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# A tour in the Luberon Regional Nature Park UNESCO Global Geopark

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**Fieldtrip guide INA18 – 2-3 September 2022**  
**A tour in the Luberon Regional Nature Park**  
**UNESCO Global Geopark**

**Pauline Coster**  
**Stéphane Legal**  
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**International  
Nannoplankton  
Association**





# Fieldtrip guide INA18

## Luberon Regional Nature Park – UNESCO Global Geopark

### 2-3 September 2022

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#### Introduction

The Luberon regional nature park is located in Provence and is part of the French Prealps. The region presents a high diversity of geological deposits. The area is protected by a national geologic nature reserve and is recognized as a UNESCO Global Geopark. It includes three mountain ranges that are oriented W-E: The Monts de Vaucluse (Vaucluse Mountains) and the Montagne de Lure (Lure Mountain) to the north, and the Luberon Range to the south. They are composed of Upper Jurassic to Lower Cretaceous carbonates that are often karstified. They form the northern and southern limb of a narrow syncline filled with mid Cretaceous and middle Eocene to lower Miocene deposits, often referred as the Apt-Forcalquier Basin, drained today by the Calavon River. Folding and uplift of the Luberon as well as deposition of the Apt-Forcalquier Basin series can be related to the late Pyrenean-Provençal tectonic phase (Eocene) and the subsequent Alpine tectonic phase (Oligocene to present), including to the late Paleogene set-up of the Middle Durance fault zone that bound the Park to the east.

We will visit five geological highlights of the Luberon during the fieldtrip (Fig. 1), including:

- 1 – the Cretaceous ochre sands at the Roussillon Village;
- 2 – the Aptian historical stratotype at Saint-Saturnin-lès-Apt;
- 3 – the Urgonian carbonate platform at Rustrel;
- 4 – the Miocene bioclastic molasse at Buoux castle;
- 5 – the Oligocene tracksite of Saignon.

#### Day 1 morning

##### 1. Roussillon village

The village of Roussillon is renowned worldwide for its rich deposits of ochre. Built directly on the ochre sands (Fig. 2), the old village is ranging from yellow, red to deep orange or brown colors (Figs. 3-4). Surrounded by old quarries, the view over the plain is beautiful. The ochre sandstones were exploited during the nineteenth and twentieth centuries and contributed to the economic growth of the region.

The ochres come from the alteration of Albo-Cenomanian marine, glauconitic sandy sediments (Triat, 1982). Sedimentary figures and burrows characteristic of the marine glauconous green sands are preserved in the ochre sands. The majority of the alteration occurred as the result of the upper Cretaceous emersion of the "Durancian Isthmus", while bauxites were forming further south (Guendon, 1985). In Luberon, the alteration of the sandy, glauconitic deposits produced ochre sands, whose finest fraction (commercially-exploited ochre) consists of kaolinite and goethite (Triat, 2010). Intense leaching under a hot and humid climate resulted in the hydrolysis (and associated decarbonation, desilicification, and subsequent whitening) of the uppermost part of the glauconious sediment, while the accumulation of silica and sesquioxides down-profile resulted in the formation of a continuous, thick silcrete / ironcrust horizon that today caps the ochre sand layers. The ochreous color of the sands found below the silcrete results from goethite accumulation down profile and slow solutinal weathering in phreatic waters, contemporaneous of the pedogenic weathering in the upper part of the profile. This alternate mechanism resulted in the decarbonation of the lower parts of the profile and in the replacement of glauconite by kaolinite without altering the sedimentary structures of the Albo-Cenomanian marine sands. These processes form a typical paleoalteration profile (Triat, 2010) that can be observed in Roussillon and presents the following sequence, from bottom to top: (1) unaltered sandy to quartzitic rocks; (2) green decarbonated glauconious sands; (3)

rubified sands and ochreous kaolinitic sands; (4) whitened sands with thick siliceous and ferruginous concretions (Fig. 5).

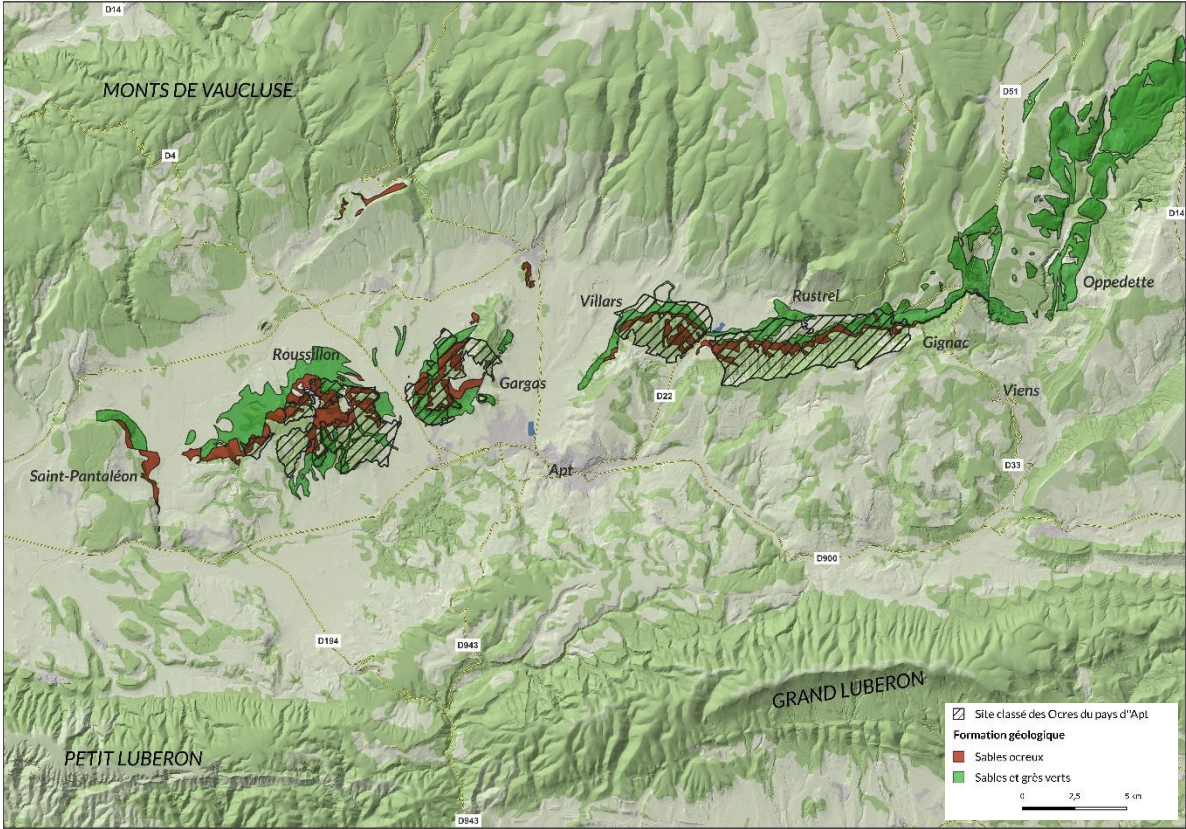


Fig. 2: The ochre massif in Luberon with ochre deposits (red) and glauconitic sandstones (green). Map SIT PNR PACA, Raphaël Loiseau.



Fig. 3: View of Roussillon village.



Fig. 4: Roussillon ochre sand deposits.

