From the North Pyrenees surface outcrops to the deep buried Aquitaine basin gas fields

Geological field trip guide book

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GéolVal

Programme and objectives of this field trip in the North Pyrenean Zone

- This field trip includes about half a dozen stops, all located in the so called « Béarnais chainons » in the North Pyrenean Zone.

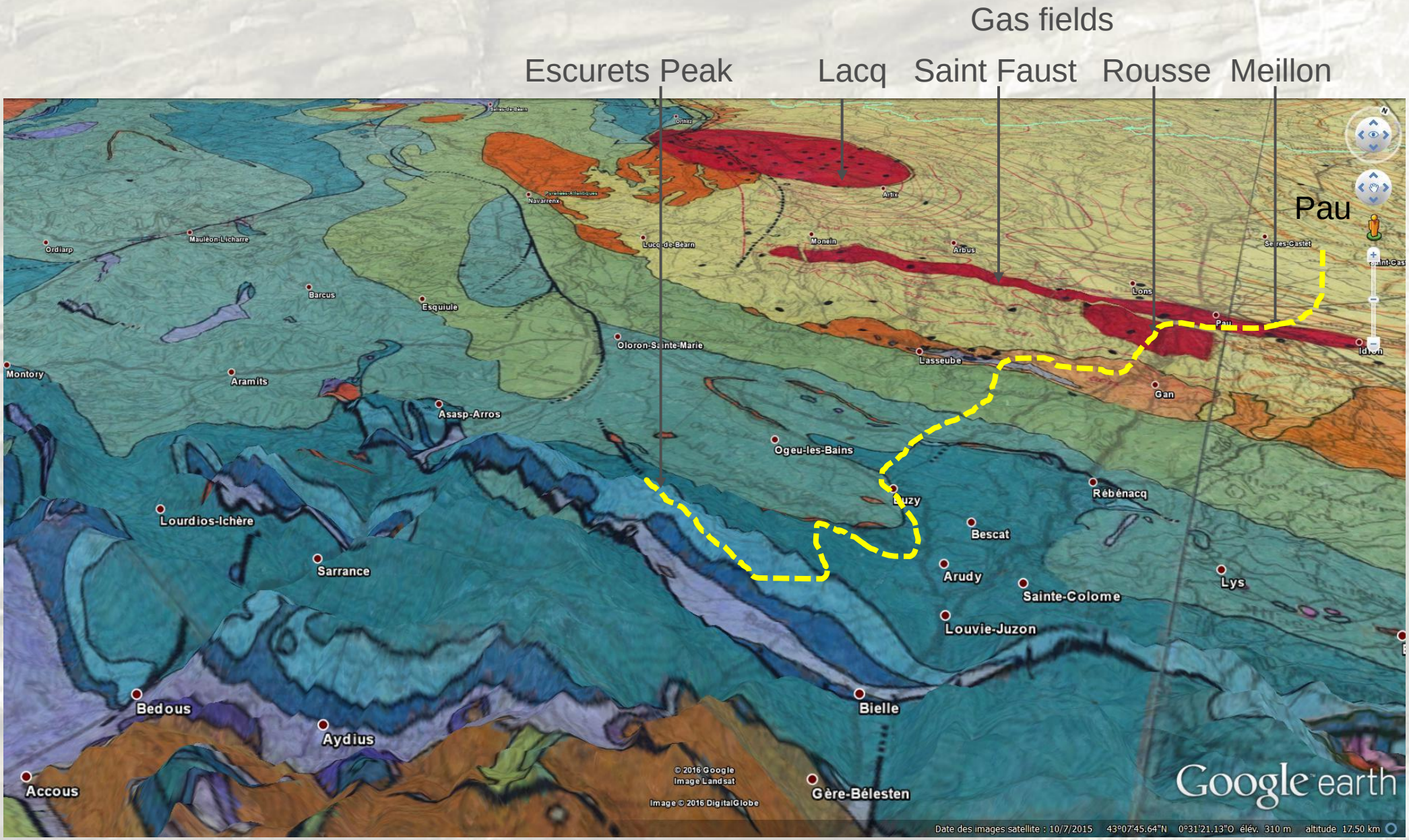
- Some elements of the petroleum system of the Aquitaine basin (source rocks, reservoirs rocks, seal rocks) can be observed on the outcrops.

-These rocks are similar to those found in some gas fields (Lacq, Meillon, Rousse) located at several thousands meters deep, only a few kilometers to the North

- Some outcrops, like the « Mail d'Arrouilh,» have been used as a fractured reservoir analog to the Meillon gas field.

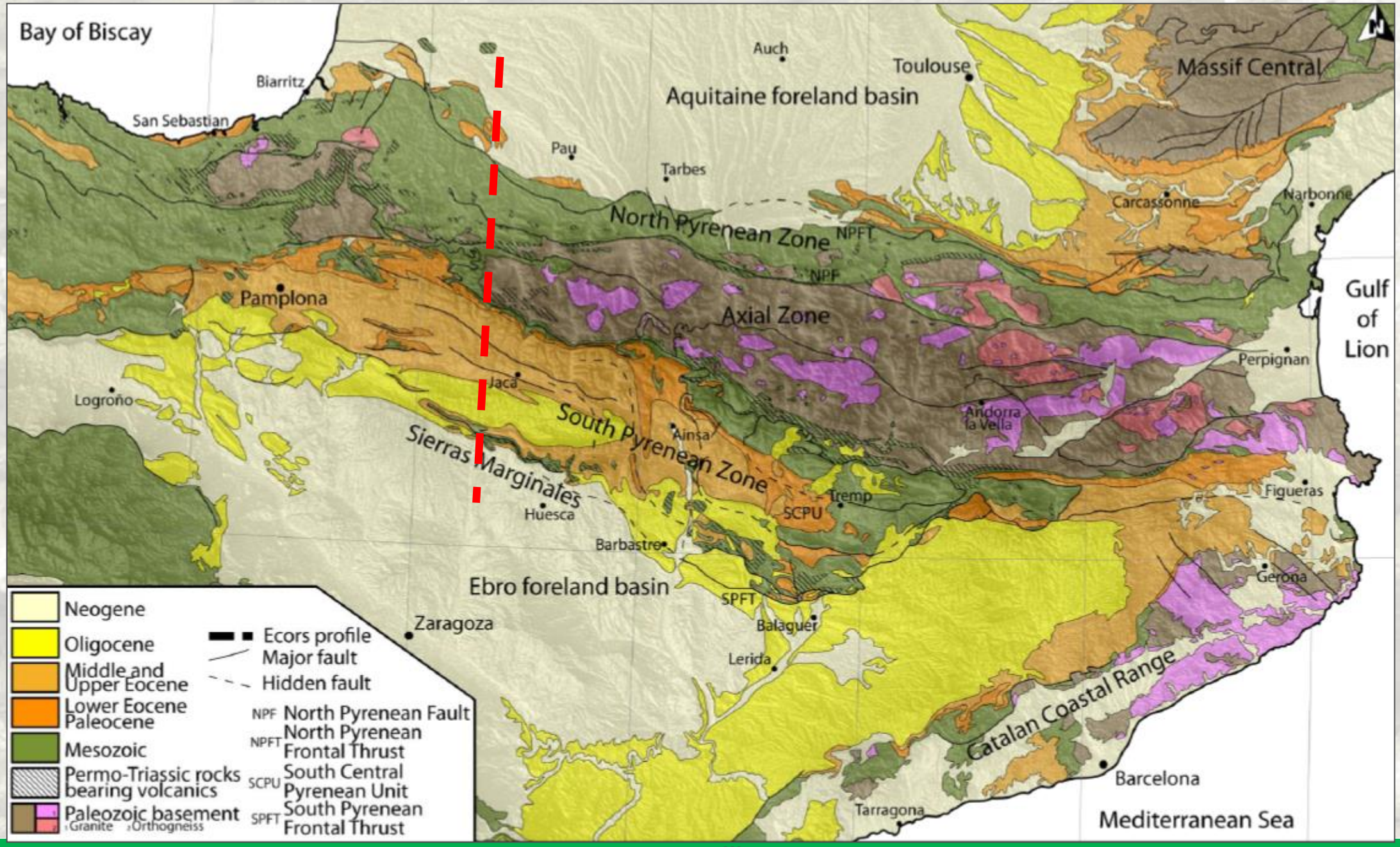
- This field trip highlights the importance of the field geology in the oil and gas exploration process .

Escurets field trip location, relative to the Pau area gas fields

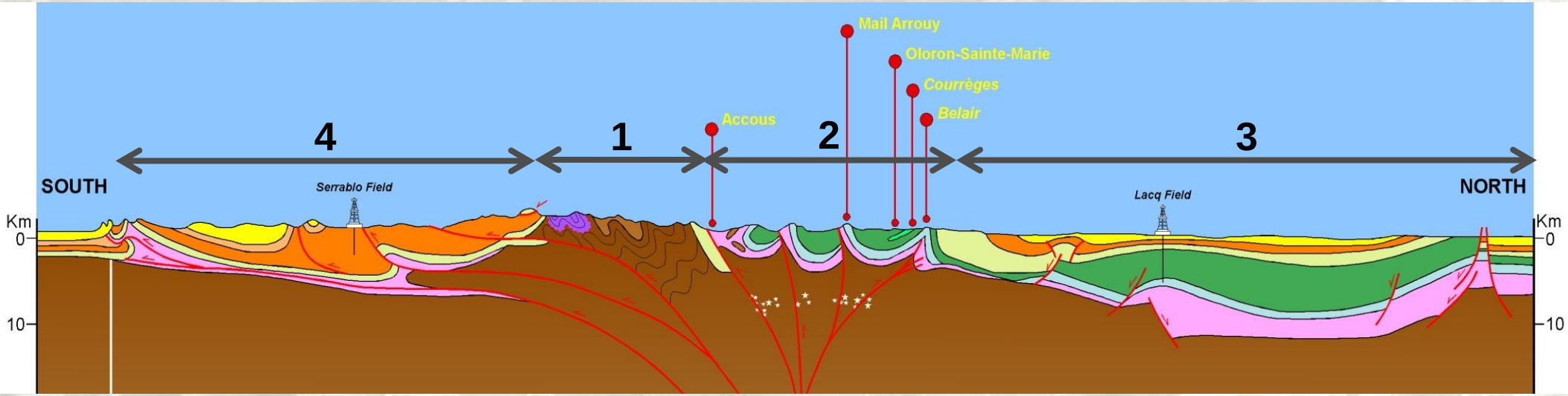


Pyrenees geological abstract

Simplified structural framework of the Pyrenees



Geological cross-section and main structural domains of the Western Pyrenees



N – S Geological cross-section of the Western Pyrenees

High chain (1) :

This is the internal metamorphic zone of the chain. It consists of crystallophyllian Paleozoic material (-540 to -250 My) granitized and metamorphosed during the Hercynian orogeny, then remobilized during the Alpine orogenic cycle. The "North-Pyrenean Fault (NPF)" separates this area from the North Pyrenean Zone.

North Pyrenean Zone (2):

It consists of Mesozoic sediments (-250 to -65 My), deformed and locally, metamorphosed; it also includes crystallophyllian Paleozoic series (-540 to -250 My) - the Palaeozoic North-Pyrenean Massifs - thrusted northward during collision.

Aquitaine Basin (3):

Limited to the South by the North Pyrenean Frontal Thrust (NPFT)

South Pyrenean Zone (4) :

It consists of a Meso-Cenozoic sediments (- 250 My to Recent), folded and thrusted southward. The South Pyrenean Frontal Thrust (SPFT) separates this zone from the Ebro Basin.

- Oligo-Miocène conglomérats
- Upper Eocene (Sandstones)
- Lower Eocene (Platform limestones / Turbidites)
- Upper Cretaceous (Platform limestones / Turbidites)
- Lower Cretaceous (Limestones / Marls - *Volcanism)
- Jurassic (Limestones)
- Triassic (Evaporites / ophites
- Permian (Silt)
- Carboniferous (Limestones / Turbidites)
- Devonian (Limestones)

Summarized geological history of the Pyrenees

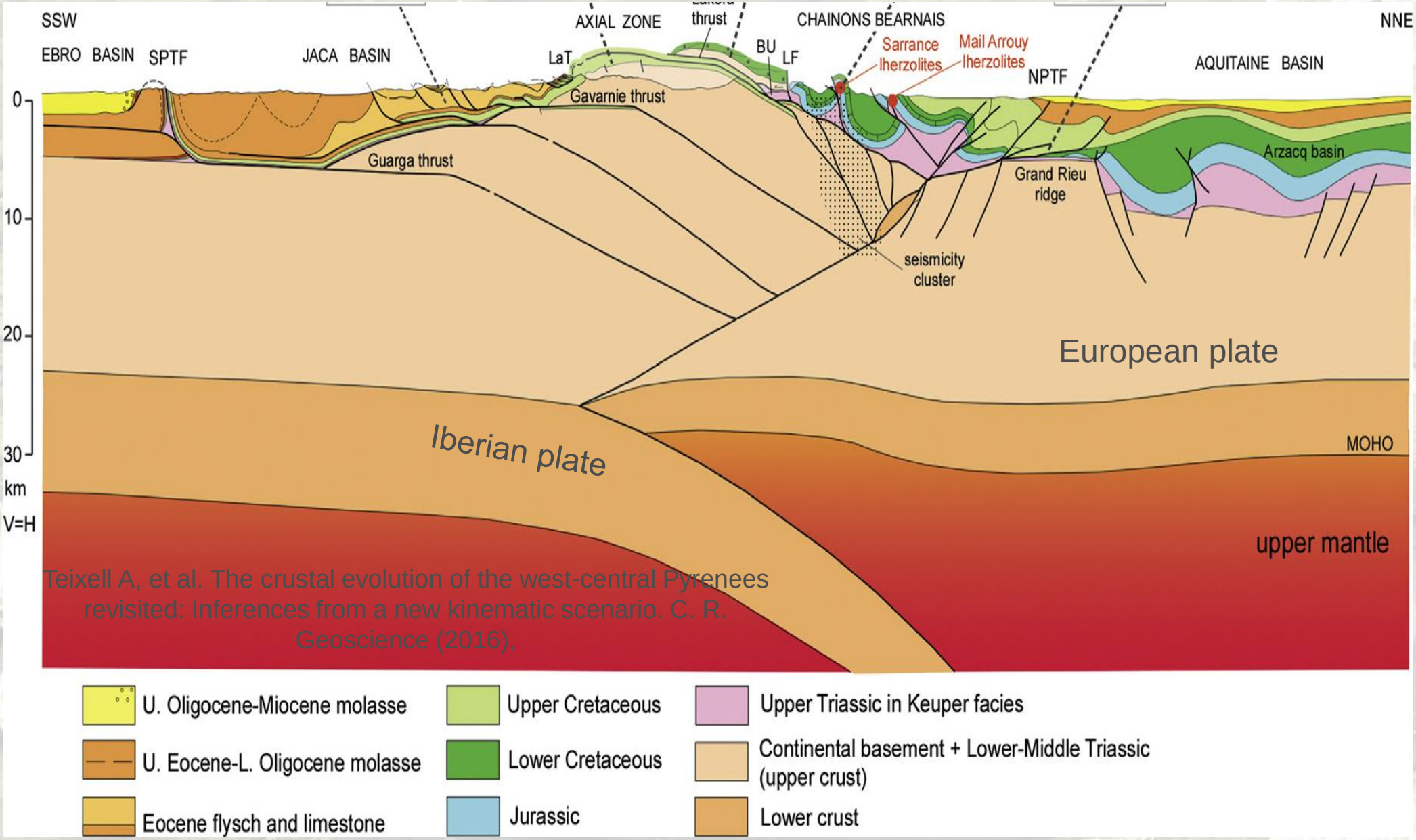
The Pyrenees are the result of the collision of two continental plates: the Iberian plate to the South and the European plate to the North. The history of the Pyrenees can be summarized in three main phases:

- **Hercynian phase**, ending in the Permian (- 295 to - 250 My). At that time Pyrenees belong to a much wider mountain range: the Hercynian chain that spread over the entire Western Europe.

- **Extensional phase** which begins in Triassic times(- 250 to - 203 My). This phase knows its peak during the Albo-Aptian period (-113 to - 96 My), when the Iberian and European plates moved apart and a rift was created: this is the opening of the Bay of Biscay. The opening continues until Campanian (Upper Cretaceous) (- 80 My).

