrographic basins.
- **Interfluve** : a region between the valleys of adjacent watercourses, especially in a dissected upland.
- **Laterite** : a reddish clayey material, hard when dry, forming a topsoil in some tropical or subtropical regions.
- **Little Ice Age** (LIA) : a cool, brief interval in an otherwise warm inter-glacial stage. It lasted from about AD 1300 to 1850. The LIA follow the Medieval Warm Period (MWP, also called Medieval Climate Optimum) lasting from about AD 950 to 1300. During these periods climatic effects other than temperature were important.
- **Mesozoic** : Geologic era that lasted from about 245 million to 65 million years ago. Large reptiles were dominant on land and sea throughout this time; vegetation had become abundant, and the first mammals, birds, and flowering plants appeared.
- **Neck** : a column of solidified lava or igneous rock formed in a volcanic vent, especially when exposed by erosion.
- **Orogeny :** a process in which a section of the earth's crust is folded and deformed by lateral compression to form a mountain range.
- **Paleozoic** : Geologic Era that lasted from about 570 million to 245 million years ago. The era began with the first invertebrates with hard external skeletons, notably trilobites, and ended with the rise to dominance of the reptiles. Its end is marked by the most important mass extinctions registered on earth.
- **Permian** : Last geological period of the Paleozoic Era. The Permian lasted from about 295 million to 250 million years ago. The climate was hot and dry in many parts of the world during this period, which saw the extinction of at least 90% of the flora and fauna on earth, including trilobites, and the end of proliferation of reptiles. The European Permian includes the Autunian, Saxonian and Thuringian.

- **Playa** : an area of flat, dried-up land, especially in a desert basin from which water evaporates quickly.
- **Quaternary** : the Quaternary began two to three millions years ago and extends to the present. It consists of two unequal epochs : the Pleistocene up to about 10000 years ago, and the Holocene since that time. Humans and other mammals evolved into their present forms and were strongly affected by successive glacial and inter glacial periods.
- **Sedimentary lens :** a geologic deposit bounded by converging surfaces, thick in the middle and thinning out toward the edges.
- **Stratigraphy** : the branch of geology concerned with the order and relative position of strata and their relationship to the geological time scale.
- **Subsidence** : the sudden sinking or gradual downward of the Earth's surface with little or no horizontal motion. Subsidence occurs generally relatively to its surrounding parts, such as a rift valley or the lowering of a coast due to tectonic movement.
- **Thuringian** : geological stage used in Europe. Corresponds to Upper Permian and lasted about 45 million years. Thuringian stay over Saxonian and below Triassic
- **Transgression** : define the spread or extension of the sea over land areas, and the consequent evidence of such advance, such as strata of marine sediments deposited unconformably on older rocks.
- **Unconformity :** a substantial break or gap in the geological record, where a rock unit is overlain by another that is not next in stratigraphic succession. In most cases a different dip between the two rock units is observed.
- **Volcanic center:** a site at which volcanic activity is occurring or has occurred in the past.


Simplificated stratigraphic chart
with observation points from the permian basin
and surroundings
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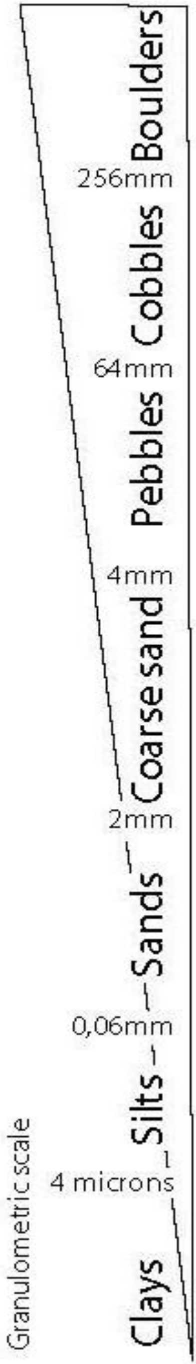
Period
Epoch
Observation points and areas
Quaternary
Miocene
Oligocene
Eocene
Paleocene
Upper
Lower
Malm Upper
Dogger Middle
Lias Lower
Upper
Middle
Lower
Thuringian
Saxonian
Autunian
Upper
Middle
Lower
Upper
Middle
Lower
Silurian
Upper
Middle
Lower
Upper
Middle
Lower
CENOZOIC
Neogene
Paleogene
MESOZOIC
Cretaceous
Jurassic
Triassic
PALEOZOIC
Permian
Carboniferous
Devonian
Ordovician
Cambrian
PROTEROZOIC
ARCHEAN
0
2
5,3
23,5
33,7
53
65
96
135
154
175
203
230
240
250
295
325
355
375
390
410
435
455
465
500
520
540
2500
3600
Plan de Basse,
Carlencas
Lows of Clermont l'Hérault
Tannes Basses
Mt Redon
emersion
(Carlencas- Bédarieux)
Mourèze
Haut de Salasc
Highs of Clermont l'Hérault
Brenas, Lavalette
St Martin de Combes
Octon, La Lieude
Rabejac
Late hercynian unconformity
Le Puech
Graissessac
Main hercynian unconformity
Cabrière, Vallemascle
Vissou Peak Pass
Vissou Peak
Peret
Agasse Mountain
(Mourèse-Villeneuvette)
Lodève, Super U parking
Pic de la Vierge
Olmet, south Lodève
Les Saulières,
NE from Lodève
Marine Cont.
Continental (emersion)
Marine
Continental
Marine
Marine
Marine
Marine
Modified after SGF 2002
http://home.worldnet.fr/sgf
Drawing JFD-2012-1, MAS des Terres Rouges


Boulders
256mm
Cobbles
64mm
Pebbles
4mm
Coarse sand
2mm
Sands
0,06mm
Silts
4 microns
Clays
Granulometric scale

M.A.S. des Terres Rouges
Mairie de Salasc
34800 Salas**c**

Version 30 avril 2013
Mise à jour 19 juillet 2015

MAS des Terres Rouges
www.masdesterresrouges.asso.fr