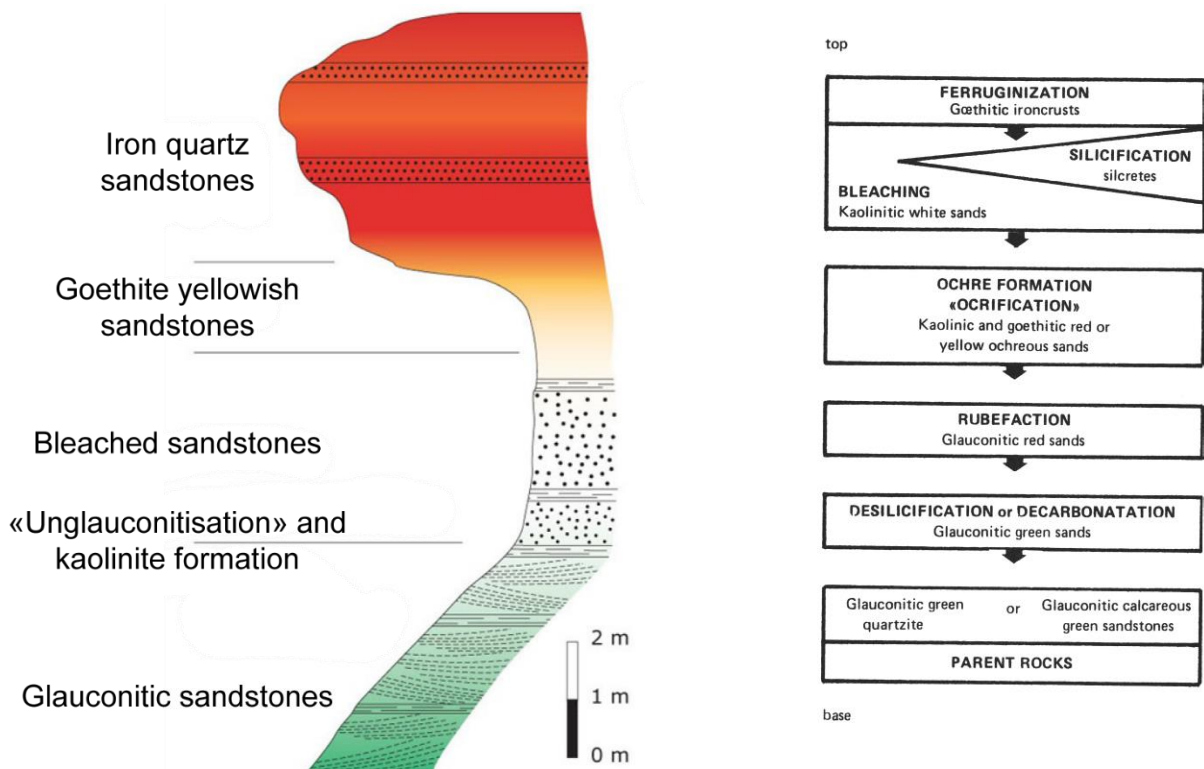


Fig. 5: The ochreous paleoalterations presenting a vertical succession of replacing facies (Triat, 2010).

## Day 1 afternoon

### 2. Aptian marine marls near Apt

The Aptian stage was created in 1840 by Alcide d'Orbigny based on observations of ammonites in the so-called Plicatules claystones which corresponds to the bluish/greyish marls northeast from Apt (d'Orbigny, 1940; 1942; 1950). Those marls are erodible outcrops from which abundant pyritized ammonites and belemnites could be retrieved. Historically, the Aptian was divided in 3 parts:

- the lower Aptian – named Bédoulien in Provence in relation to Roquefort-la-Bédoule near Marseille – is represented by Urgonian thick bioclastic carbonates in some part of the Luberon. Only the very end of this regional stage is represented by calcareous marls. However, in other part of the Luberon, the lower Aptian is represented by yellowish and bluish marls relatively similar to the middle Aptian.

- the middle Aptian – Gargasien in Provence named after Gargas near Apt. This part of the Aptian corresponds to the original description of d’Orbigny.

- the upper Aptian – called Clansayésien in Provence named after Clansayes in the Rhône valley near Montélimar – is partly represented by the marine green glauconitic sandstones.

Nowadays, the Aptian is divided into two substages with the lower Aptian corresponding to the Bédoulien and the bottom half of the Gargasien and the upper Aptian corresponding to the top half of the Gargasien and the Clansayésien. This division is originally based on ammonite zonation. The lower Aptian is represented by four ammonite zones, namely from bottom to top *Deshayesites oglanlensis*, *De. forbesi*, *De. deshayesi*, *Dufrenoyia furcata*. The upper Aptian is represented by four ammonite zones namely from bottom to top by *Epicheloniceras martini*, *Parahoplites melchioris*, *Acanthohoplites nolani* and *Hypacanthoplites jacobi* (Reboulet et al., 2018).

STAGES		ZONES	SUBZONES
APTIAN	upper	<i>Hypacanthoplites jacobi</i>	
		<i>Acanthohoplites nolani</i>	<i>Diadochoceras nodosocostatum</i>
		<i>Parahoplites melchioris</i>	
		<i>Epicheloniceras martini</i>	<i>Epicheloniceras buxtorfi</i>
			<i>Epicheloniceras gracile</i>
			<i>Epicheloniceras debile</i>
	lower	<i>Dufrenoyia furcata</i>	<i>Dufrenoyia dufrenoyi</i>
			<i>D. furcata</i>
		<i>Deshayesites deshayesi</i>	<i>Deshayesites grandis</i>
		<i>Deshayesites forbesi</i>	<i>Roloboceras hambrovi</i>
	<i>Deshayesites oglanlensis</i>	<i>Deshayesites luppovi</i>	

Fig. 6: Aptian scheme and ammonite zonation according to the Killian group (Reboulet et al., 2018).

The Aptian marls outcropping in La Tuilière (Saint-Saturnin-lès-Apt), as well as the site of Clavaillan (Roussillon), located 3.5 km west of La Tuilière, are close to the historical stratotype. However, there is no remaining outcrop of the historical stratotype as all original outcrops have been covered by urban development in Apt (Balme and Legal, 2018). The historical outcrops were however lacking the base and the top of the current definition of Aptian (Moullade et al., 2009). Up to now, there is no GSSP for the Aptian and it cannot be defined near the historical stratotype. Considering that the original Aptian *sensu* d’Orbigny (1940) – termed Aptian *sensu stricto* – corresponds to the base of *Du. furcata*, a GSSP was proposed based on the Clavaillan section (Fig. 7; Moullade et al., 2011; 2017; Frau et al., 2017). Although no outcrop depicts the full Aptian s.s. marly sequence – especially now with a higher anthropic cover – the sole *Du. furcata* zone is 100 m thick (Moullade et al., 2017). The marly Aptian makes a series of badlands in the landscape that are very difficult to connect stratigraphically. A previously used horizon for correlating the sites, the “niveau blanc” (*i.e.* white level; Fig. 8) does not correspond to one lithologic level but at least two (Moullade et al., 2017).