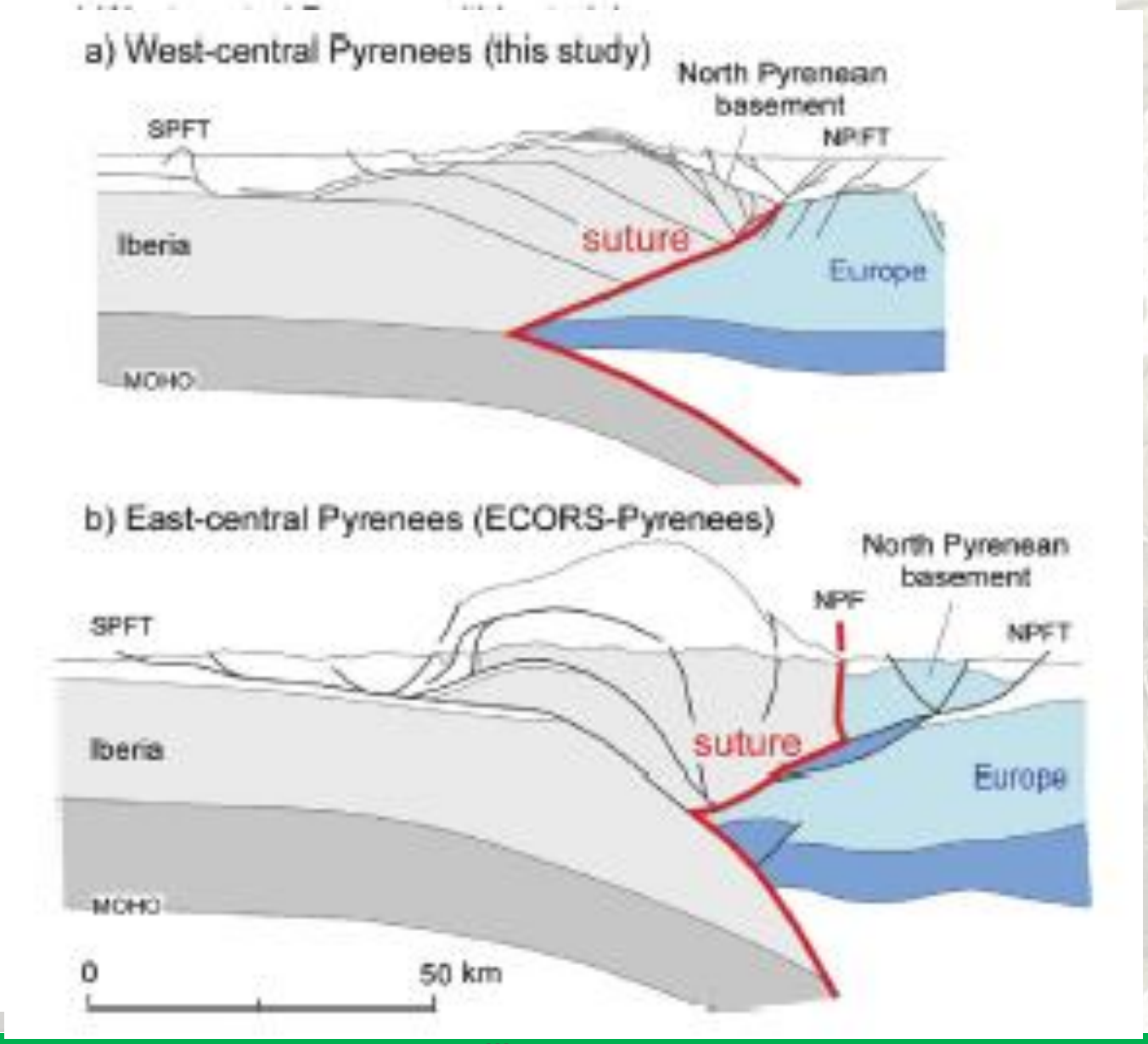
- **Collision phase**, from Campanian (- 80 My) up to present. The Iberian and European plates collide, inducing first the closure of the previous rift, and from the Paleocene-Eocene (- 65 to - 33.7 My) the main deformation phase, leading to the present Pyrenees mountain chain.

Deep crustal structure of the Western Pyrenees

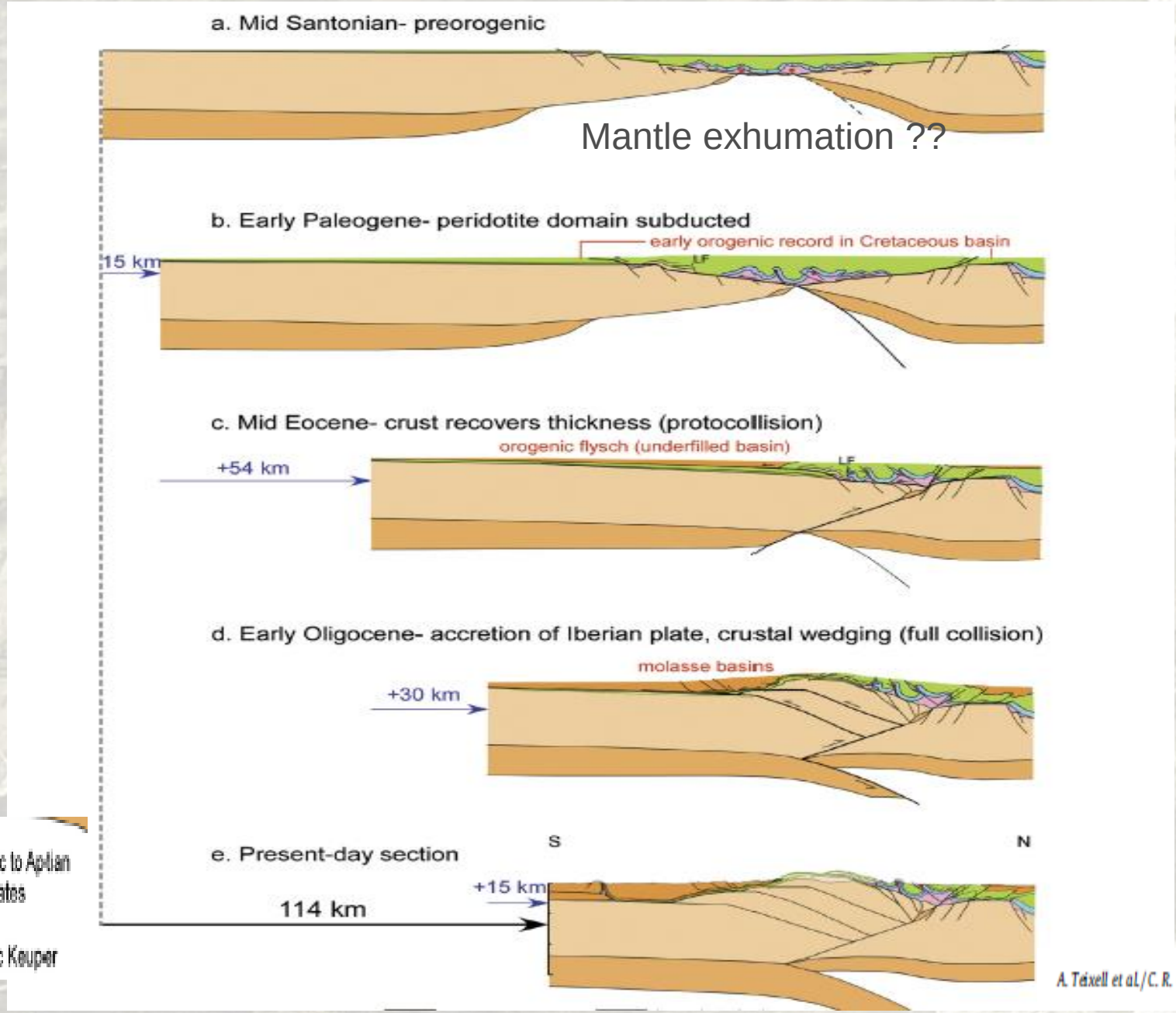


Teixell A, et al. The crustal evolution of the west-central Pyrenees revisited: Inferences from a new kinematic scenario. C. R. Geoscience (2016),

Comparison of crustal sections, across the western and central Pyrenees



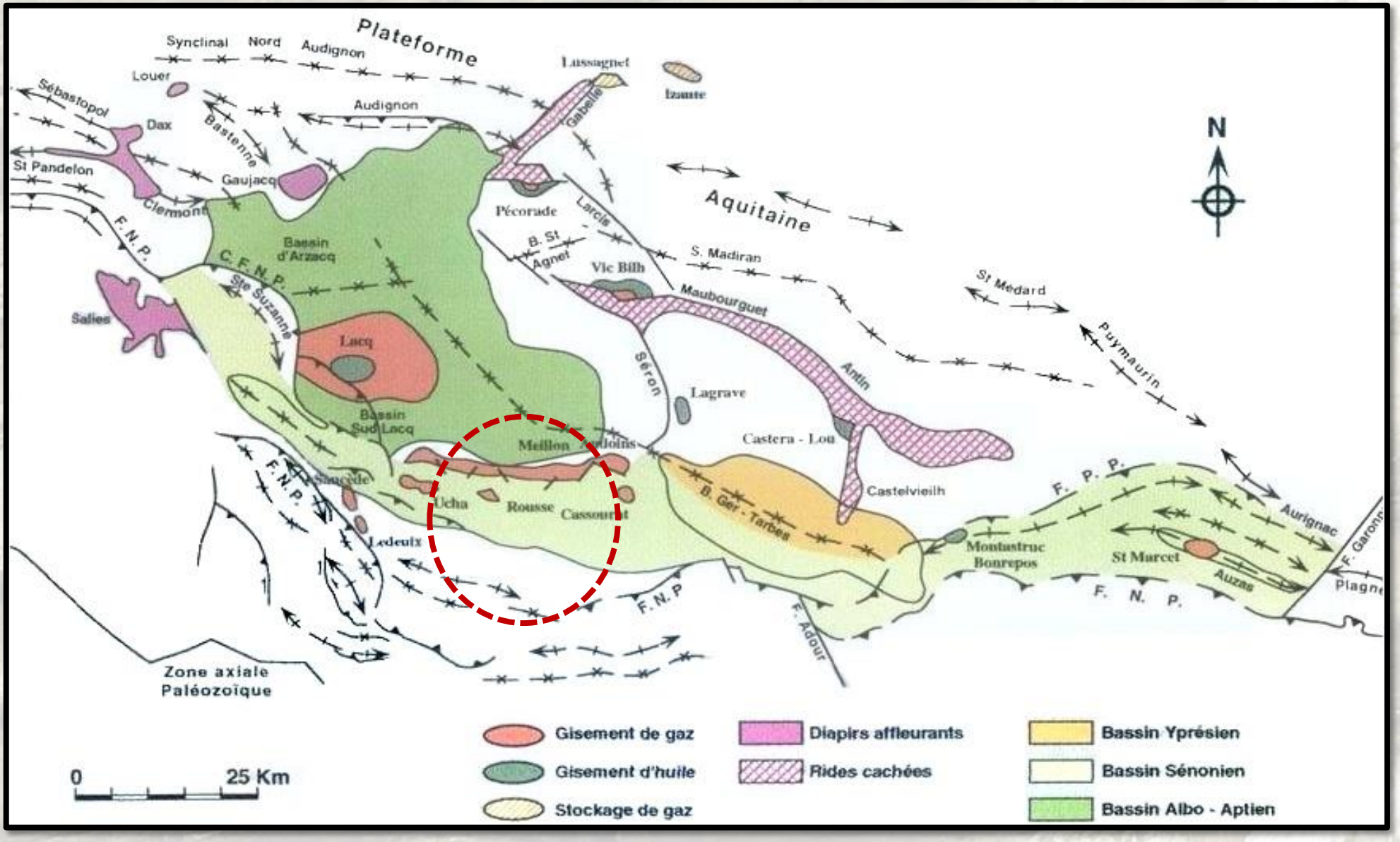
Sequential reconstruction of the the western Pyrenees



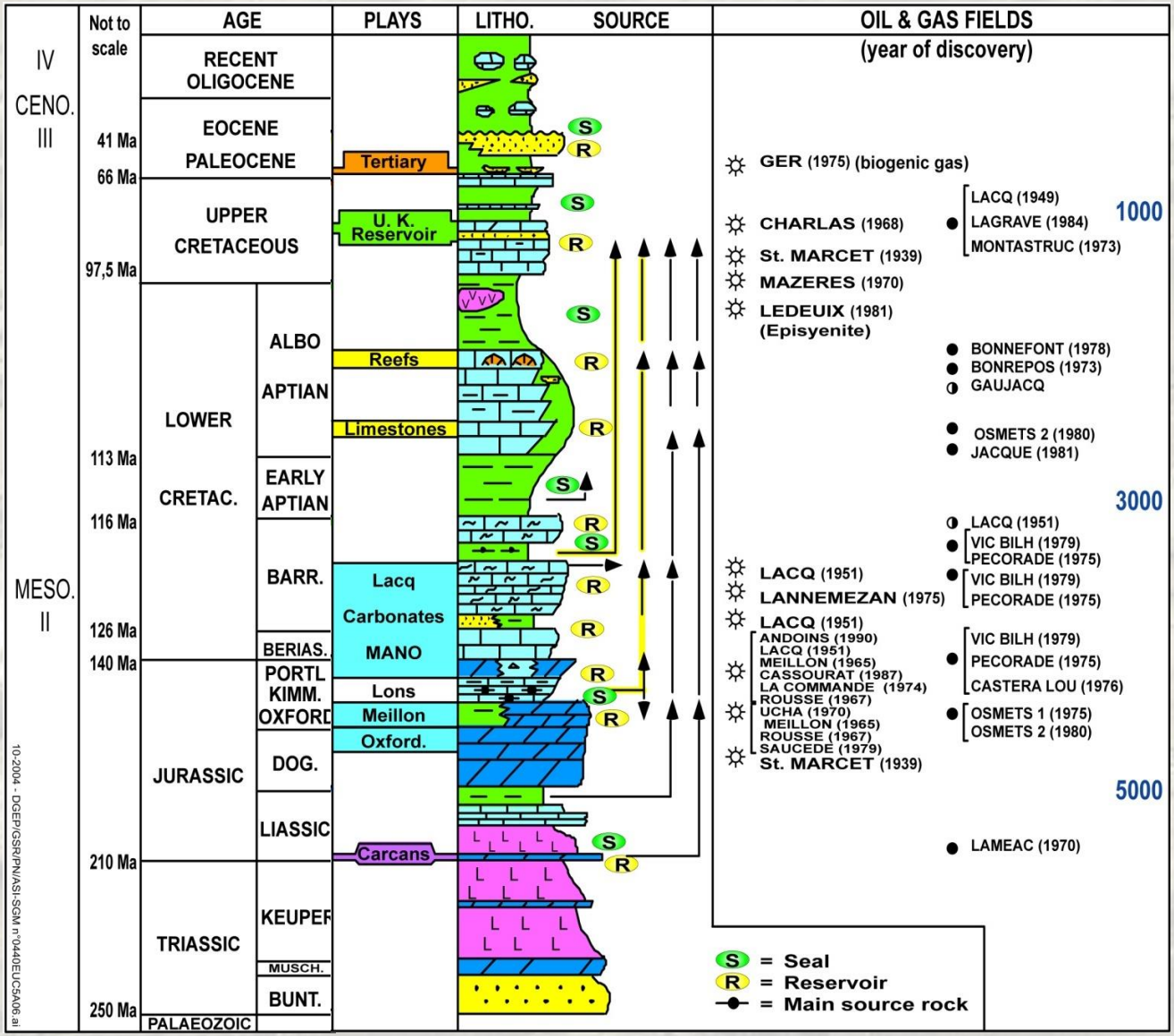
A. Teixell et al. / C. R. Geoscience xxx (2016) xxx–xxx

Meillon – Rousse gas field

South Aquitaine Basin: main oil and gas fields



Lithostratigraphic chart et petroleum systems (southern part of the Aquitaine Basin)



Several oil and gas fields have been discovered in the Aquitaine basin, with different reservoir types. R

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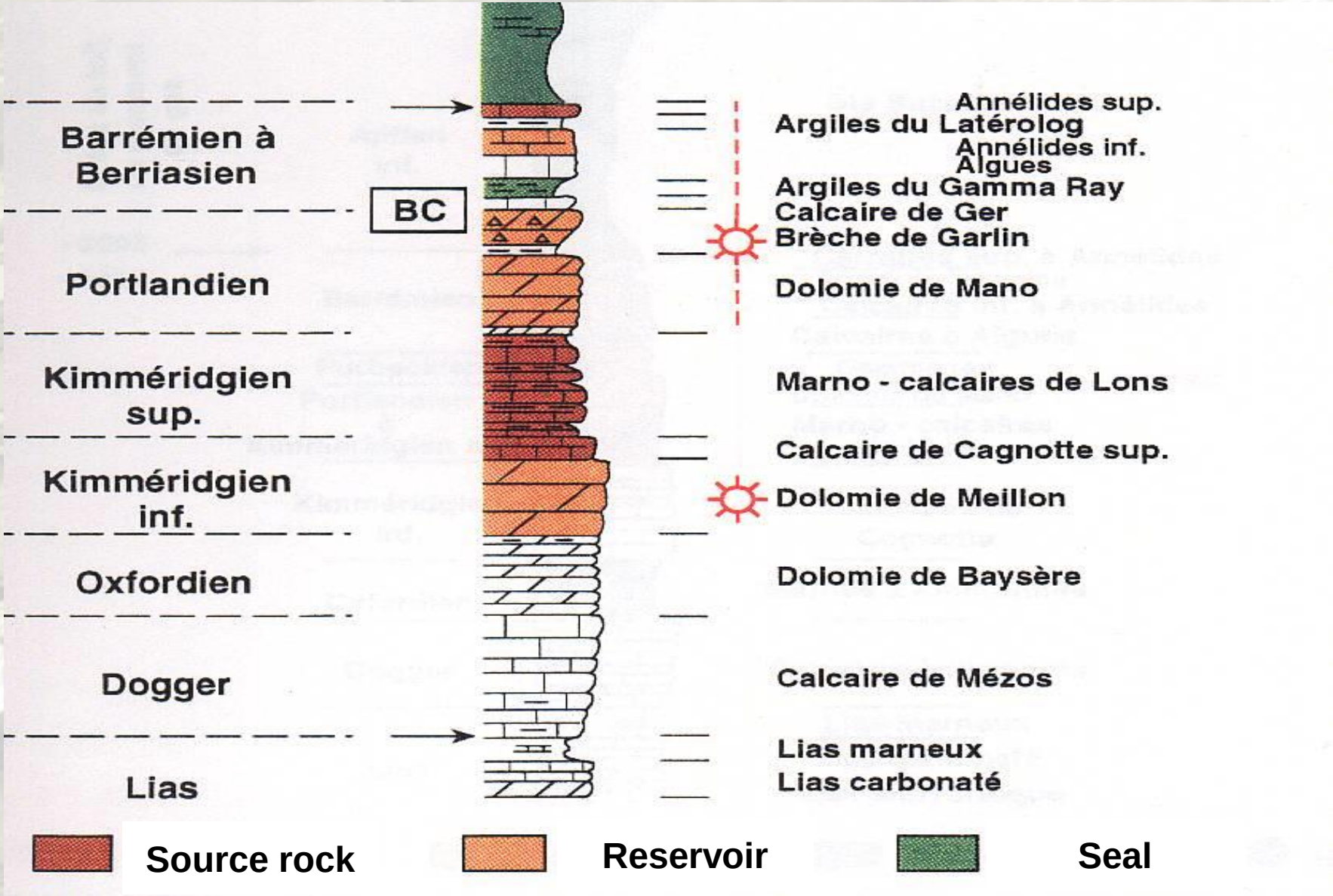
The main source rock (-●-) is of Kimmeridgian age (Lons limestone Formation) which charged the Jurassic reservoirs (Lacq et Meillon), the Barrémien reservoir (Lacq) and through a complex migration pattern the Upper Cretaceous reservoir (shallow oil Lacq field, Lagrave).