The macrofauna is mainly composed of Mollusca and Cephalopoda with ammonites and belemnites (Figs. 9-11). Relatively diluted in the outcrops, belemnites and pyritized ammonites are easy to sample downslope thanks to weathering and erosion. The marls also host benthic and planktic foraminiferas and ostracods (Moullade et al., 2008; 2017). The nannofossil

biostratigraphic limit between NC6b and NC7a (Fig. 12; following Bralower et al., 1995) was identified (Bornemann in Moullade et al., 2017). You can see some species retrieved in this section (Fig. 13). Nevertheless, the current position of NC6b/NC7a boundary at Clavaillan is in contradiction with the integrated biostratigraphic chart which place this boundary above *Deshayesites deshayesi*/*Dufrenoyia furcata* boundary (Fig. 12; Bown et al., 1998). This contradiction may be related to the low preservation of calcareous nannofossil in this section.

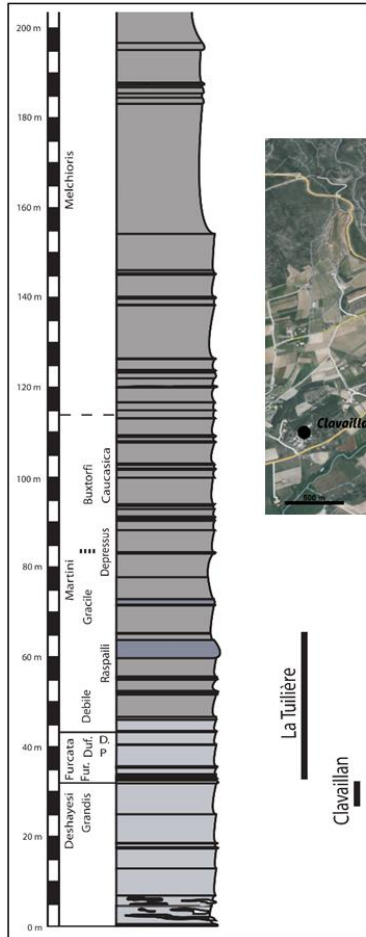


Fig. 7. Stratigraphic extension of La Tuilière (Les gays) and Clavaillan sections.



Fig. 8: Clavaillan section proposed for GSSP of Aptian s.s. The level at 10 m less erodible and marking a color limit in the outcrop is a stratigraphic marker called *niveau blanc* (Frau et al., 2017; Moullade et al., 2017).

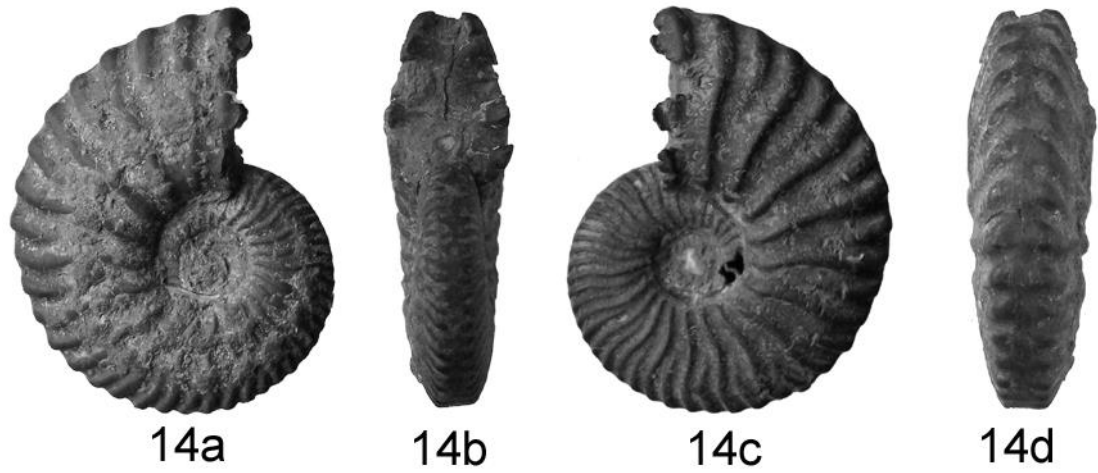


Fig. 9: *Dufrenoyia furcata* La Tuilière, (TU Pi 1 ), *Du. furcata* zone, *Du. furcata* subzone, FSL 584256, coll. Dutour et Atrops.



Fig. 10: *Aconeceras nisus*. La Tuilière, *Du. furcata* zone, *Du. dufrenoyi* subzone, FSL 584377, coll. Dutour et Atrops.

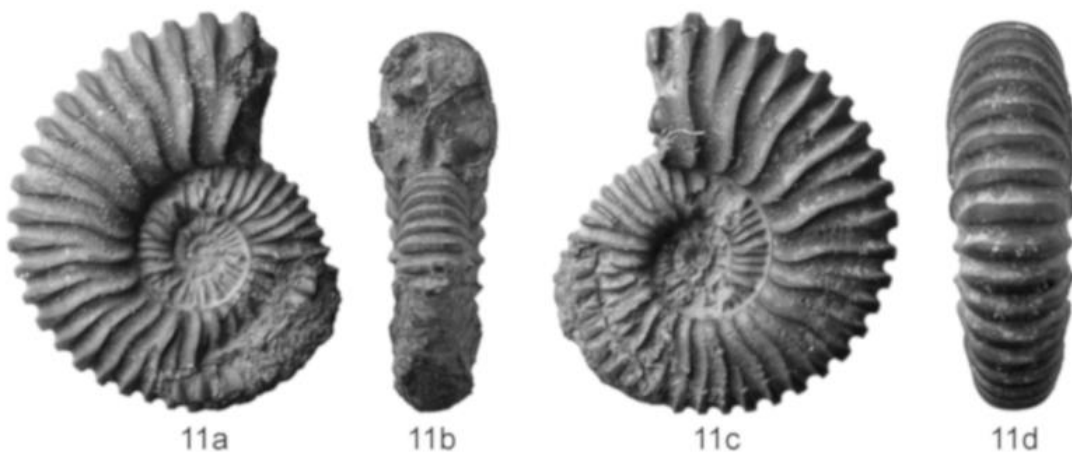
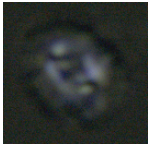
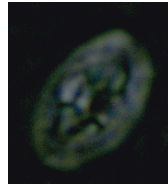


Fig. 11: *Colombiceras crassicostatum*. La Tuilière, *E. martini* zone, *E. debile* subzone, FSL 584191, coll. Dutour.