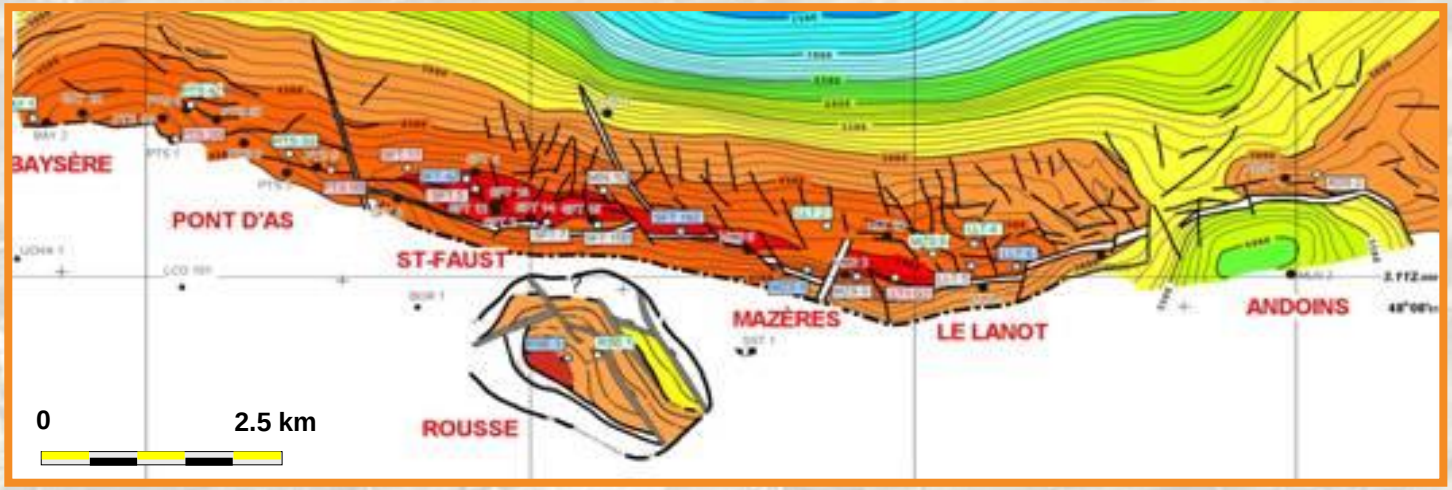
Some other minor source rocks (Lias, Albian) are at the origine of small Cretaceous oil or gas accumulations.

Tertiairy source rocks are at the origin of some minor biogenic gas accumulations (Ger)

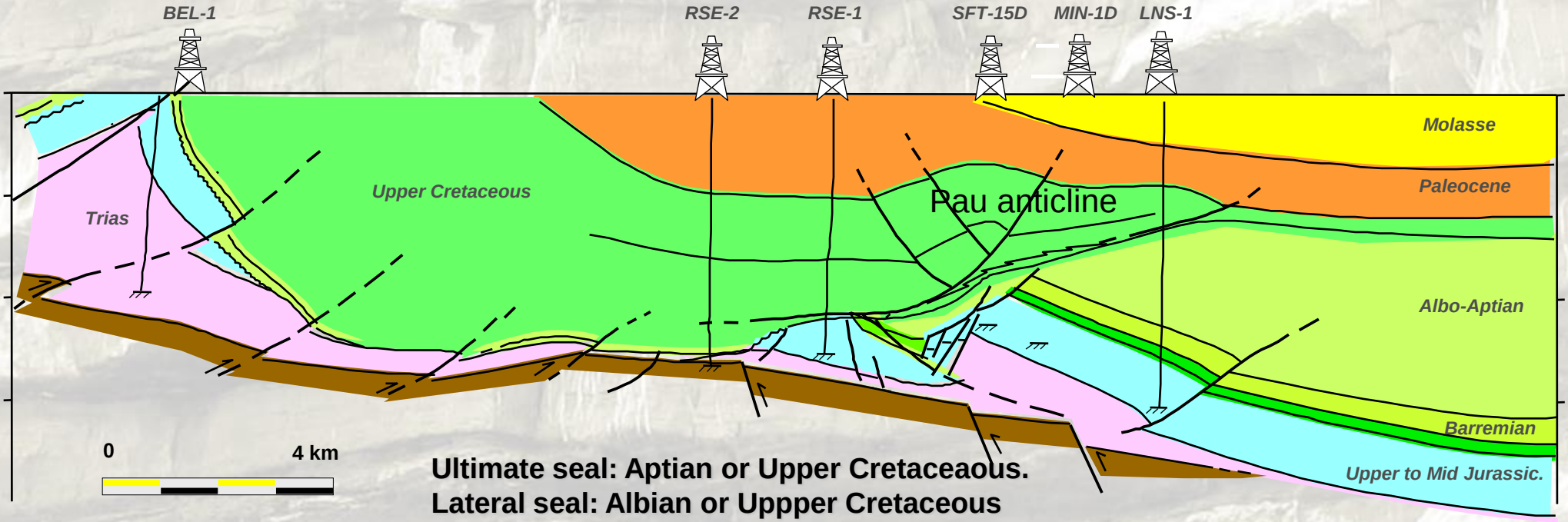
Source rocks, reservoirs and seals in the Meillon field area



Meillon – Rousse gas field

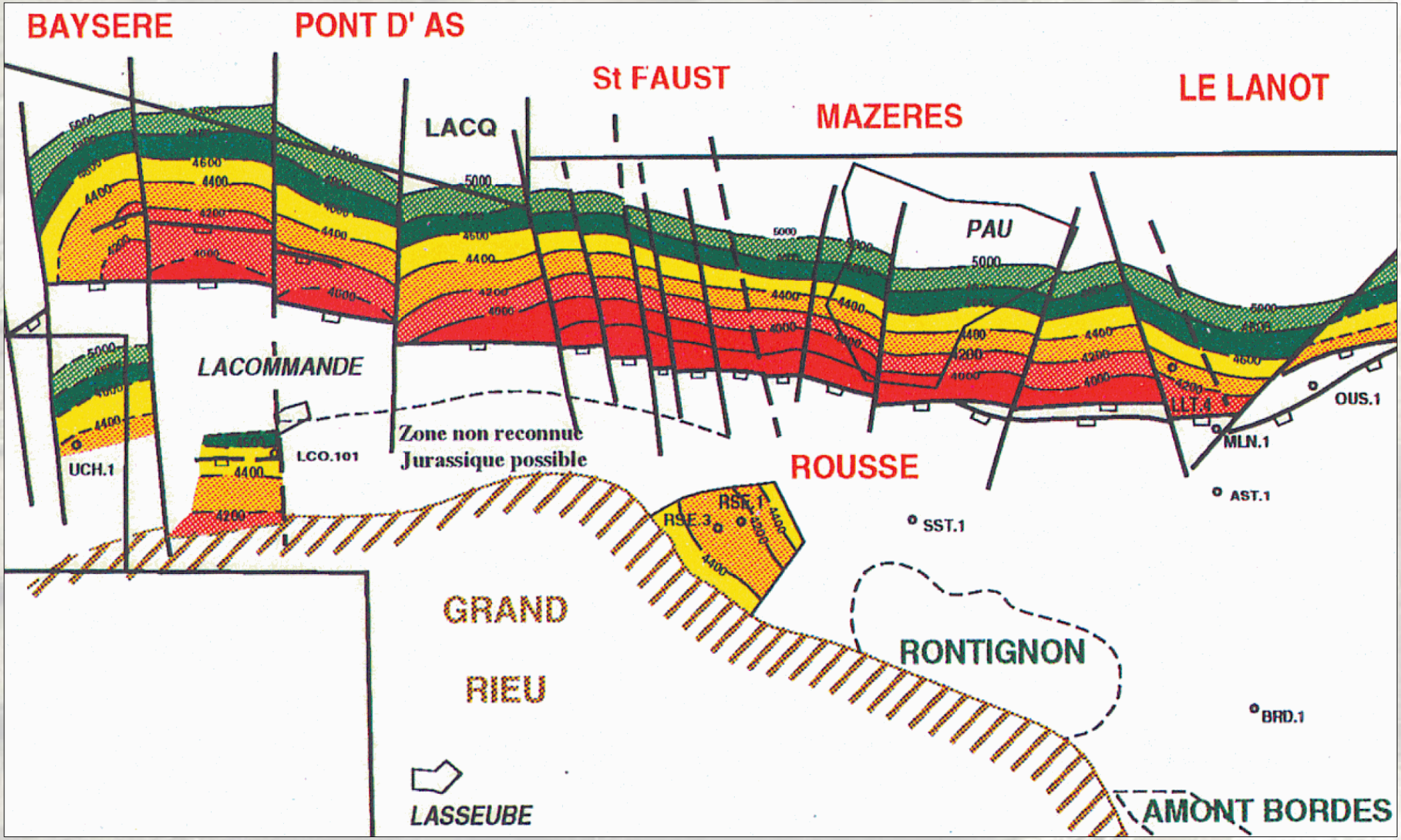


- Dry gas, methane
- CGR: 15 MMscf/bbl
- H_2S = 6.5%,
- CO_2= 9.5%
- Hydrostatic, water drive
- 2 TCF reserves

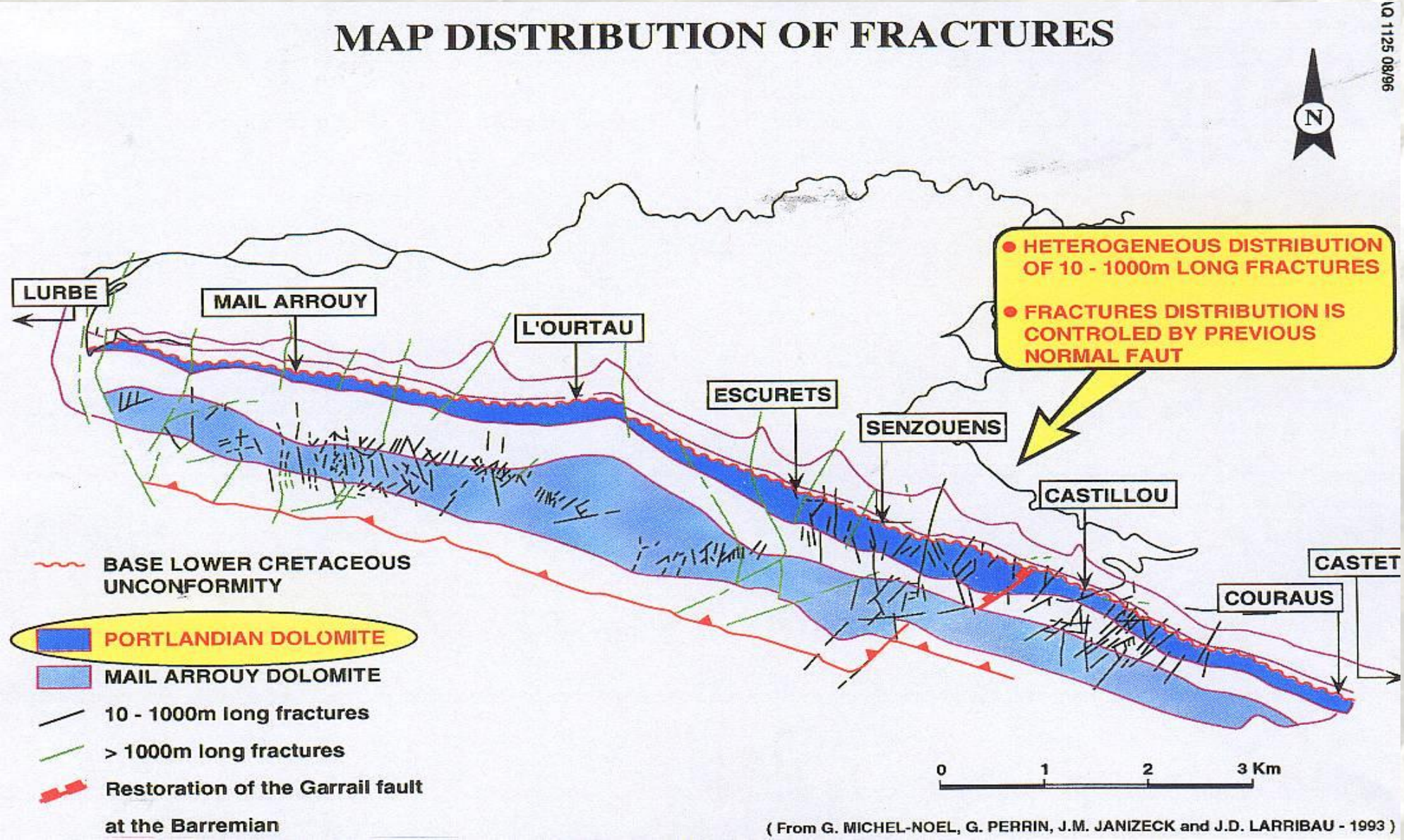


Ultimate seal: Aptian or Upper Cretaceaous.
Lateral seal: Albian or Uppper Cretaceous

Meillon –St Faust field fault segmentation



The Mail Arrouy outcrop in the Pyrenes mountains as an analog for the Meillon reservoir



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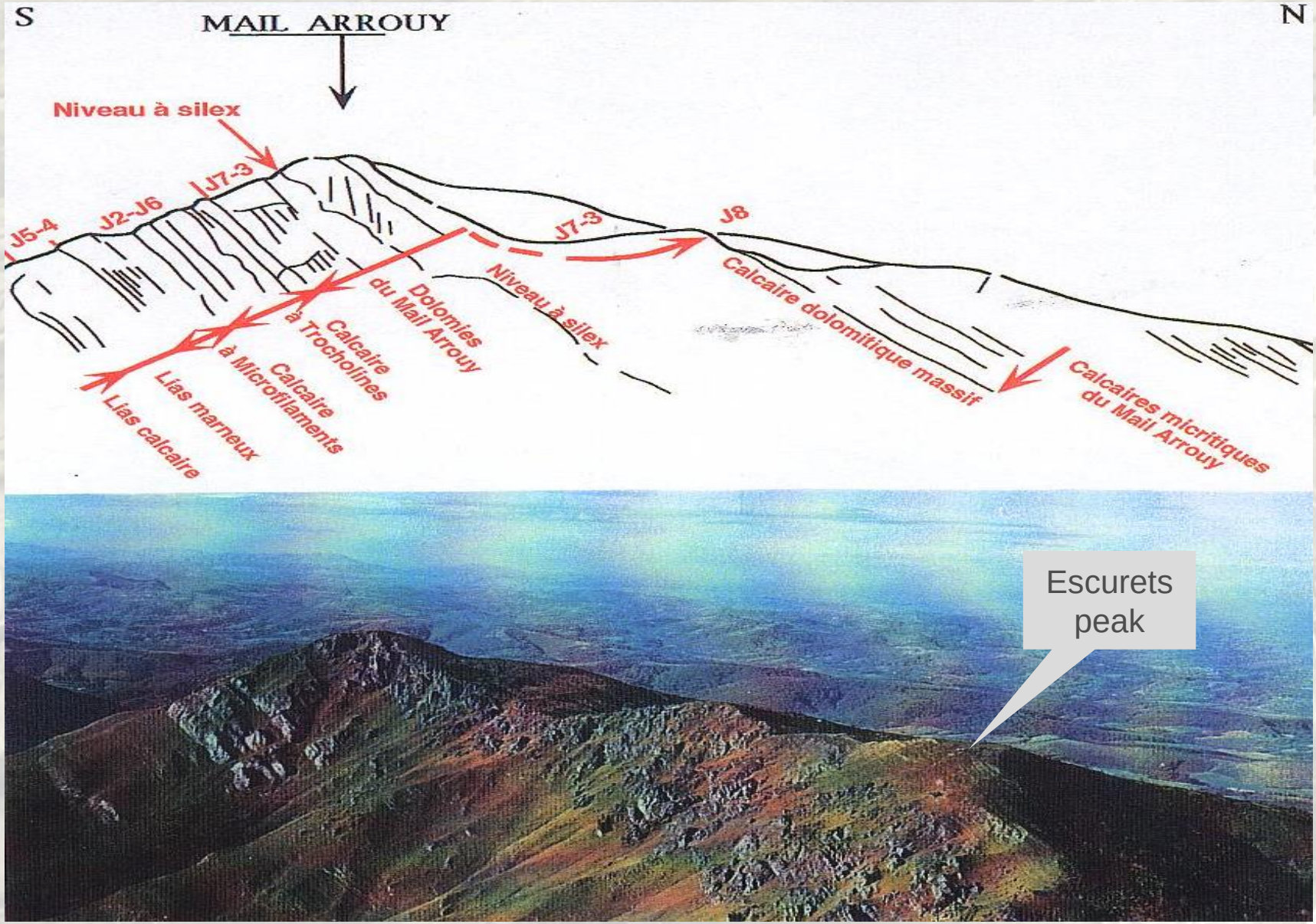
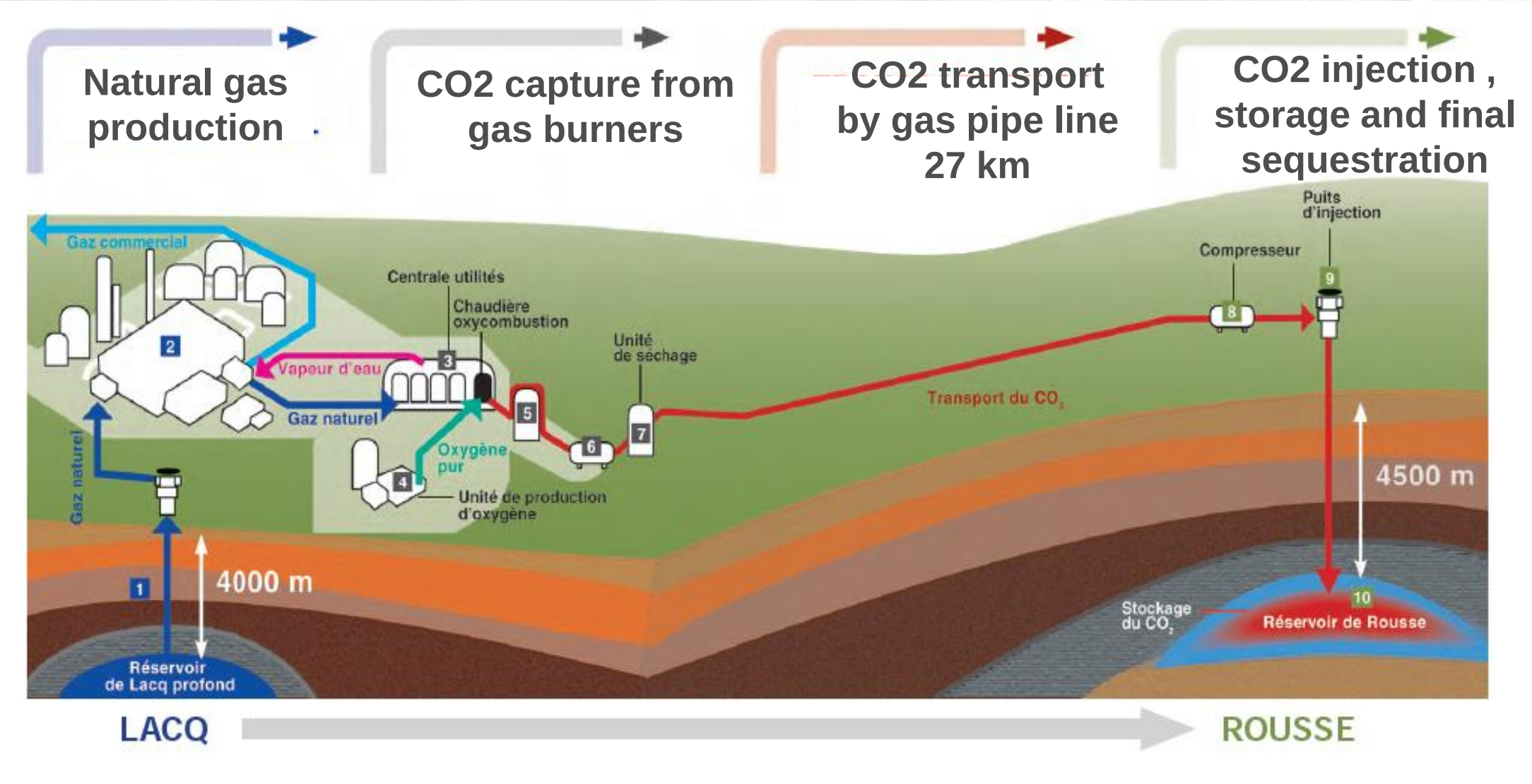
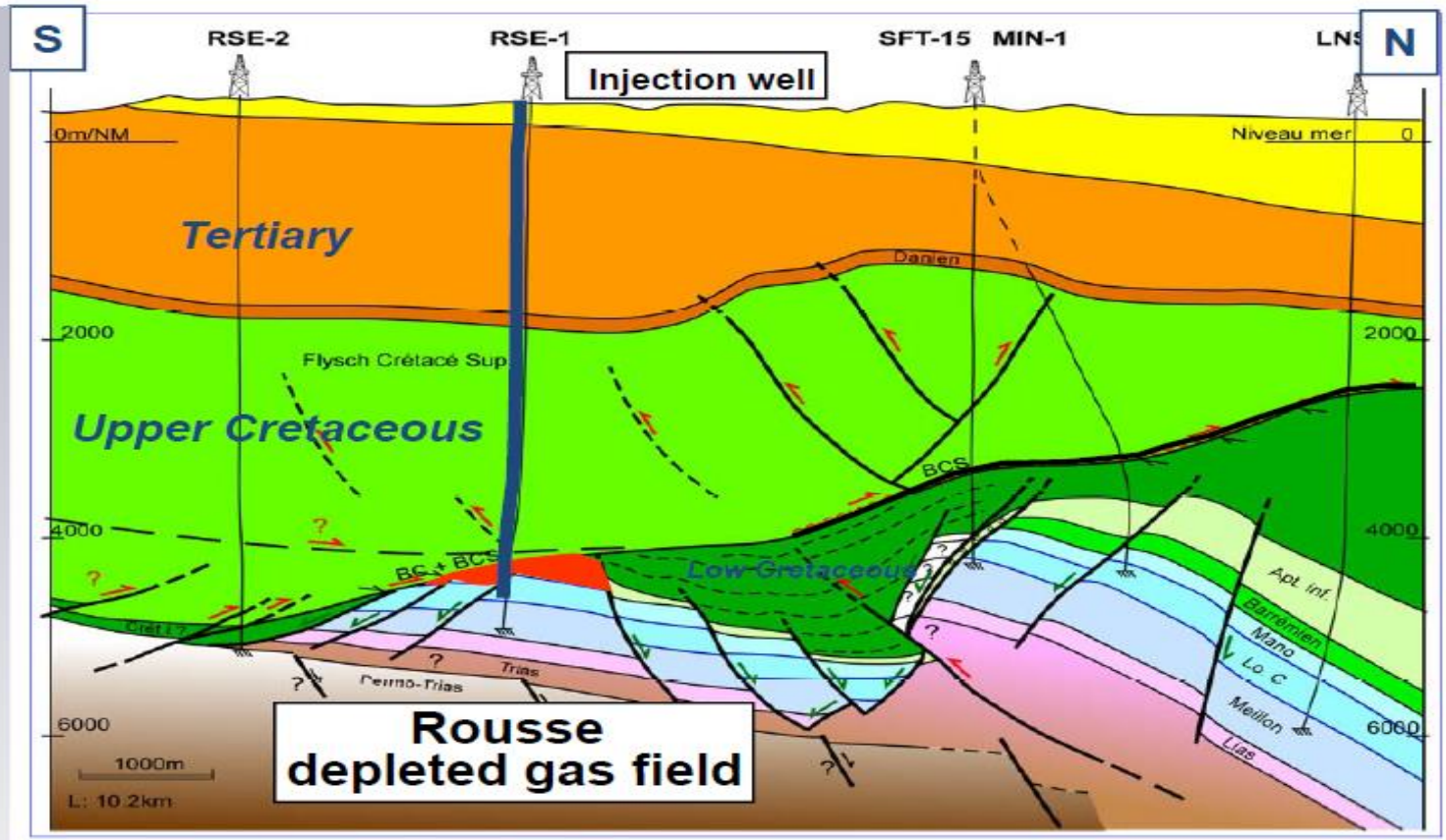


Lacq –Rousse CO2 capture and sequestration pilot plant (2009-2013)



CO2 injection pilote in the Rousse depleted field

- Jurassic fractured dolomitic reservoir
- Depth # 4500m/MSL
- Temp. # 150°C
- Initial P: 485 bar
- P before inj: # 40 bar
- Final pressure: # 80 bar
- Initial CO_2 = 4,6%
- Initial H2S < 1%
- Av. Porosity: 3%
- Av. matrix Perm. < 1mD
- Av. SW: 40%
- Only one well: RSE-1, producing since 1972, transformed into injector in 2009.



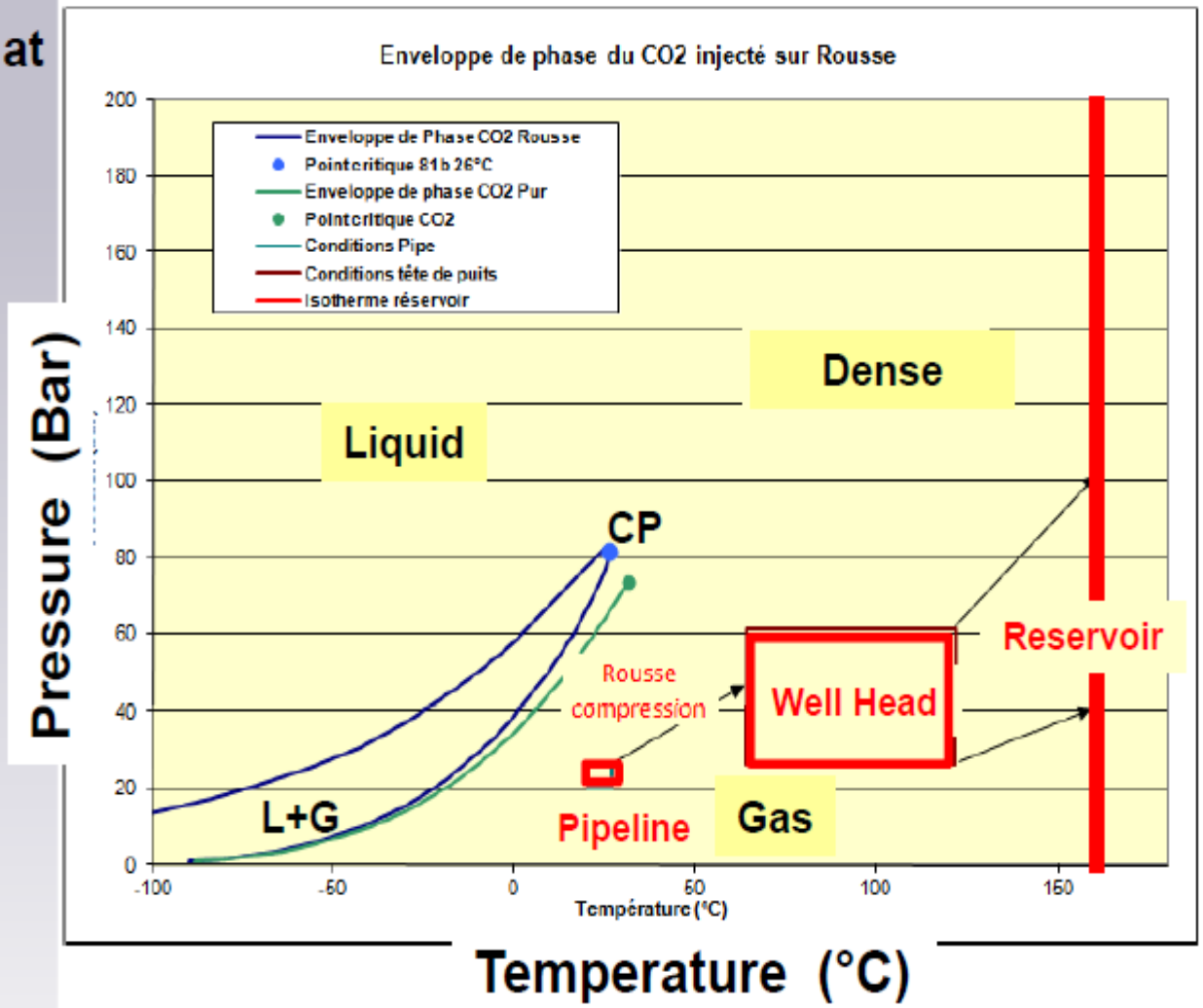
- Cumulated injected CO_2 = 10kt (end 2010)
- CO_2 flowrate: 92 t/d
- Reservoir pressure increases as simulated

150 Bcf natural gas reserves

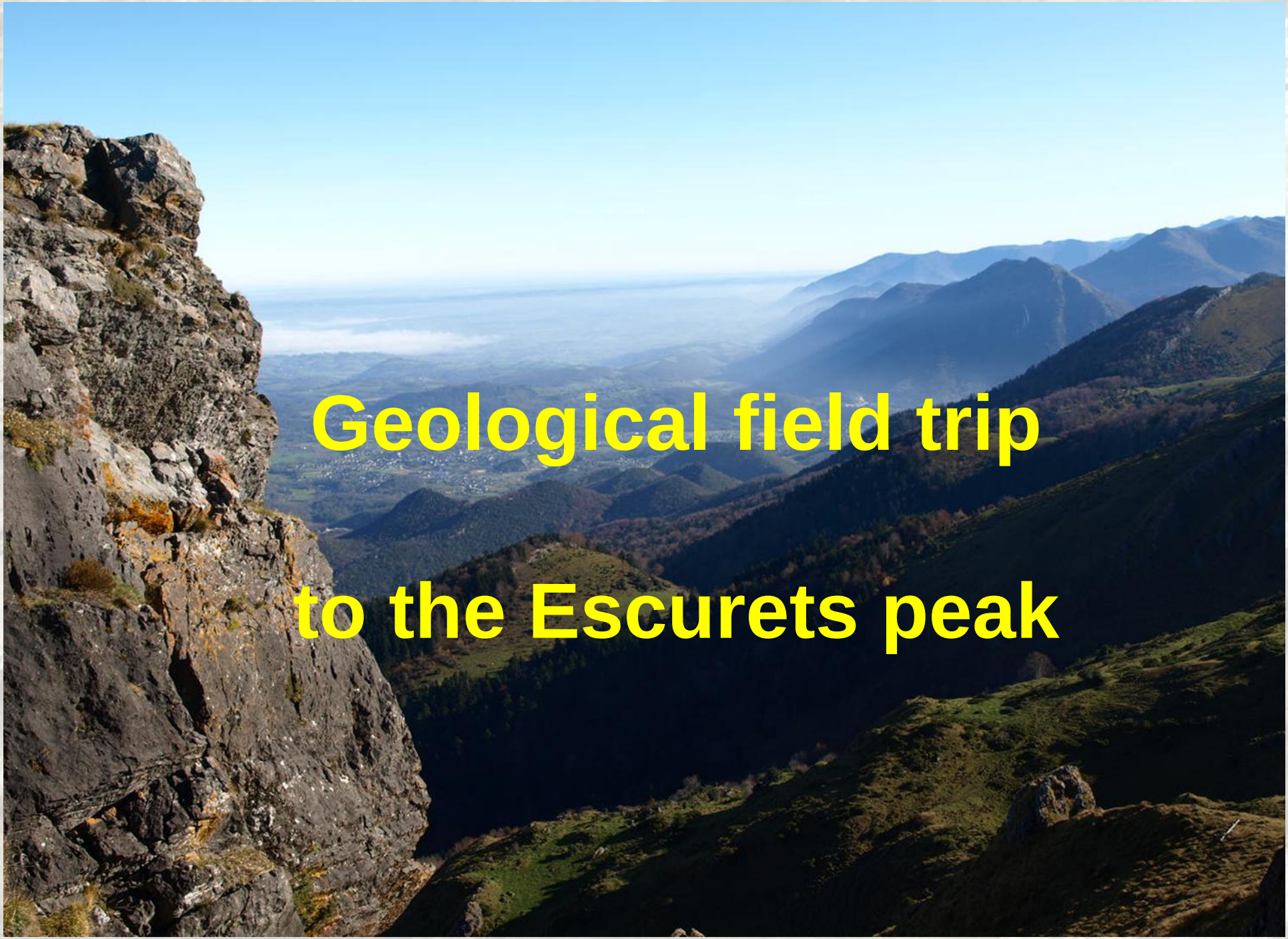
TOTAL

CO2 Injection : flow rate and composition

- Flow rate and Composition measured at Lacq plant, before transport.
- CO_2 composition (@98% O_2 purity):
  - CO_2 : 92.0 %
  - O_2: 4.0%
  - Ar: 3.7%
  - N_2: 0.3%
- Flow rate Q: 52 kSm3/day (95 ton/d)
- Injection in gas phase