*Biscutum constans*



*Bukrylithus ambiguus*



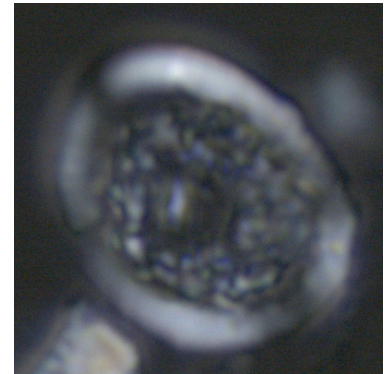
*Discorhabdus ignotus*



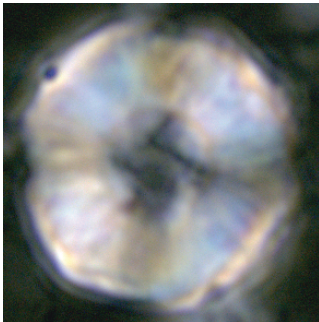
*Rhagodiscus asper*



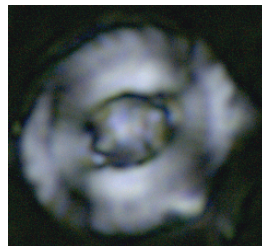
*Rhagodiscus asper*



*Rhagodiscus amplus*



*Nannoconus sp.*



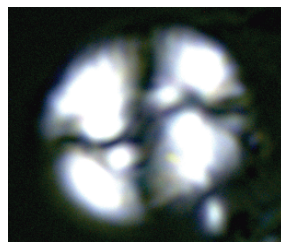
*Tubodiscus burnettiae*



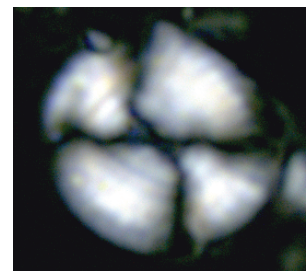
*Watznaueria ovata*



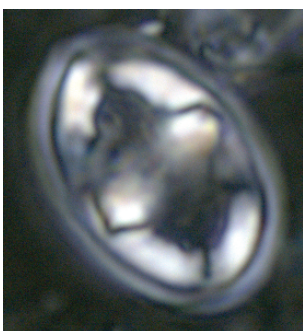
*Watznaueria britannica*



*Watznaueria fossacincta*



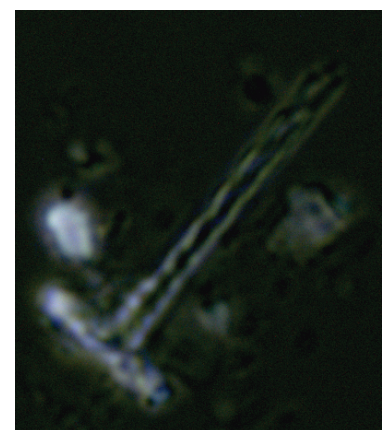
*Watznaueria barnesiae*



*Zeugrhabdotus embergeri*



*Zeugrhabdotus erectus*



*Tetrapodorhabdus coptensis*

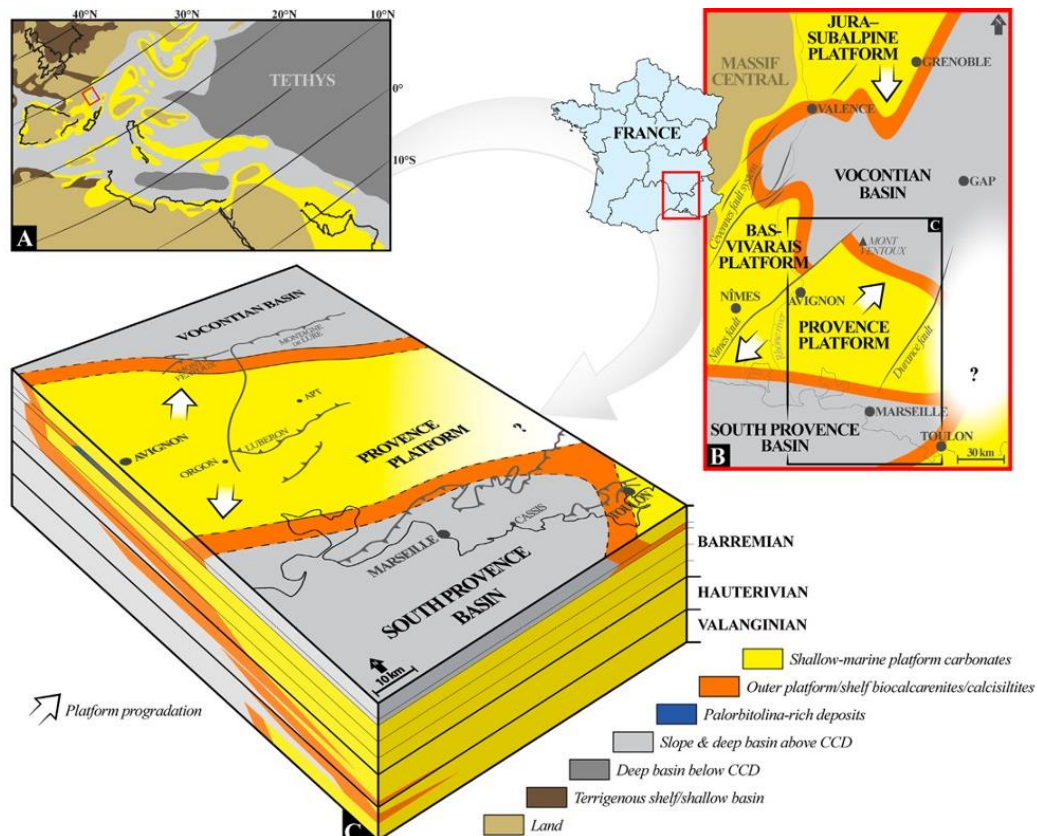


Fig. 14: A. Palaeogeography of the West-European Tethys during Barremian to Aptian ages (modified from Masse et al., 1999). B. Palaeogeographic reconstruction from South-East France. C. Chronostratigraphic diagram from Valengianian to Barremian carbonate platforms. Figure from Tendil (2018).

The composite Rustrel succession is based on the study of a borehole section and three outcrops as described below (Fig. 15). The 408 m-deep borehole section in the Gavotte area, near the Emergency Exit of the Low-Noise Underground Laboratory (LSBB), exhibits a subcomplete succession of the U1, U2 and U3 formations as follows:

- U1 – Oobioclastic, echinoderm-dominated, limestones with a minimum thickness of ~170 m are documented in the basal part of the borehole.
- U2 – This formation grades upward into a ~180 m-thick, rudist-rich limestones divided into four main units: a. Above a coral-rich bed, an *Agriopleura*-bearing unit (~20 m), is recognized. The LO of *Agriopleura* is associated with a regional emersive surface (UB.d2). b. A ~30 m-thick, Orgon-type requieniid–monopleurid-dominated unit, marked at its base by a foraminiferal-rich bed. c. A thick echinoderm-dominated, pack- to grainstone unit (~40 m) with a well-developed coral-rich bed (~12 m) in its middle part. This marked change in the sedimentary pattern is herein interpreted as a lateral counterpart of the *Palorbitolina–Heteraster* drowning event (UB.d3). d. The upper unit consists in the recovery of the rudistid platform, represented by a chalky, grainstone-dominated (Fig. 16A), caprinid beds (U2 s.s.) which defines the Rustrel fauna (*Offneria–Pachytraga–Praecaprina* assemblage). Foraminiferal-rich, rudist-free intervals are notably observed. This unit terminates at a well-expressed, irregular exposure surface (UB.d4) characterised by extensive dissolution of rudist shells.
- U3 – This ~50 m-thick formation is represented at its base by *Palorbitolina*-rich, packstone (Fig. 16B) deposits (~5 m) which fill the underlying dissolution-related voids. The latter orbitolinid horizon passes vertically into a ~45 m-thick oobioclastic-dominated, grainstone unit (Fig. 16C).

Northeast to Rustrel, along the departmental road D30, the section (Les Antennes in Léonide et al., 2012) is composed at its base by a 10 m-thick coral unit overlain by a caprinid-coral rudstone channel followed by the deposition of the caprinid beds (U2 s.s.; ~90 m) The U2/U3

transition includes a distinct emersive surface (UB.d4) overlain by *Palorbitolina*-rich packstone (thickness 4 m), oolitic grainstone (thickness 8.5 m), coral-rich episode topped by a coral-rudist rudstone (thickness ~7 m) and ends with coarse, graded biocalcarenites.