Rousse CO2 injection pad location

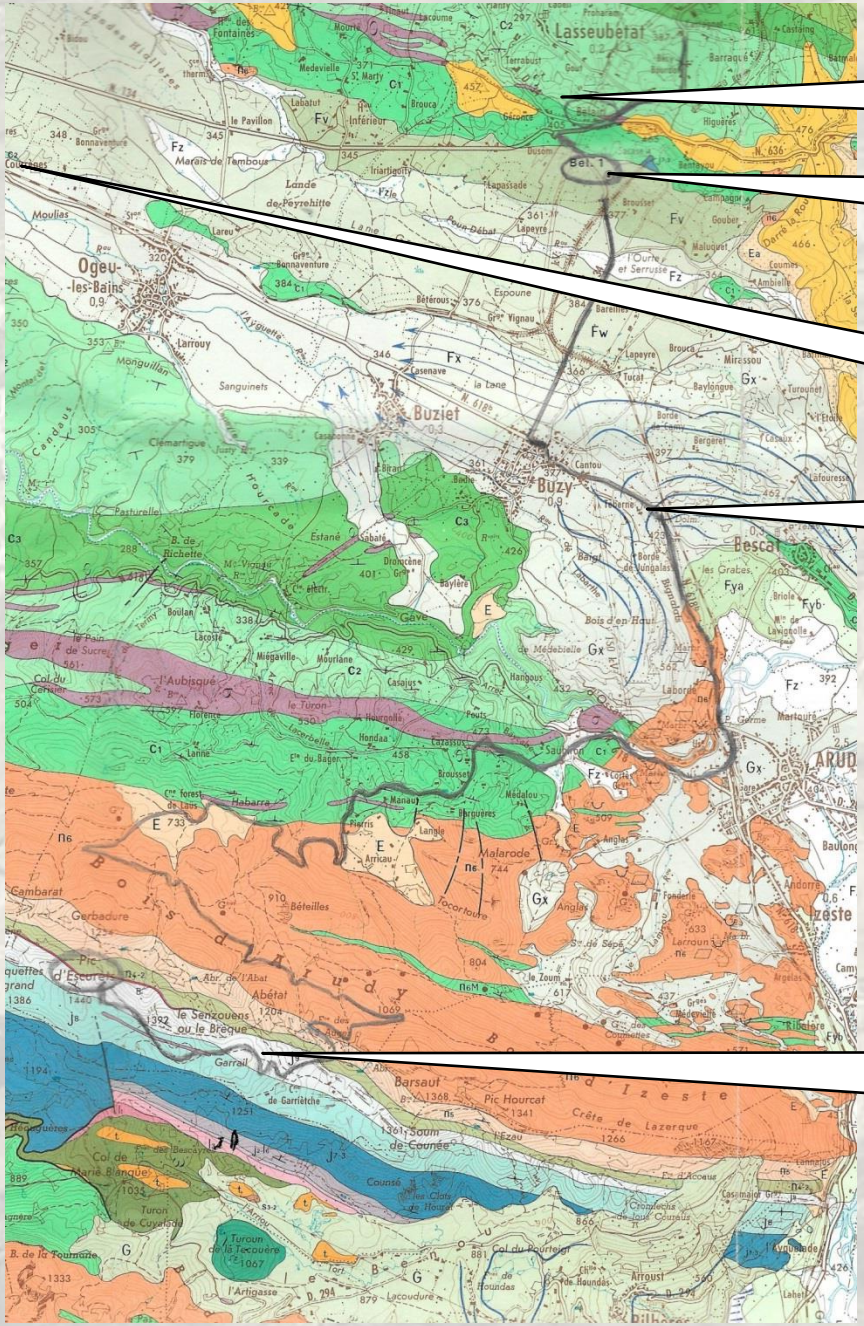


Geological field trip

to the Escurets peak

J.Mouillac

Field trip itinerary



Belair panorama over the Pyrenees

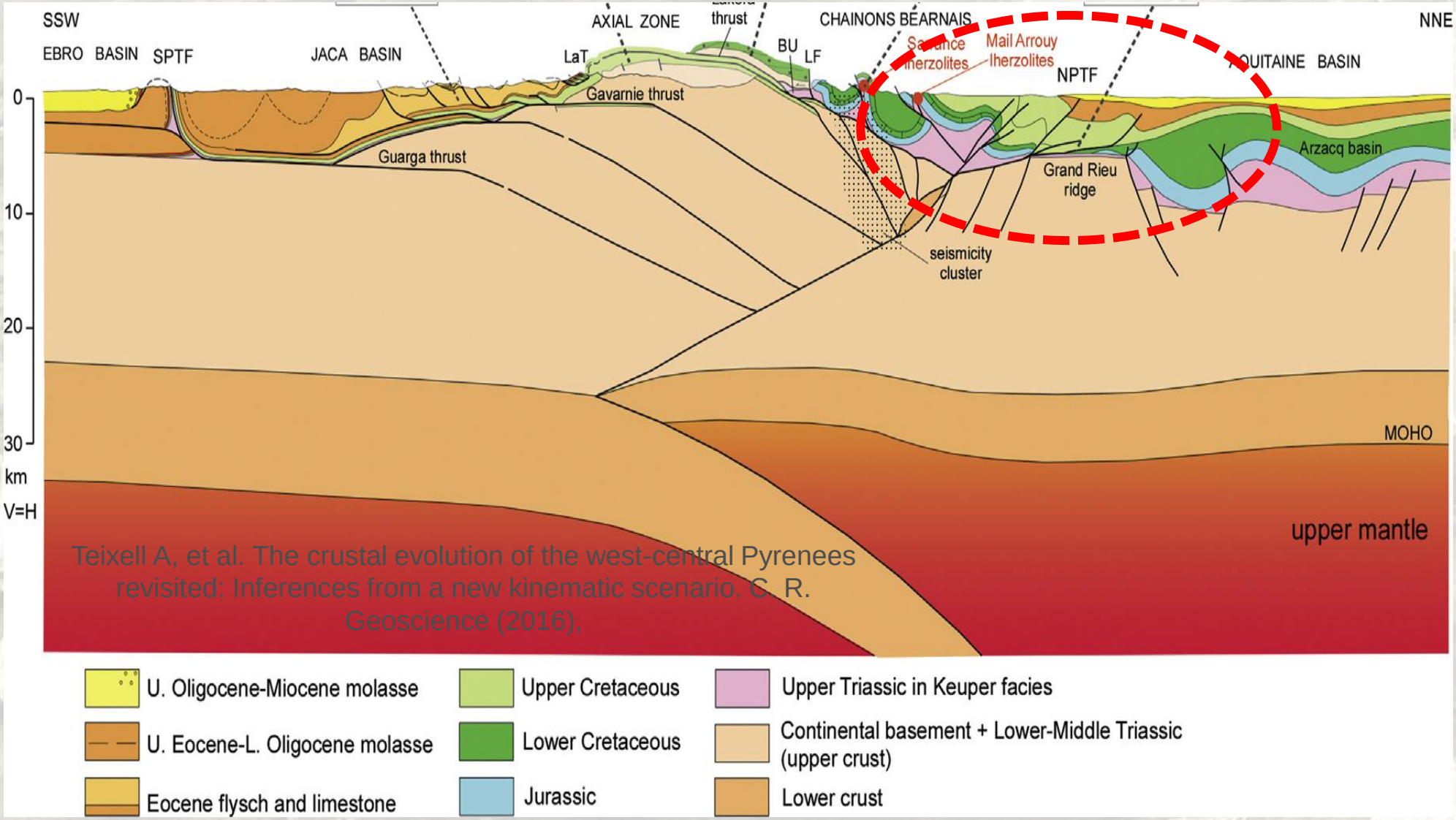
Belair-1 well

Volcanic pillow lavas (optional)

Frontal moraine of the Ossau valley glacier

Observation of the Cretaceous and Jurassic outcrops

Location of the field trip, in the northern Pyrenees environment



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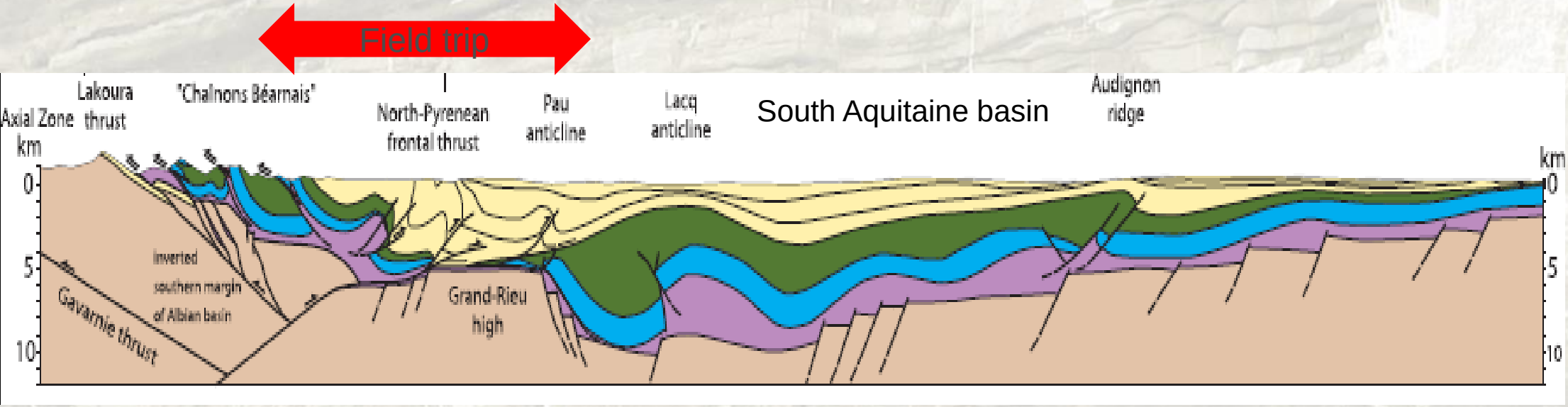
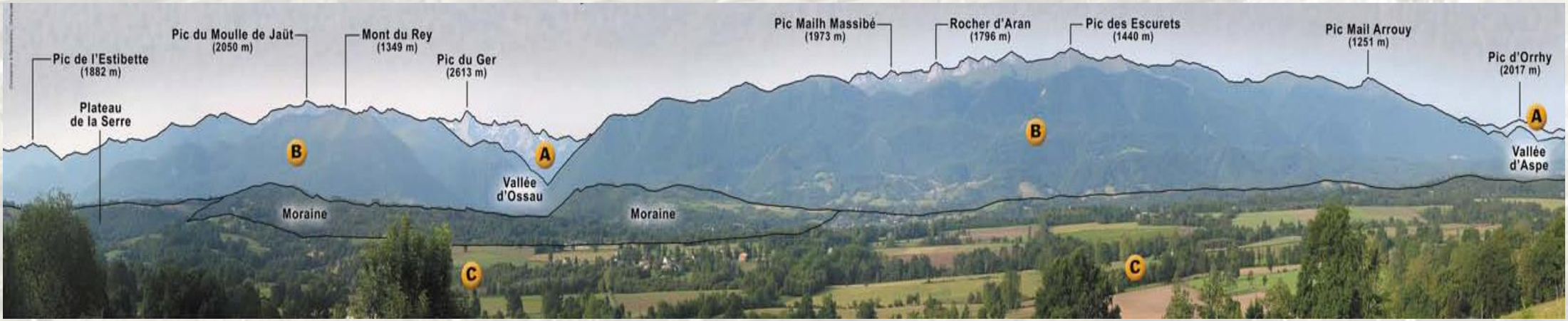
Geological cross section (zoom)



U. Oligocene-Miocene molasse
U. Eocene-L. Oligocene molasse
Eocene flysch and limestone
Upper Cretaceous
Lower Cretaceous
Jurassic
Upper Triassic in Keuper facies
Continental basement + Lower-Middle Triassic (upper crust)
Lower crust

Panorama from the GeolVal Belair site: introduction to the Pyrenees

From this site, we can observe the three morphological zones of the Pyrenees.
The Ossau and Aspe valleys are also visible.



A :**The "High Range"**
(about 3000 m) is mainly composed of Paleozoic granites, sedimentary and volcanic rocks, sometimes capped with Upper Cretaceous sediments.

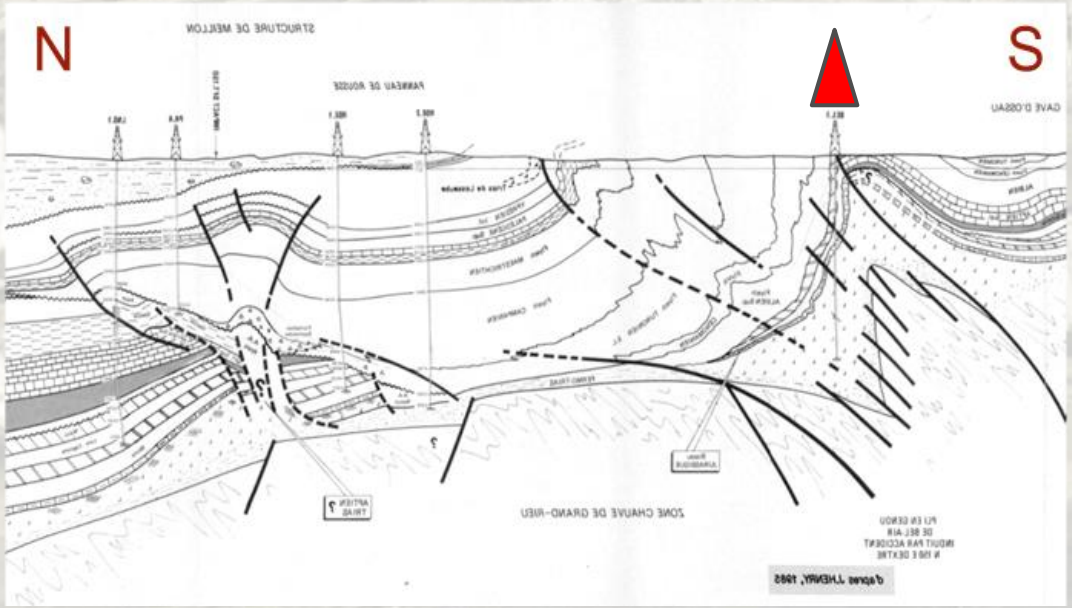
B : **The « chainons béarnais »**
(up to 2000m) are composed of folded and faulted Mesozoic limestones and shales, forming the first reliefs

C : The "foothills"
(about 500m above) are formed by hills made of folded Cretaceous soft sediments capped with Quaternary fluvial deposits (terraces) and glacial tills (frontal moraine).

Belair-1 well (1963)

Identification du forage

Archivage au BEPH :	12-1730-
Nom du forage :	BELAIR
Abréviation :	BEL
Numéro :	1
Type défini à l'origine :	Exploration (W)
Dates d'exécution :	22/11/1962 - 12/07/1963
Opérateur :	SNPA
Profondeur atteinte :	4572 m
Niveau géologique atteint :	TRIAS EVAPORITIQUE



Extract from the final well report (1963)

OBJECTIVES:

- Exploration of Early Cretaceous and Jurassic on a high zone visible in the Rebenacq region and supposed to sink towards the NNW close to the "*Triassic Lasseube accident*"
- Well spudded from the synthesis of field data and restricted seismic data

RESULTS

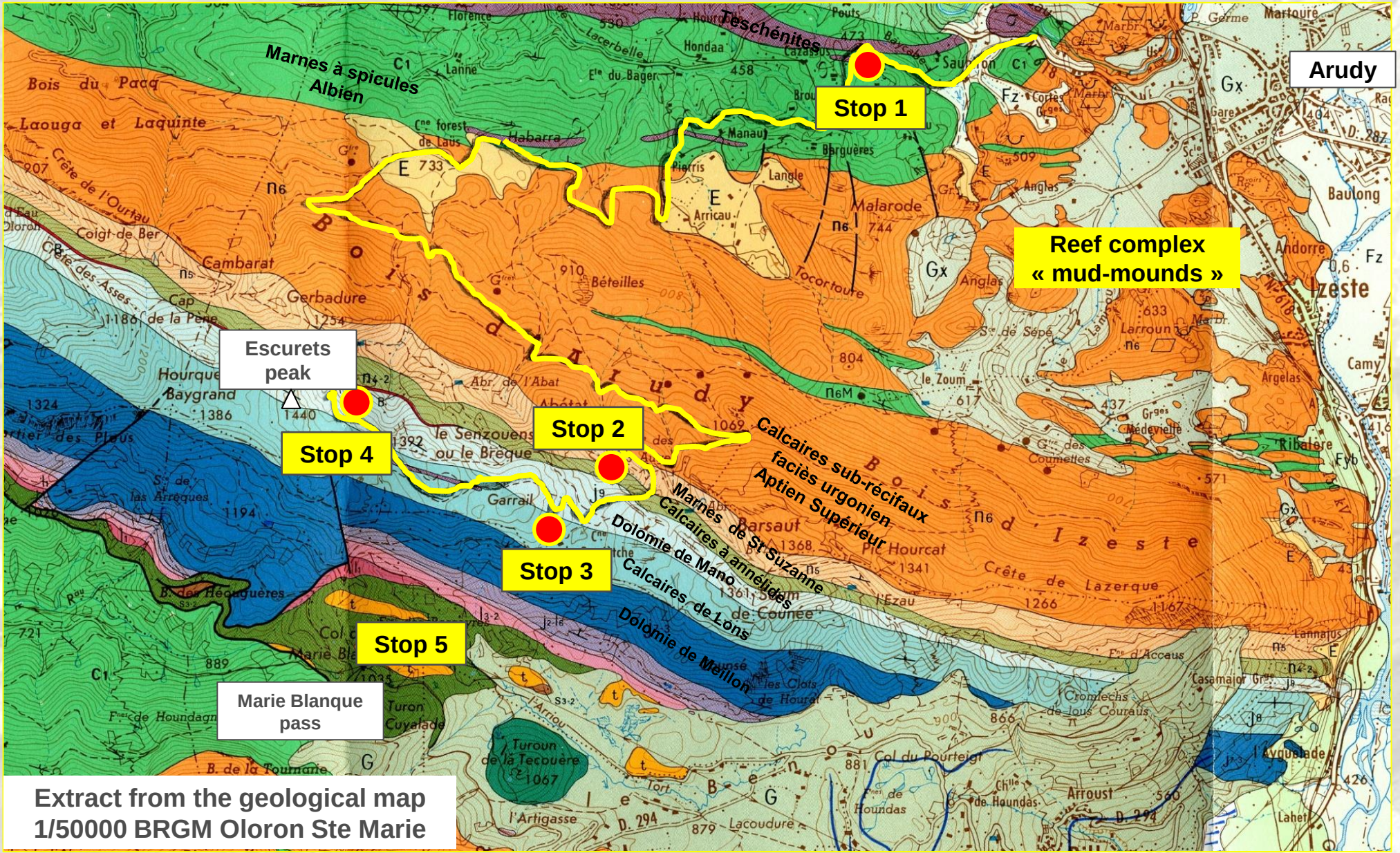
- Immediatly beneath Mio-Pliocene sediments the well has encountered a subvertical Callovo-Oxfordian dolomite (initially expected a few thousand meters deeper !!).Then, at 1956 m the well entered in the Triassic evaporites (...) up to 4576.50 m, final depth.

- "No evidence of hydrocarbons were detected, but the Jurassic dolomite forms a beautiful carbonate aquifer, probably invaded by freshwater."