The Urgonian limestones from Provence are valid outcrop analogues of Middle East carbonate reservoirs (Thamama, Kharai and Shuaiba formations; Alsharhan and Nairn, 1997), from different points of view: age, facies, paleoenvironments and reservoir properties (pore types, porosity, permeability) (Borgomano *et al.*, 2002; Sallier and Hamon, 2005; Sallier, 2006; Fournier *et al.*, 2011; Léonide *et al.*, 2012).

Porosity values within the chalky packstone/grainstones (Fig. 16D) range from 10 to 23%. Thin beds (<0.5 m) of greyish tight limestones (porosity <10%) are related to cementation processes within the intercrystalline micropore space of the microporous grains (Fig. 16D). Tight grainstones (Fig. 16C) are interpreted to have been deposited in the shallowest and innermost part of the carbonate platform (see Léonide *et al.*, 2014 for details of the diagenetic sequence).

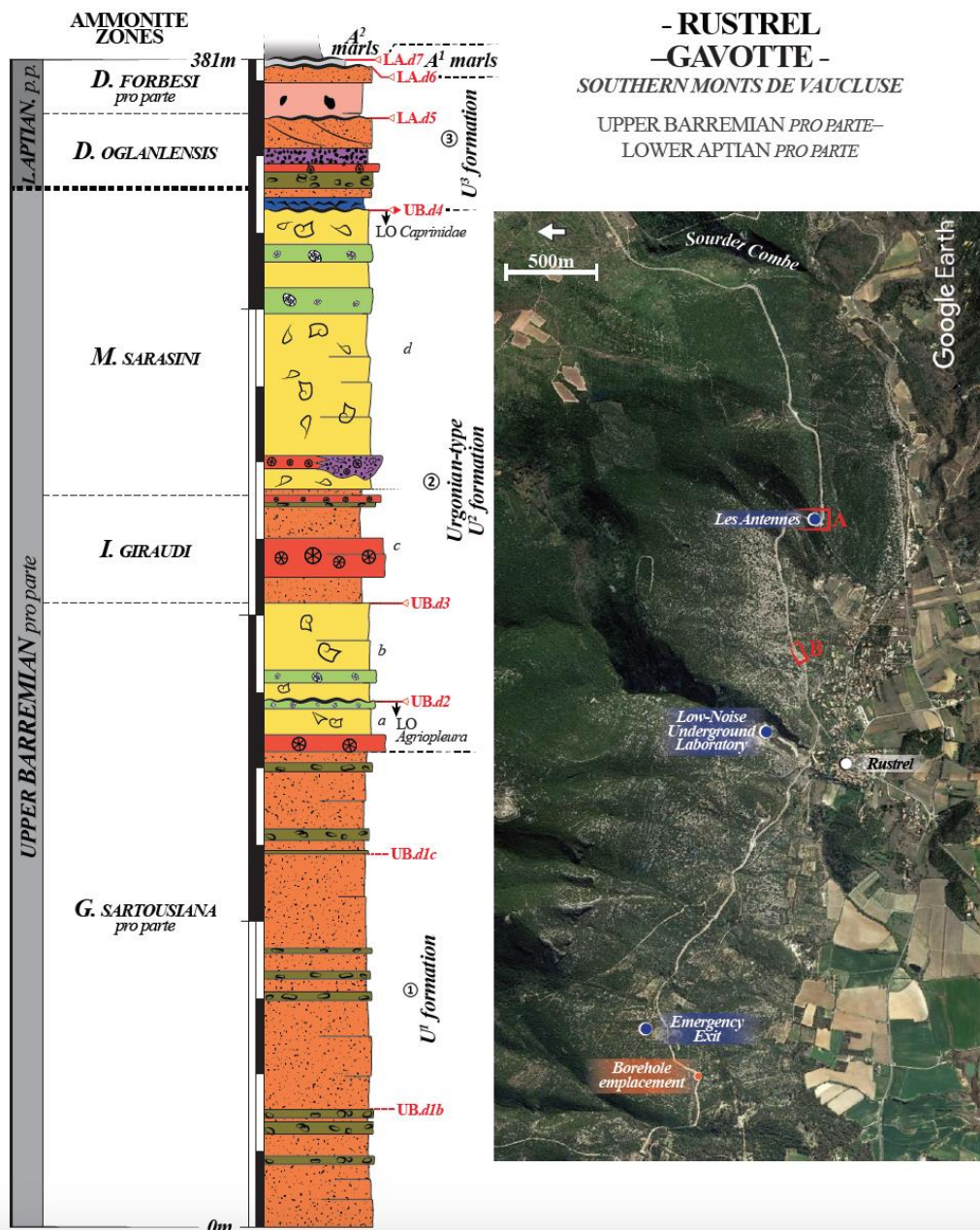


Fig. 15: Localisation and synthetic litho-log of the Rustrel–Gavotte composite section (Southern Monts de Vaucluse). Figure from Tendil, 2018.

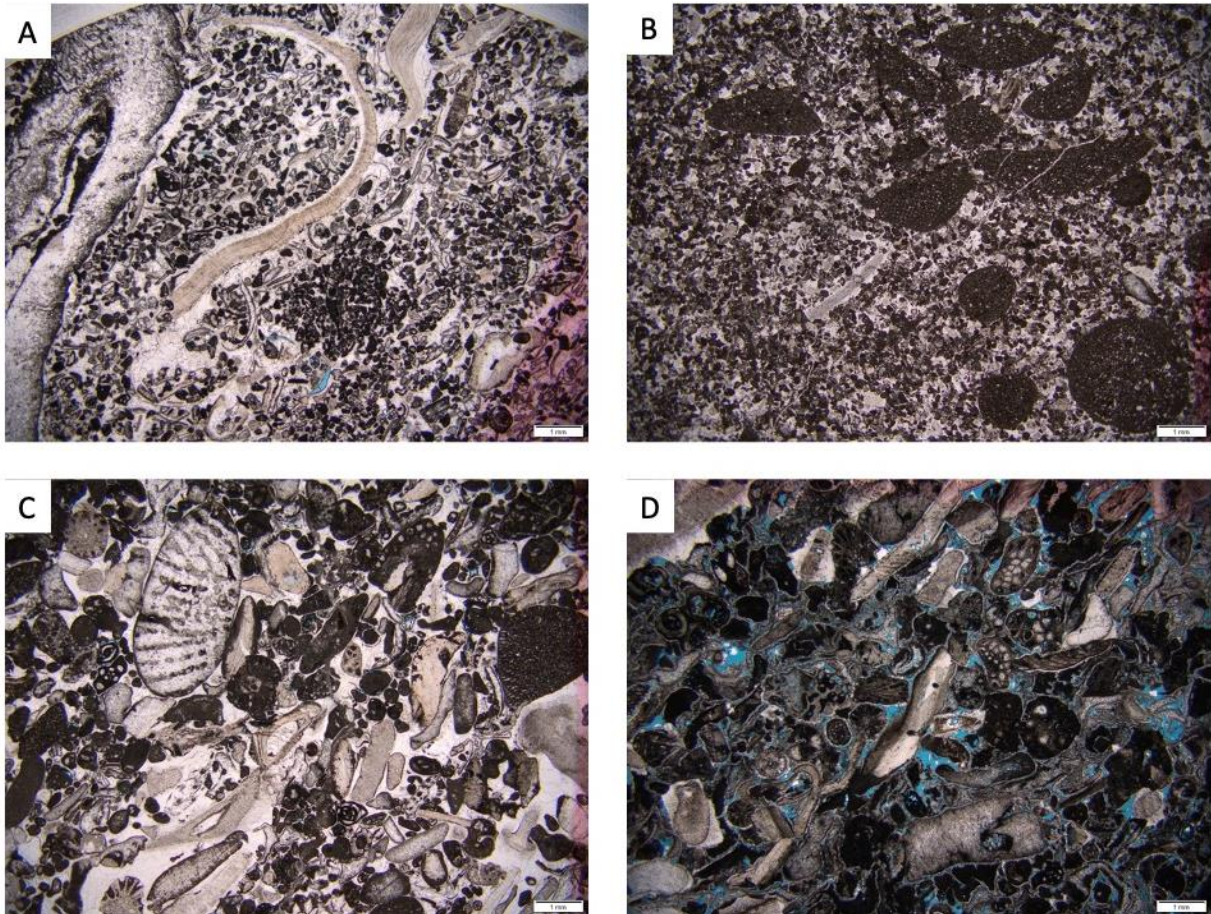


Fig. 16: Typical carbonate platform facies from Rustrel section. A. Tight rudistid grainstone. B. *Paleorbitonila* echinids -rich facies. C. Tight cemented bioclastic grainstone. D. Porous (microporosity and intergranular porosity) bioclastic grainstone.

## Day 2 morning

### 4. Fort de Buoux (Buoux Castle) and the Miocene marine molasses

The Fort de Buoux is located in the Aiguebrun valley, south of Apt. The Aiguebrun valley marks the separation between the eastern (Grand Luberon) and western (Petit Luberon) parts of the Luberon Mountains and offers a corridor through the range, connecting the plains of the Calavon River to the Durance River further south.

The Buoux area has been inhabited since the middle paleolithic. The middle and upper neolithic is particularly represented as well as the bronze age but only artefacts are observed. The most famous ruins in this area are from Fort de Buoux. The site was originally a medieval castrum located on the side of a path crossing the Luberon mountain. The foundation of the fort dates back to the 10<sup>th</sup> century. Defended by ramparts which extend the walls of the cliffs, the village of Biolis/Biols acquires the various attributes characteristic of social and administrative entities: the houses of the village, the church, the defenses and the castle placed at the top (Markiewicz and Hartmann-Virnich, 2007). The current castle was built in 13<sup>th</sup> century but may come from previous fortification based on the organization and part of the church. The Fort de Buoux is particularly well situated to prevent attack, being place on the top of a cliff. the defenses composed of barrier walls, ditches and chicane passages are rare and complex. The construction cleverly takes advantage of the natural setting and is based on an advanced knowledge of poliorcetics (the art of attack and defence), inspired by the great Middle Eastern achievements of the time of the Crusades. Several silos for food or water conservation directly dug into the rock are also present. From the 13<sup>th</sup> century, the main door, the angle tower, and the watchtower are present. From the 16<sup>th</sup> century, the guardhouse, the main house and the village, the 3 floored tower and the fortified house were constructed.

The castrum went through feudal times marked by rivalries between the counts of Forcalquier, Toulouse and Provence without any real problem until the terrible “great plague” or “black plague” which decimated more than half of the population in Pays d’Apt in the years 1348-1349.

Fallen into disuse, the old village was re-occupied during periods of trouble in the 16th century. By that time, the lords of Buoux had already built their new castle in the countryside, far from the deserted village. The presence of soldiers, less and less busy and useful in the defense of the fort, is attested until the middle of the 17th century. In 1649, the garrison composed of only a few men definitively left the place dedicated to natural demolition or caused by visitors.

Given to the town by the owner in 1986 and then listed as a heritage site, the site was officially opened to the public. Since 2007, the Fort has been the subject of programs that include archaeological studies and conservation work, the main objective of which is the protection of the ruins.

The Fort de Buoux is built on Miocene calcareous sandstones of marine origin locally called “molasse”. The lower and middle Miocene series are visible along continuous cliffs of the Claparèdes plateau in the Aiguebrun valley. The Miocene deposits up to 100 m-thick unconformably overlies the Urgonian tilted limestones. The base of the Miocene formation is dated to the Aquitano-Burdigalian (Besson, 2005). The Miocene series is composed of conglomerates and bioclastic calcarenites where oblique laminations are clearly visible. The fossil fauna includes *Chlamys praescabriuscula*, *Flabellipecten* and *Echinolampas*. Marine organisms composing the bioclastic mixture are often difficult to identify: calcareous algae, bivalves, corals. The fragmentary fossil fauna indicates deposition in a warm and well-oxygenated marine environment agitated by currents. The Aquitanian to Tortonian marine transgression is related to the Oligocene post-rift subsidence and Miocene Liguro-Provence drifting (Besson et al., 2002; Clauzon et al., 2011).

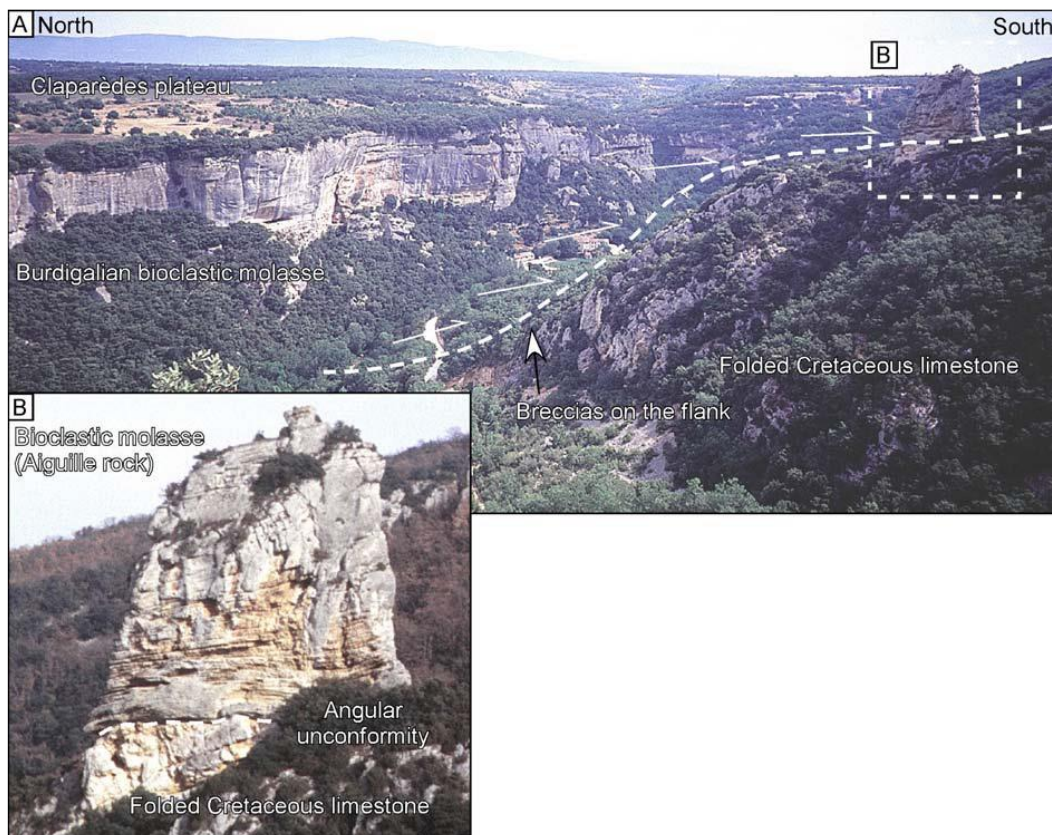


Fig. 17: A. General view of the Aiguebrun valley (Besson, 2005). B. Angular unconformity of the Burdigalian molasse on the folded limestones of the Cretaceous and the onlap of the Burdigalian limestones.