The Pyrenees covered with ice … (- 20 000 years)

Frontal moraine of the Ossau glacier

From Arudy to the Escurets Peak



Extract from the geological map 1/50000 BRGM Oloron Ste Marie

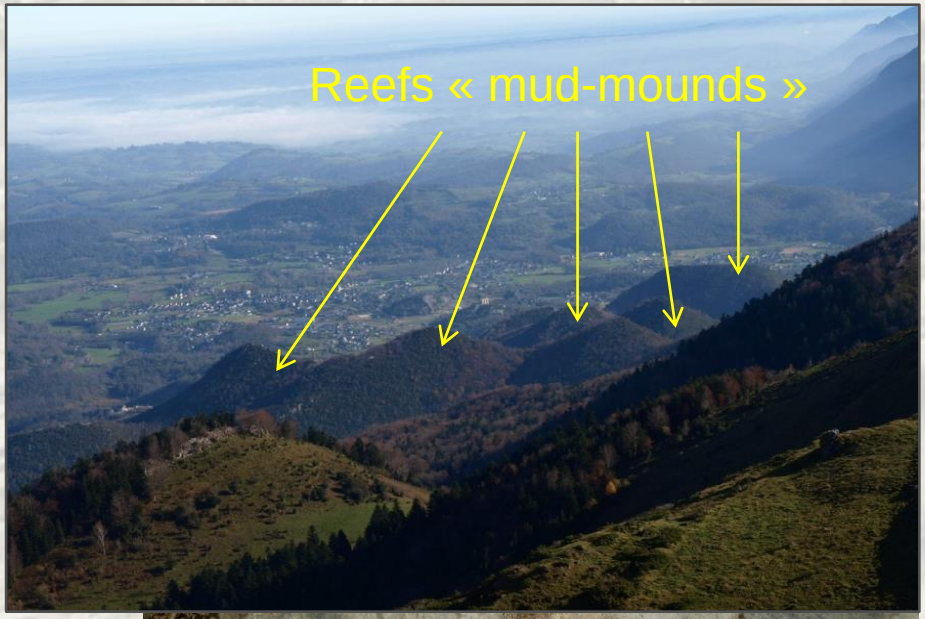
Stop 1: « Teschénites » outcrop

Massive outcrops, with fractures and no bedding: it is a undersaturated basic volcanic rock locally called « teschénites » and belonging to the gabbro family. Mineral composition: white feldspar crystals and dark green, needle shape, amphiboles (hornblends).

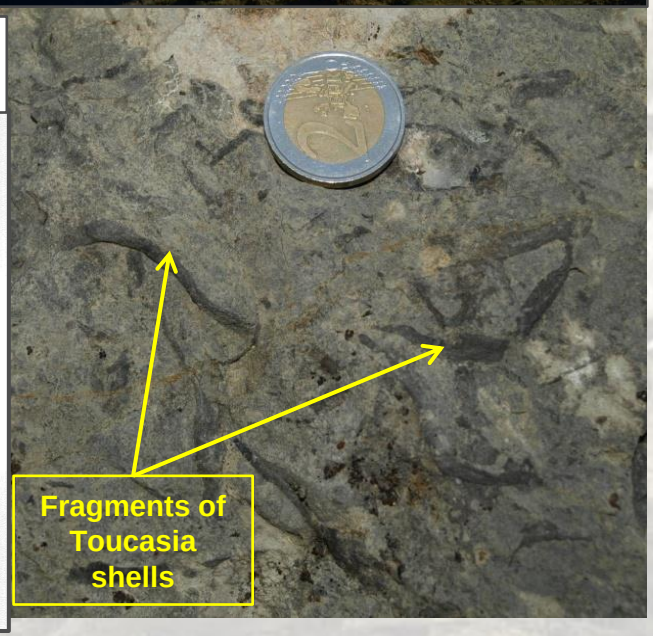
From the l'Aptian-Albian extension phase (- 113 to - 96 My) associated with the the oceanic Gascogne Gulf opening, an active volcanic activity took place: lava flows on the sea floor (pillow lavas) and basic magmatic intrusions interstratified in the Albian shales.These intrusions are of Turonian age.
In the Buzy area, the sills are orientated E-W ; as they are more resistant to the erosion compared with the surrounding Albian shales, they form some typical hills easy to follow in the landscape.

The volcanic rocks, in general, have no interest for oil and gas exploration. However at Ledeuix, a few km to the West, a small gas field (only 49 Bcf reserves) has been discovered « by accident » in the 70's. The reservoir consists of a fractured and altered lava sill, called « épisyénite »; 11 m net pay, 10% porosity, 2 producer wells. The source rock is probably the surrounding Albian shales, as there is no H2S or CO2 in the natural gas.

Stop 2: « Toucasia » limestones with « urgonian » facies»



Rudist Toucasia



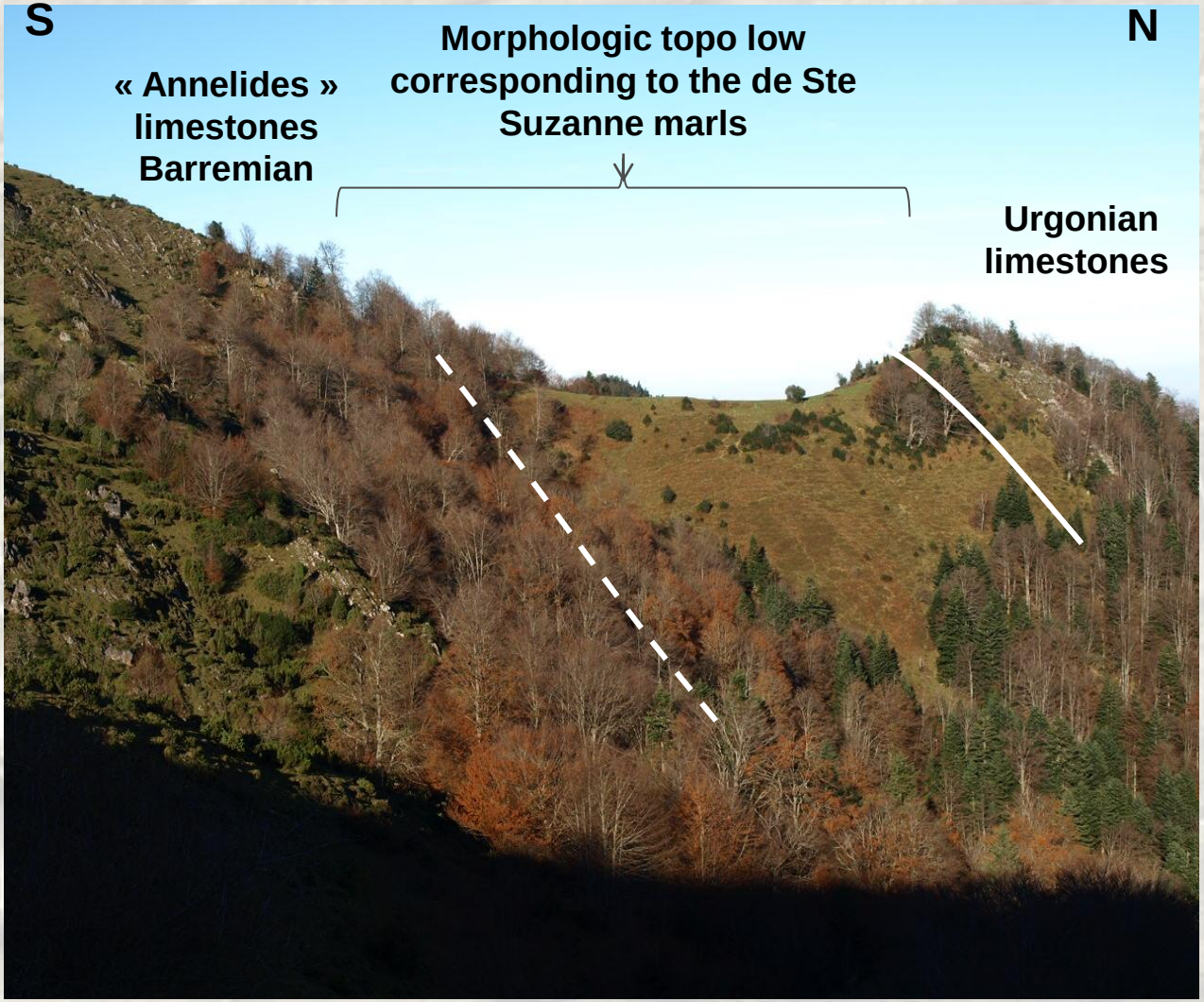
« Urgonian » Limestones (with Toucasia fossils) (Upper Aptian)

Reef limestones showing the called « urgonian » facies with a very large geographical extension (Alpes). Carbonate plateform corresponding to a marine shallow depositionnal environment. Many fragments of toucasia shells, belonging to the rudist family can be seen on the outcrops.

These limestones, abusively callled « Arudy marbles » are extracted in several quarries at Arudy and have ben used for centuries, as ornemental stones in many buildings of the region.

Locally, like in the Arudy area, and also in the Aquitaine basin, some reef buildups (mudmound type) are developped on this plateform forming some typical topographic highs. All of these « reefs » have been drilled in the Aquitaine basin, but with no commercial success.
However, in some other places in the world, these mudmounds are interesting potential targets. Example: the « Leduc» reef in Alberta/Canada made the initial fortune of Aquitaine Canada Company in the 70’s.

Stop 2 : « Sainte Suzanne » marls



« Sainte Suzanne » marls/shales (Upper Aptian)

Interstratified between two limestone formations more resistant to the erosion, the Sainte Suzanne marls Formation correspond to a topographic low, which can be easily followed in the landscape along the Northern Pyrenees.

With a thickness of 50 to 250 m, these silty greyish or blackish marls are associated with interbedded calcareous sandstones. This Formation represents the main, regional seal for many gas or oil fields in the Aquitaine basin.

Echantillon provenant des marnes du col d'Andorte

Stop 2 : « Annelides » (worms burrows) limestones and karstic bauxitic breccias

The Annelides limestones (Valanginian to Barremian), show on the outcrops, some annelide sections (fossilized worm burrows). The more or less circular shape depends on the orientation of the section.

The Barremian can be either reservoir (Lacq, Pecorade, Vic Bilh), waste zone and/or source rock + reservoir (Vic Bilh)

At the top of the du Barremian, in some areas, we can oberve some calcareous breccia, lying over a kind of bauxitic crust. These bauxitic levels are sometimes well developpped, like in Provence with some past aluminim production. The breccias correspond to the filling of karstic cavities during an emersion phase of the carbonate plateform.

In oil and gas exploration, this emersion episodes (Low stand) with karstification through carbonate secondary dissolution, can develop some interesting reservoir characteristics.

Stop 2: Different facies of the Mano dolomite Formation (Portlandian)

massive outcrop: : oolithe bar

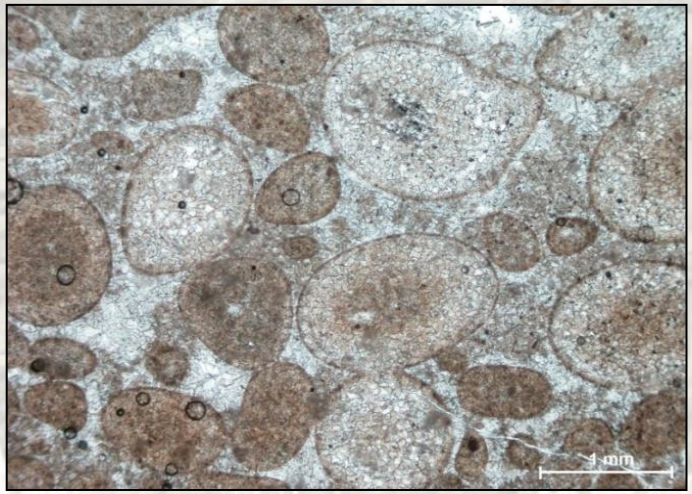
Micro-cristalline dolomite with fossilized prints of burrowing worms

Present day karstic alteration , underligning the fracture network

Dolomitic breccia

Stop 2:The Mano dolomite formation reservoir at Rousse gas field

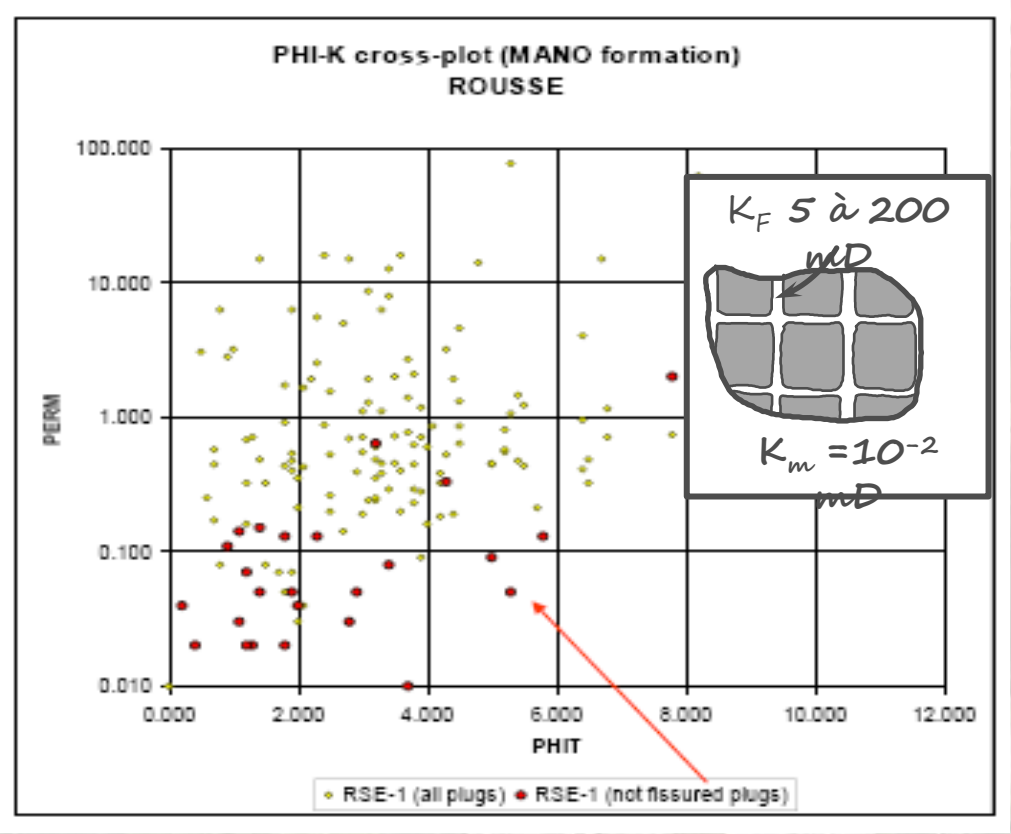
The Mano dolomite is a fractured carbonate reservoir in some Aquitaine basin fields, showing both a matrix and a fracture porosity. The gas production come from different facies: oolite bar, breccia , cristalline dolomite , etc The matrix porosity (average 3%) and the permeability (< or = 1 Milli-Darcy) are very low, but sufficient to to induce a good gas production, thanks to the fracturation and adapted well trajectory, interseting many fractures.



Thin section of the Mano dolomite: Partially dolomitized oolites (Rousse gas field)

Thin section of the Mano dolomite: dolomite with very fine dolomite crystals (Rousse gas field)

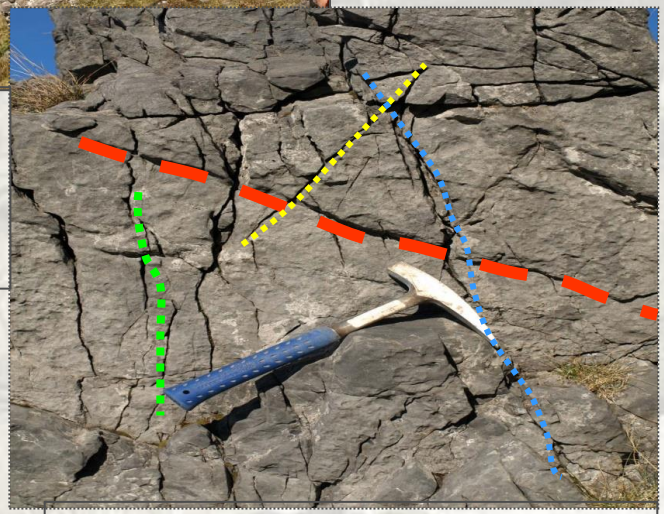
Diagramme Porosity vs Permeability in the Mano reservoir(Rousse gas field)



Mano Dolomite: fracturation at every scale

Mountain scale: preferential fracture corridors

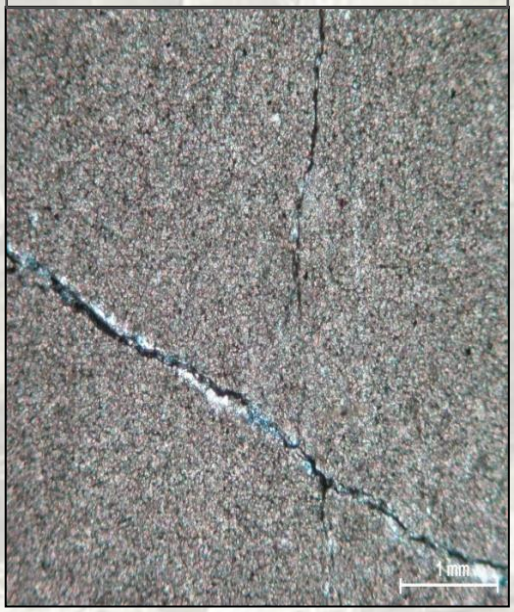
Fracturation can be observed at different scales : from the kilometer scale to the microscopic scale. The way the producer wells intersect these fractures will influence the rate of production; therefore, it is crucial to get a good understanding of the fractures network and their repartition in 3D volume



Outcrop scale : different fracture families with different orientations

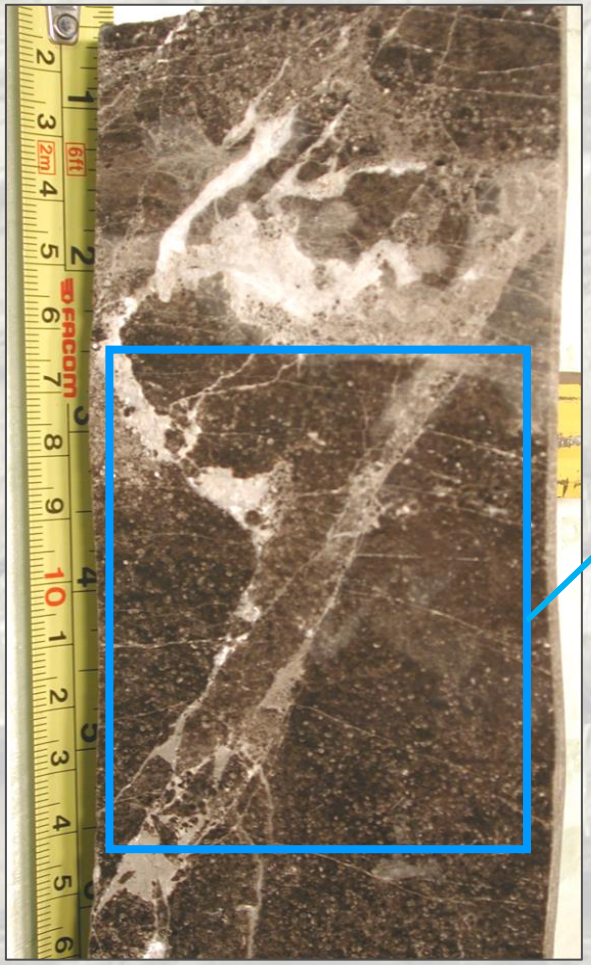
Drilling core scale: macro fractures, open or filled with calcite cement

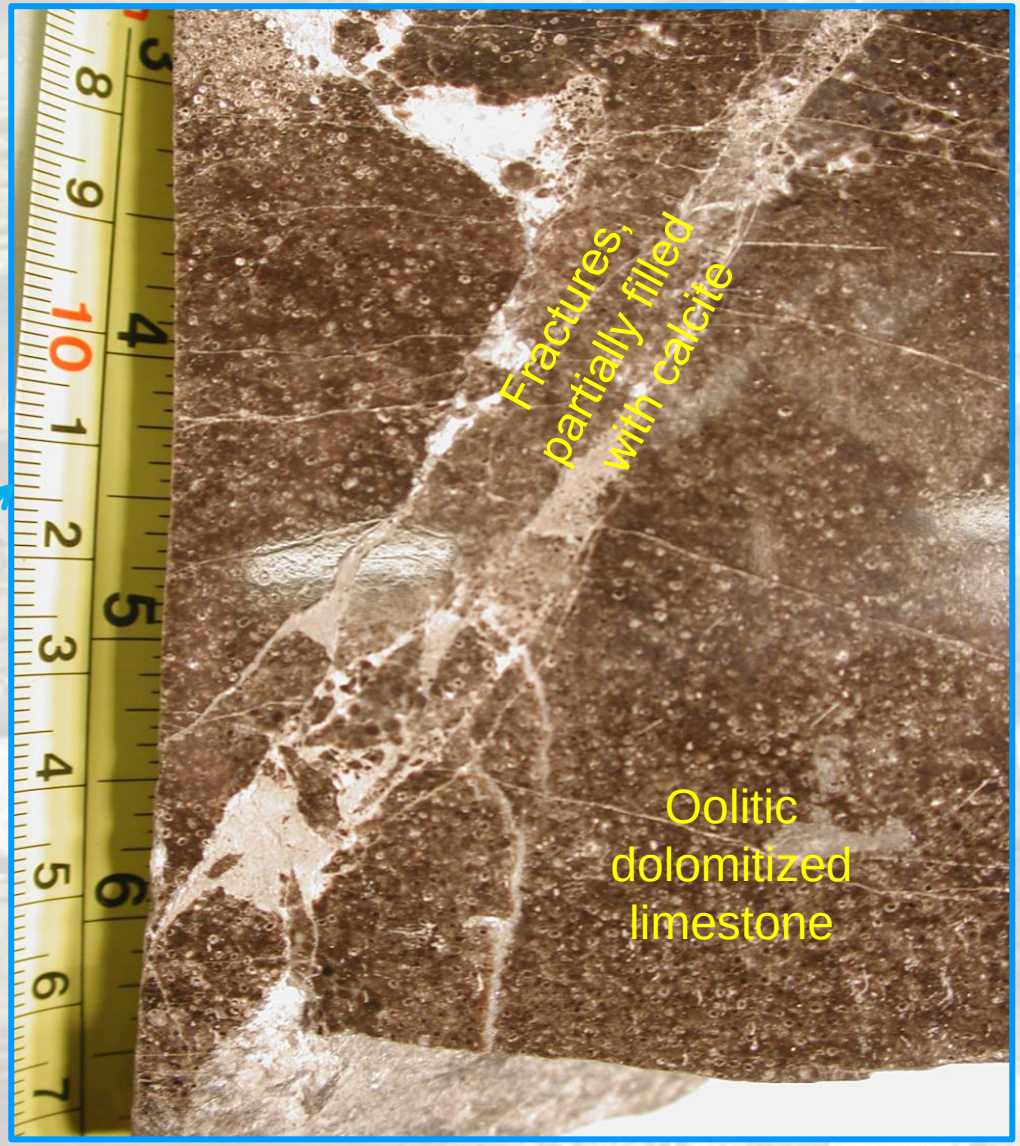
Microscope scale open microscopic fractures



Macro-photo of a piece of core from Rousse-1 well

Depth : - 4592,3m
Oolithic bar
Dolomite Grainstone/Wackstone
Partially mineralized (calcite) fractures
Partial dissolution of oolites
Good matrix porosity

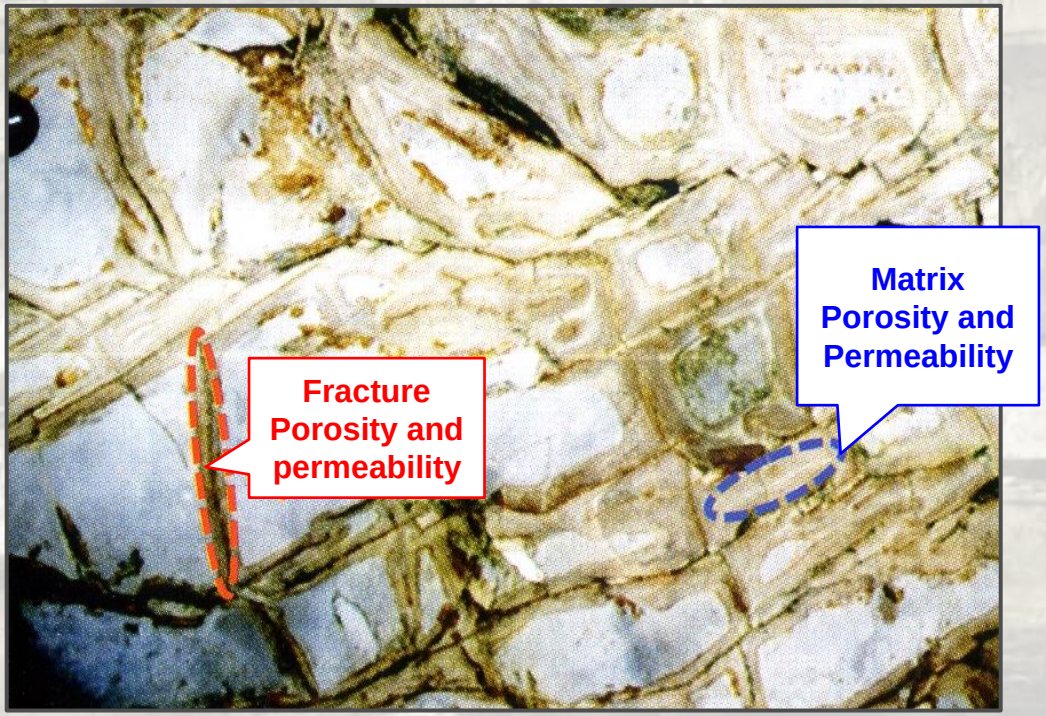


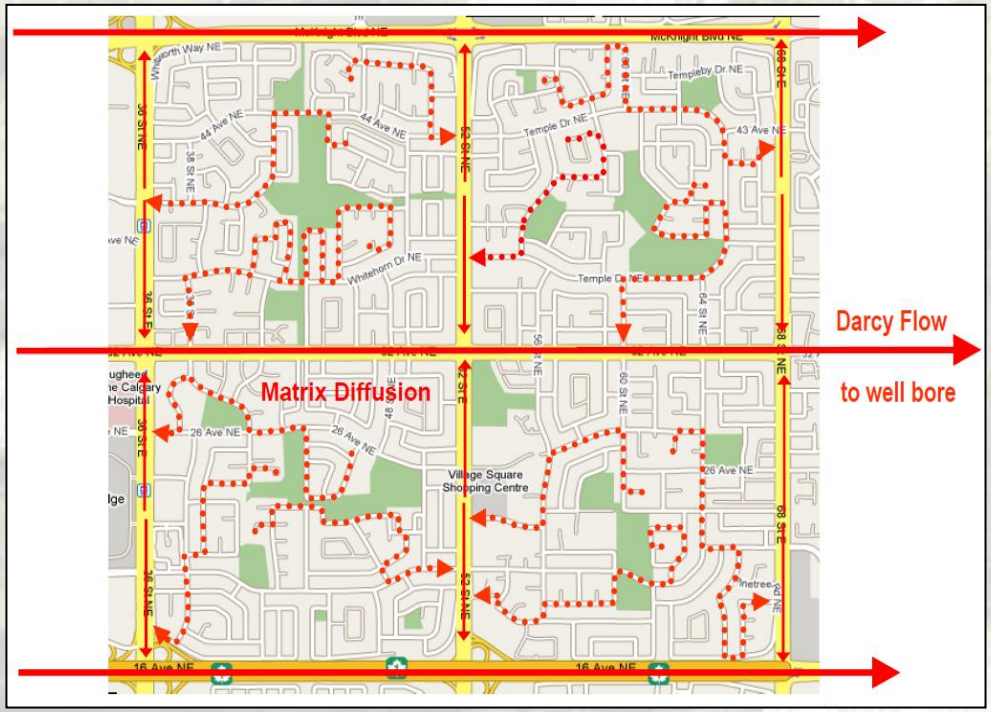


What is a fractured, dual porosity, carbonate reservoir ?

In the whole world, half the oil reserves and one third of the gas reserves, are located in carbonate reservoirs, which produce mainly through fractures.

Inside a fractured reservoir, the hydrocarbon fluids move easily through the fractures (fracture porosity and permeability), and /or diffusion through the rock matrix (matrix porosity and permeability). We are dealing with a dual porosity reservoir, like the Mano dolomite.
Analogy with the car traffic in town: a few cars move slowly from the residential areas (matrix diffusion) and « charge » a more intense and faster traffic in the main streets fracture permeability)



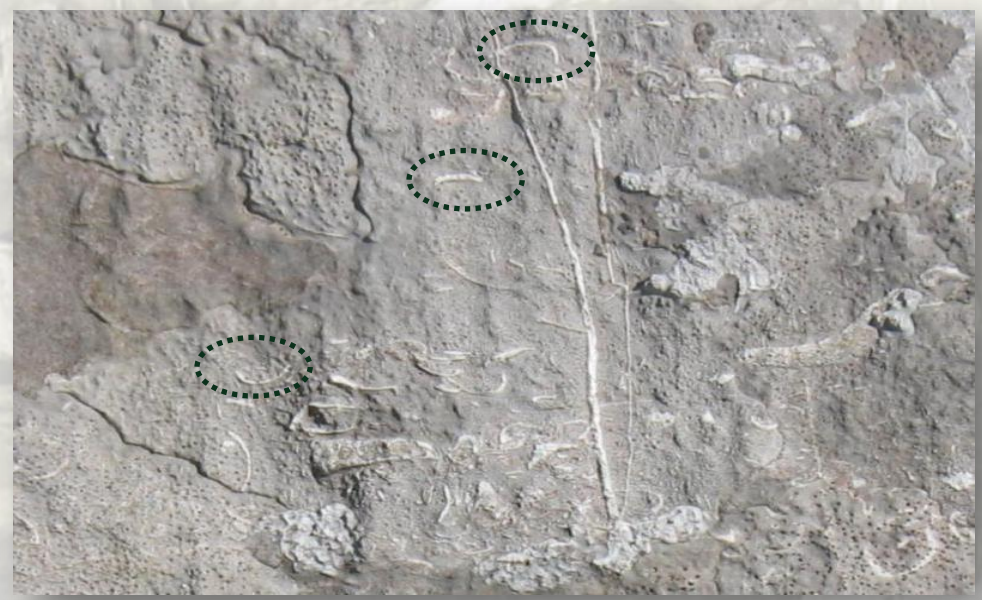


Stop 3: Lons limestone Formation (Upper Kimmeridgian)

Very fine, black limestone, well bedded, with alternances of shally limestones or dark or violet marls. The Lons Formation and in particular the upper part, of Kimmerigian age, is the main source rock for the oil and gas fields of the southern Aquitaine basin (Lacq, Meillon and satellites,Vic Bilh, Pécorade, Lagrave).
Source Rocks characteristics: The marine Upper Kimmeridgian source rocks are extensive and correlatable across the whole Aquitaine Basin. The main source section corresponds to the Catus Member (upper part of the Lons Limestones) in the South Aquitaine area. This interval is calibrated from immature outcrops in the Quercy, forms the main source interval. This section, 50 m to 150m thick, exibits initial TOC in the range of 2 to 7% and a petroleum initial potential (S2) up to 20 Kg/t. The Hydrogen index ranges between 200 to 600 HC/g of % TOC. Its Source Potential Index ranges from 0.7 MM ton per km2 over South Aquitaine sub-basins. Its kinetics behaviour suggests a retarded maturity compared to a standard type II kerogen (carbonate type II kerogen).

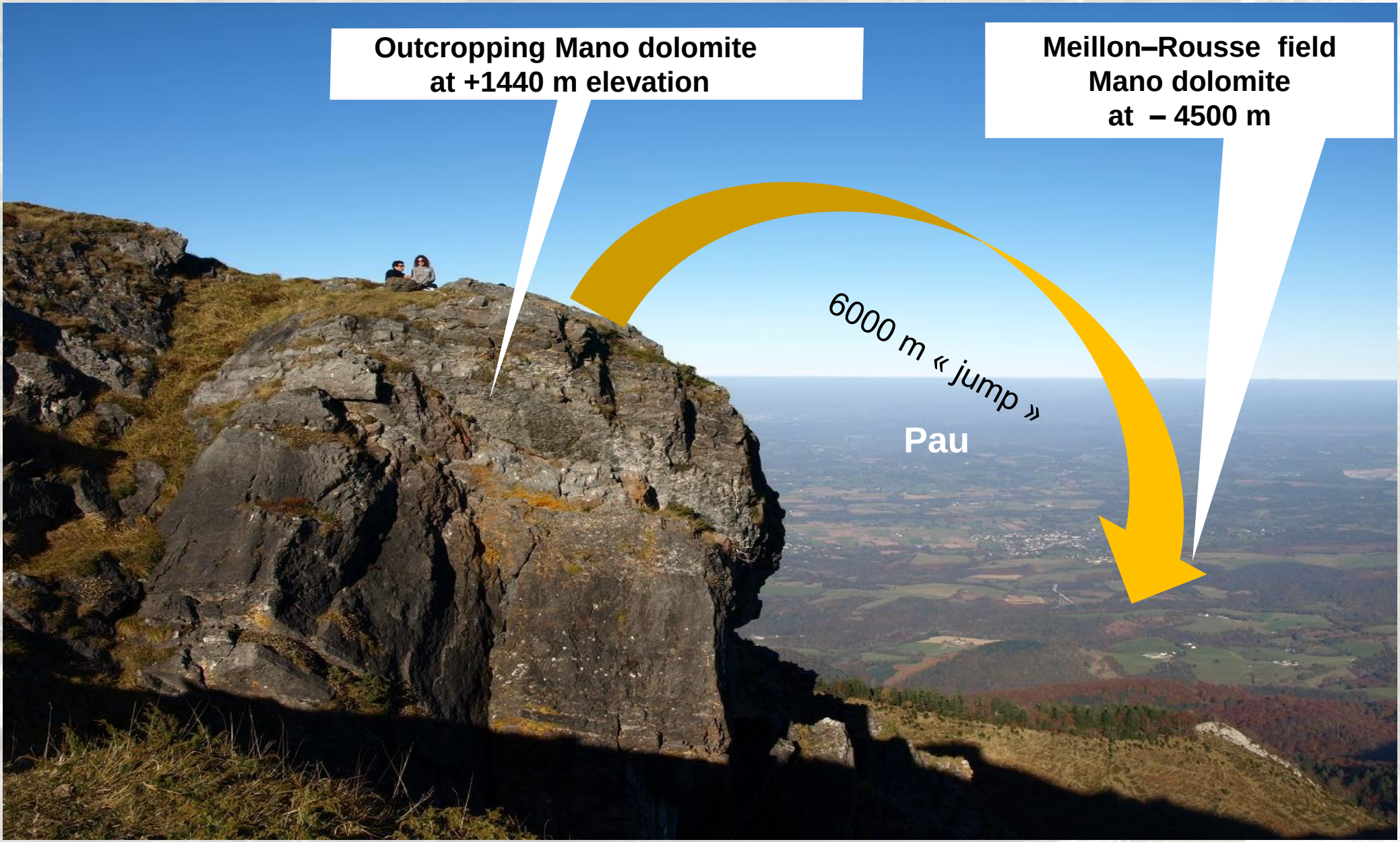
Notice that this source rock is interstratified between the Mano reservoir stratigraphically above and the Meillon dolomite reservoir below. This geometrical configuration is favourable for an easy migration from the source rocks to both reservoirs

Outcrop of the Lons limestone Formation

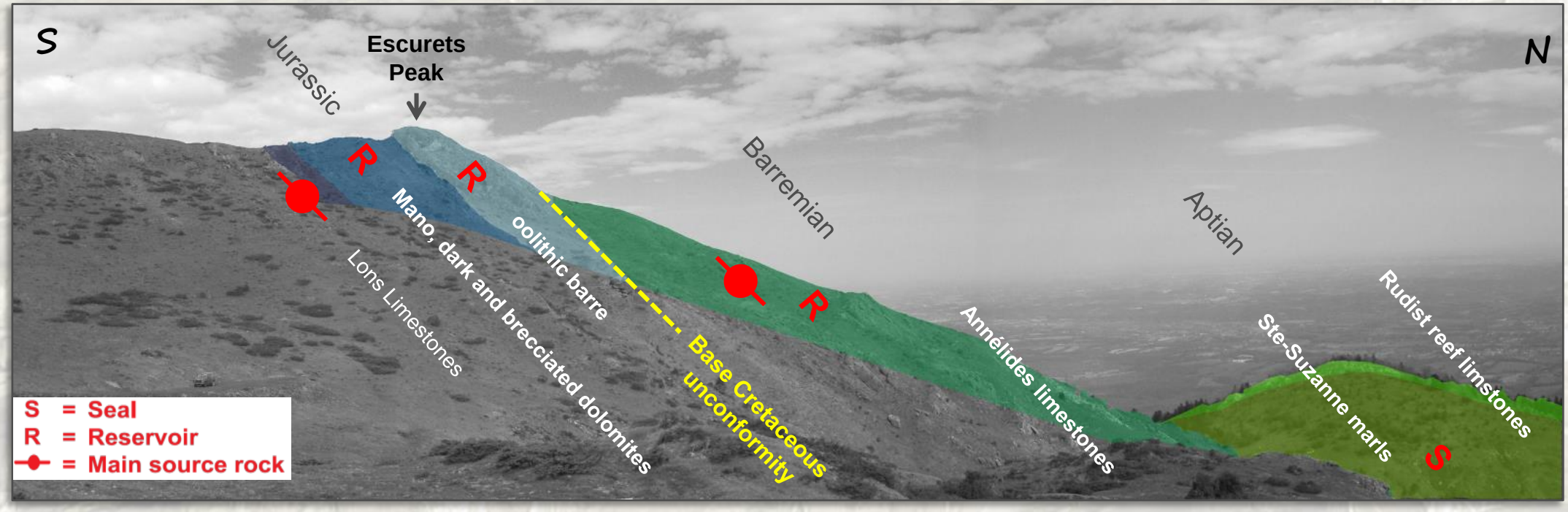


Fossils of oysters (« exogyra virgual »)

Panorama (looking North) from the Escurets peak



Stop 4 : Geological panorama of the Escurets peak



Along this landscape/cross-section, we can observe a succession of geological formations, with a strong dip to the North (>40 °). From the South to the North:

- The Lons limestone Formation (source rock, refer to stop 3)
- The Mano dolomite Formation (fractured and dual porosity reservoir, refer to stop 2)
- The Barremian limestones (either source-rock, reservoir or waste zone, refer to stop 2)
- The Sainte Suzanne marls Formation (seal rock, refer to stop 2)
- The Urgonian limestones (reefal rudist limestones, mud-mound potential reservoir, refer to stop 2)

This succesion shows the geometrical relation between source rocks, reservoirs and seals, found in several gas fields. Note that the source rock is directely juxtaposed to the reservoir above, therefore favourable to an easy hydocarbon migration.