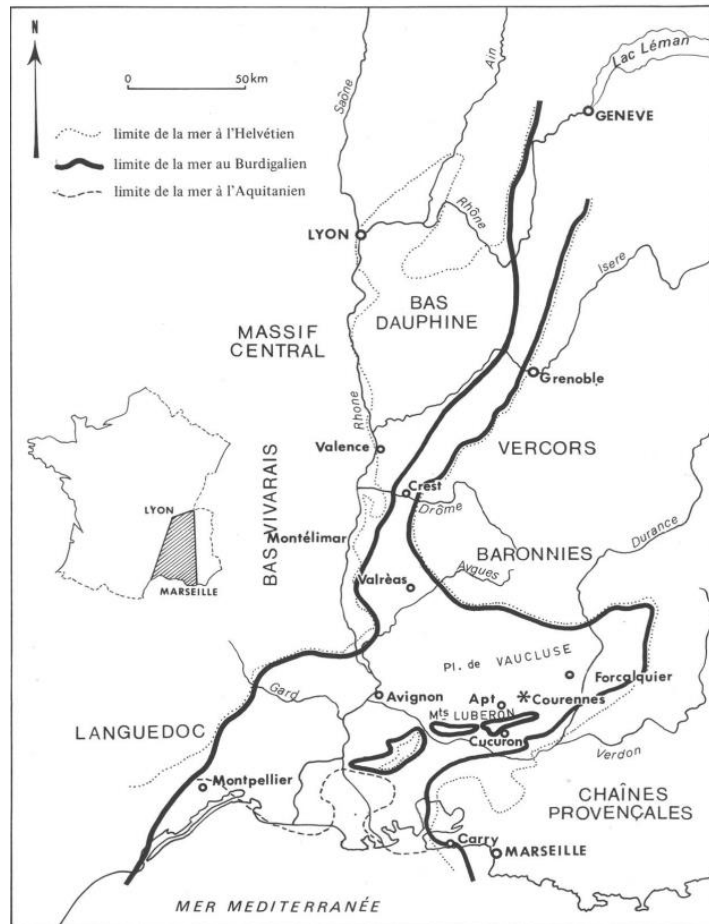


Fig. 18: Extension of the Miocene transgression in the rhodanian basin (Besson 2005).



Fig. 19: View of the Buoux Fort.

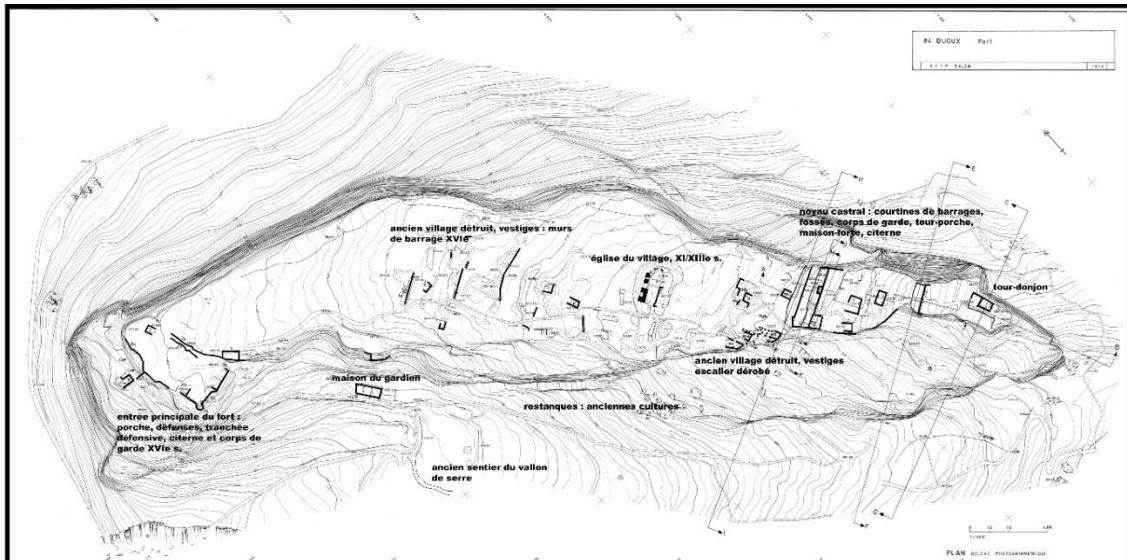


Fig. 20. Map of the Buoux Fort

## Day 2 afternoon

### 5. Mammal tracks Saignon

The Saignon tracksite is located in a former limestone quarry in Saignon. It yields thousands of well-preserved fossil tracks on the surface of a limestone bed dated to the early Oligocene. The site consists of two main levels:

- The lower level (D2) is the largest – about 400 m<sup>2</sup> – and yielded a thousand of mammal fossil footprints. Most of the tracks are attributed to small to large-sized artiodactyls (even-toed ungulates) and perissodactyls (odd-toed ungulates). Some of the tracks are organized into trackways and sometimes show pes-manus impression.
- The upper level (D6) has bird tracks and sedimentary structures (ripple marks, desiccation cracks, oncolites).

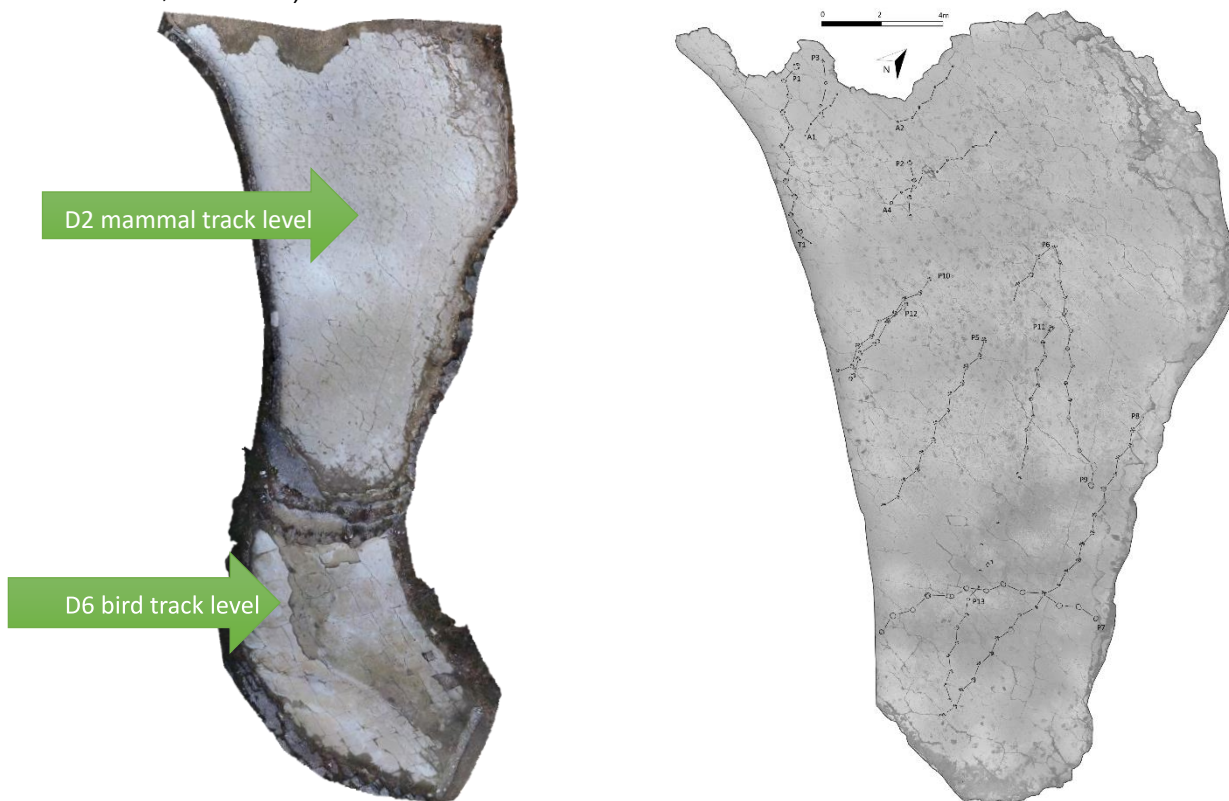


Fig. 20: Map of D2 level and location of mammalian trackways (P: perissodactyl; A: artiodactyls).

The tracks are preserved on a micritic limestone almost entirely composed of lime mud with stromatolite-like bacterial mats (Nury and Conesa, 2000). The presence of microbial mats has been hypothesized to increase the chance of preservation of tracks by stabilizing the sediment. Based on studies of gastropod molluscs, charophytes, ostracods and mammalian biozones, this track levels are dated to the earliest Oligocene (Rupelian, biozone MP21-22) (e.g. Cavalier et al., 1984, Ménouret, 2014). The gastropods fauna includes hydrobites, potamids and melaniids which reflects an open and shallow water setting characterized by euryhaline environments. The poor ostracod and foraminifer assemblage is interpreted as reflective of partially confined shallow waters. The macrofossil and microfossil fauna as well as the presence of desiccation cracks suggest lagoonal environments where water level, oxygen and salinity fluctuations were common (Nury and Conesa, 2000).

**FORCALQUIER à 1/50.000 – P. GIGOT, 1973**

Série molassique marine	m1	MIOCENE
Marnes de la Tuilerie de Manosque		
Calcaire de Reillanne	g3	OLIGO. SUP.
Marnes de Viens	g2d	
	Calcaire et lignite de Sigonce	STAMPIEN SUPERIEUR
Calcaire de Vachères	g2c	
Marnes de Caseneuve	g2b	
Calcaire de Campagne Calavon	g2a	
Niveau de Pradengue et niveau de la Mort d'Imbert		
Calcaire de La Fayette		
Argile du Marronnier	Formation détritique inférieure e7-g1	LUDIEN
Calcaire à Cyrènes		
Sables glauconieux		

Fig. 21: Apt-Forcalquier basin stratigraphic units. The track-bearing limestone beds belong to the Upper Calcaire de La Fayette Formation which forms the basal unit of the Oligocene stratigraphic series of the Apt-Manosque-Forcalquier basin (Cavalier et al., 1984).

The earliest Oligocene in western Europe is marked by the Grande Coupure. This event corresponds to a major terrestrial faunal turnover recorded in Europe associated with the overall climate change at the Eocene-Oligocene transition. It was characterized by an important decrease in global temperatures, which involved a significant change in the terrestrial faunas. In western Europe, a large number of European Eocene endemic mammals became extinct and new Asian immigrants appeared.

The fossil assemblage of Saignon tracksite (Demathieu et al., 1984) is typical for the Western European post-Grande Coupure fauna. It includes a mix of pre-Grande Coupure endemic taxa and post-Grande Coupure Asian arrivals. It is characterized by the presence of *Plagiolophus*, an early Oligocene representative of the pre-Grande Coupure European endemic palaeotheriids and by a rhinocerotid that appeared with the mammal migration wave from Asia into Europe following the Grande Coupure. The Saignon rhinocerotid tracks is considered as one of the earliest occurrences of the arrival of Asian mammals into France.



Fig. 22: Mammal and bird tracks from Saignon. A. *Lophiopus isp.* (small tridactyl tracks attributed to a palaeothere, an endemic mammal from Europe distantly related to equids). B. *Rhinoceripeda voconcense* (large tridactyl tracks attributed to a rhinocerotid trackmaker). C-D. Artiodactypedida (Didactyl tracks attributed to even-toed ungulate trackmakers). E. *Pulchravipes* (Tetradactyl tracks attributed to shorebirds). Scale 5 cm.

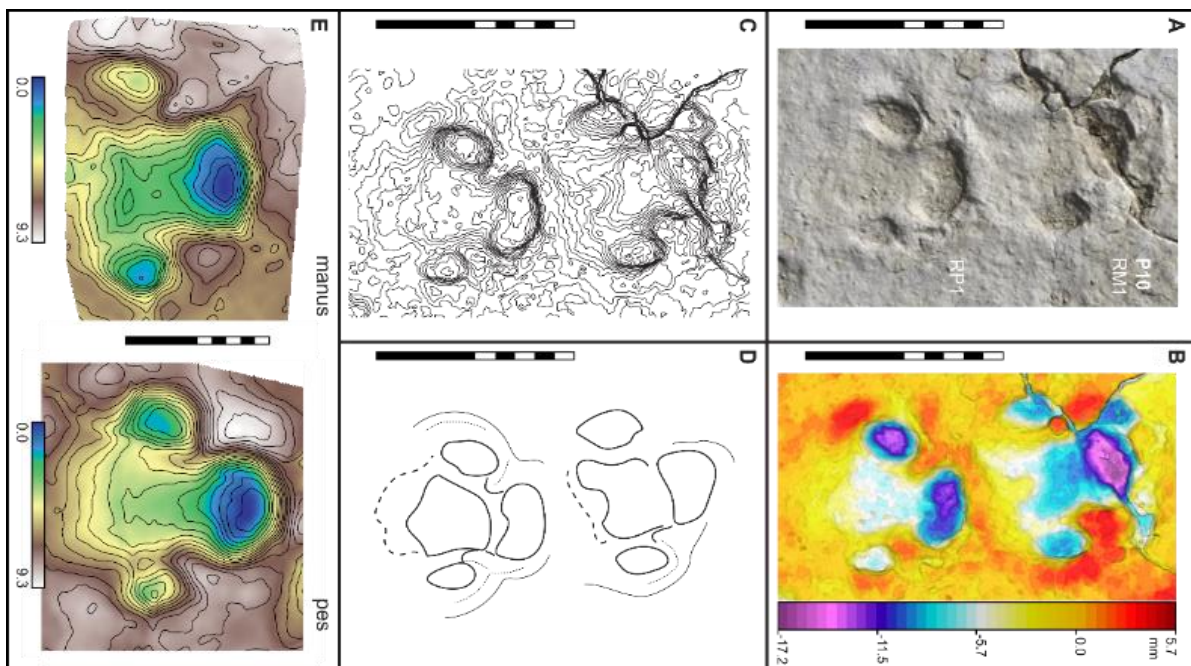


Fig. 23: Contour line, depth map and line drawing of the rhino tracks (neotype of *Rhinoceripeda voconcense*). Scale 10 cm.

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