-

Stop 4: Conclusions on the Northern Pyrenean Zone

1) From Arudy to the Escurets peak, 3 elements of the North Pyrenean petroleum system has been observed:

- seal (Ste Suzanne marls),
- main reservoir (Mano dolomite),
- source rock (Lons Formation).

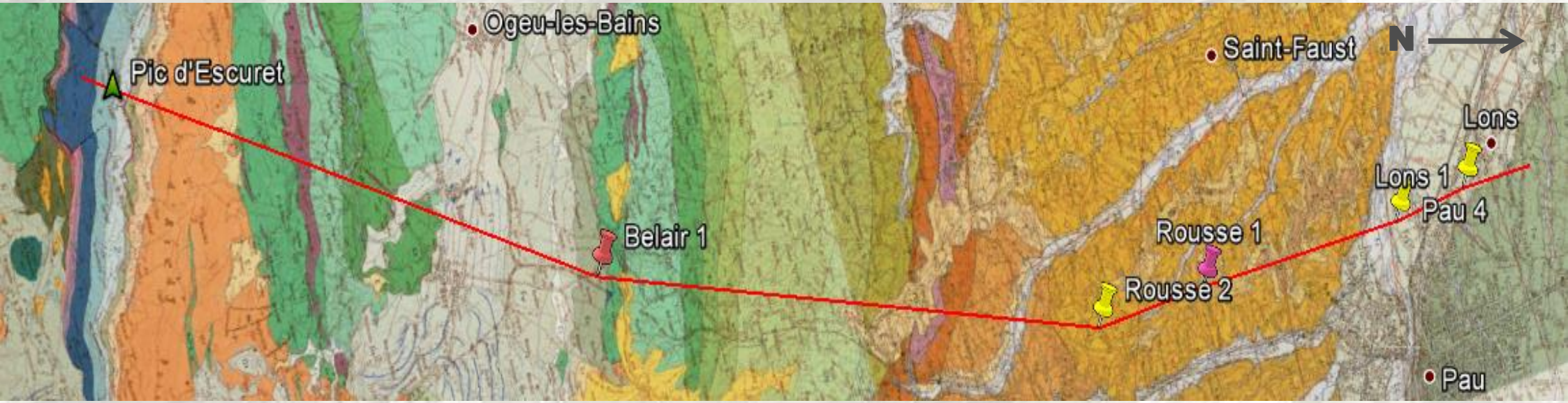
These are similar to those known in the Aquitaine Basin located northward in the foreland.

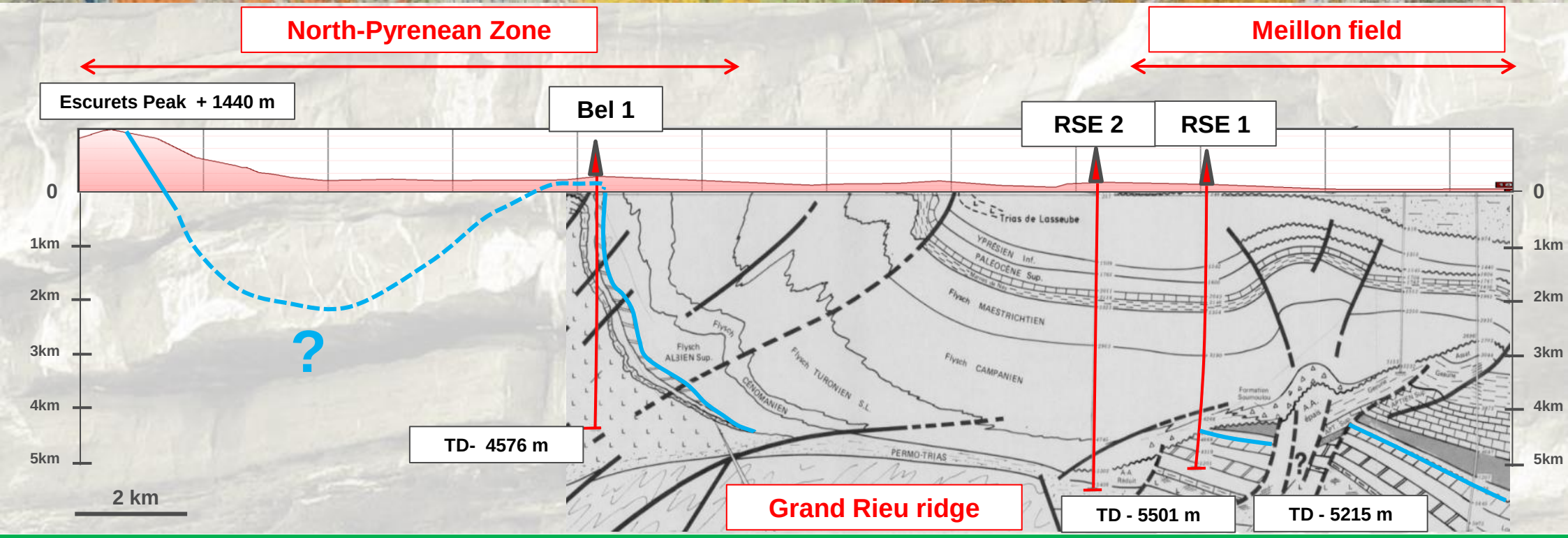
Pau

2) North of Escurets peak, the presence of thick Albian, Cretaceous and Tertiary deposits, indicates that burial of Jurassic source rock has been sufficient to mature and generate hydrocarbons, *as in the Aquitaine Basin*.

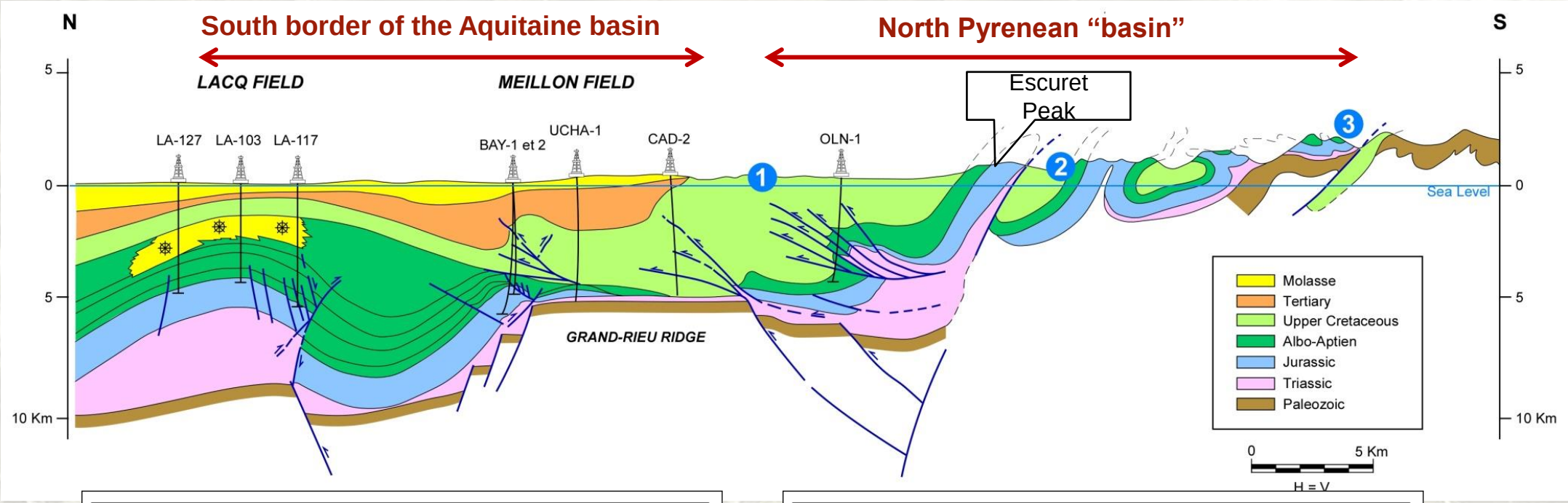
3) The analysis of outcrops shows that all formations encountered are strongly dipping to the north (45°dip) and intensely fractured. *Therefore structuration occured as in the foreland.*

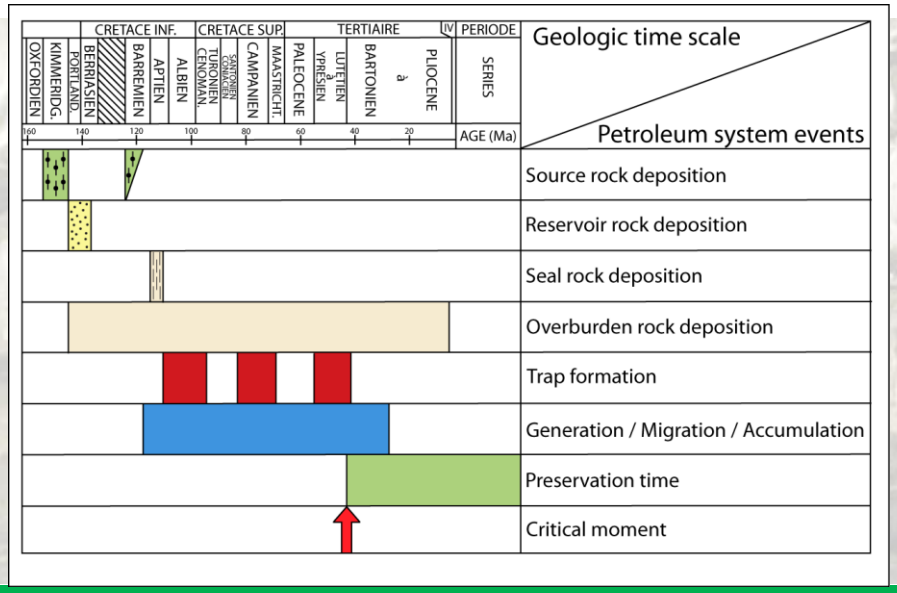
Integration of field data with subsurface data

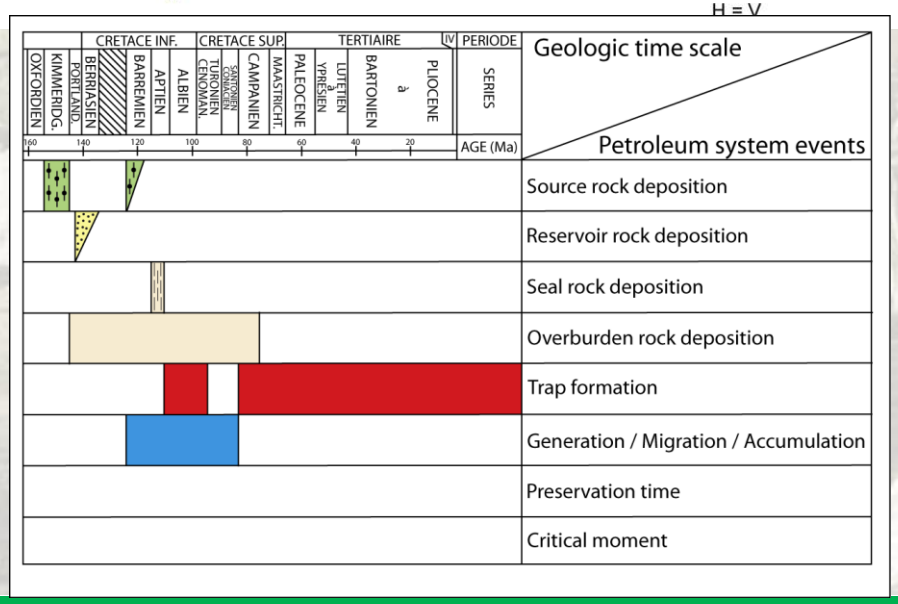




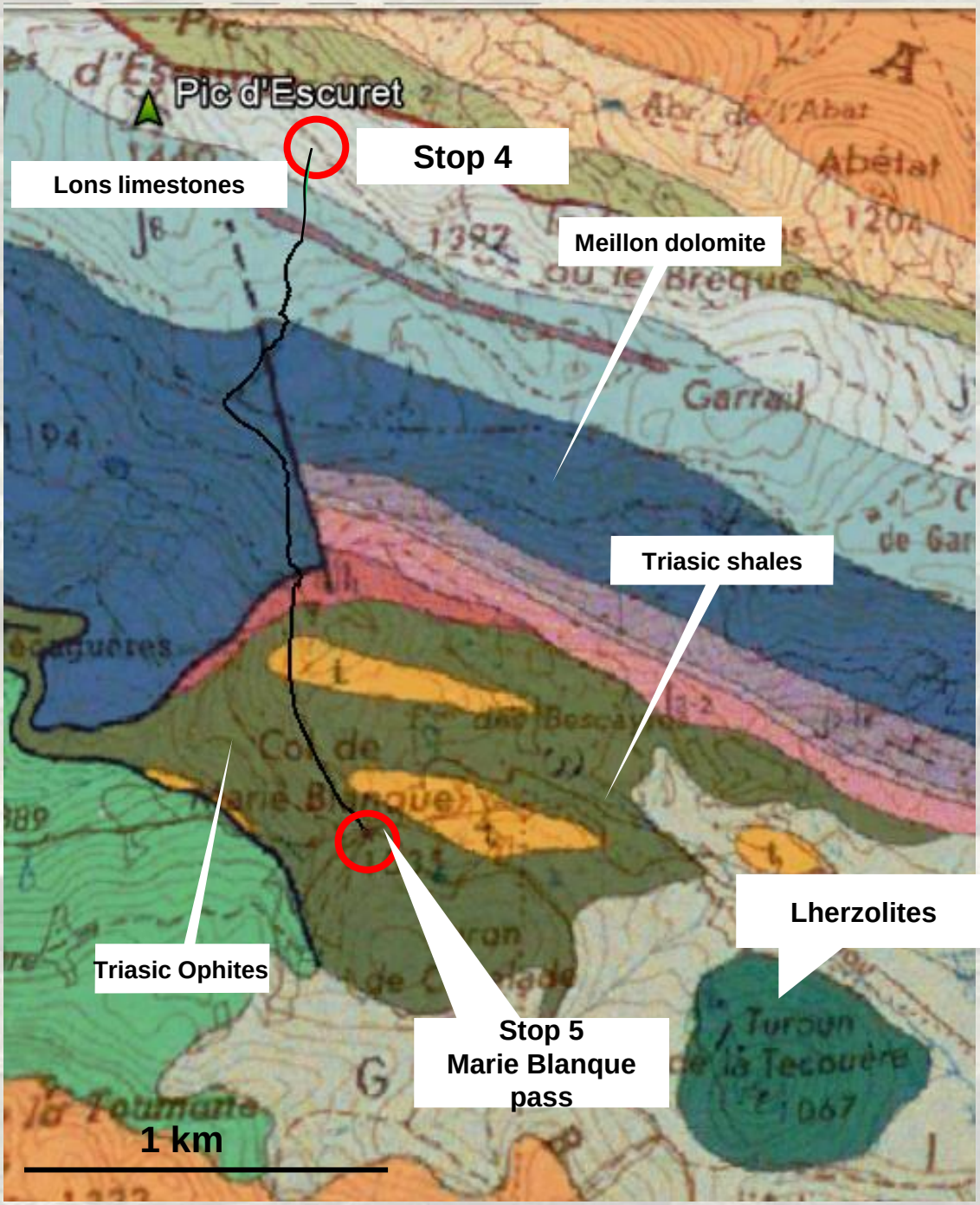
Comparison of the Aquitaine basin and the North Pyrenees petroleum systems







From the Escurets peak,
walking down to the « Marie Blanque » pass
(optional)

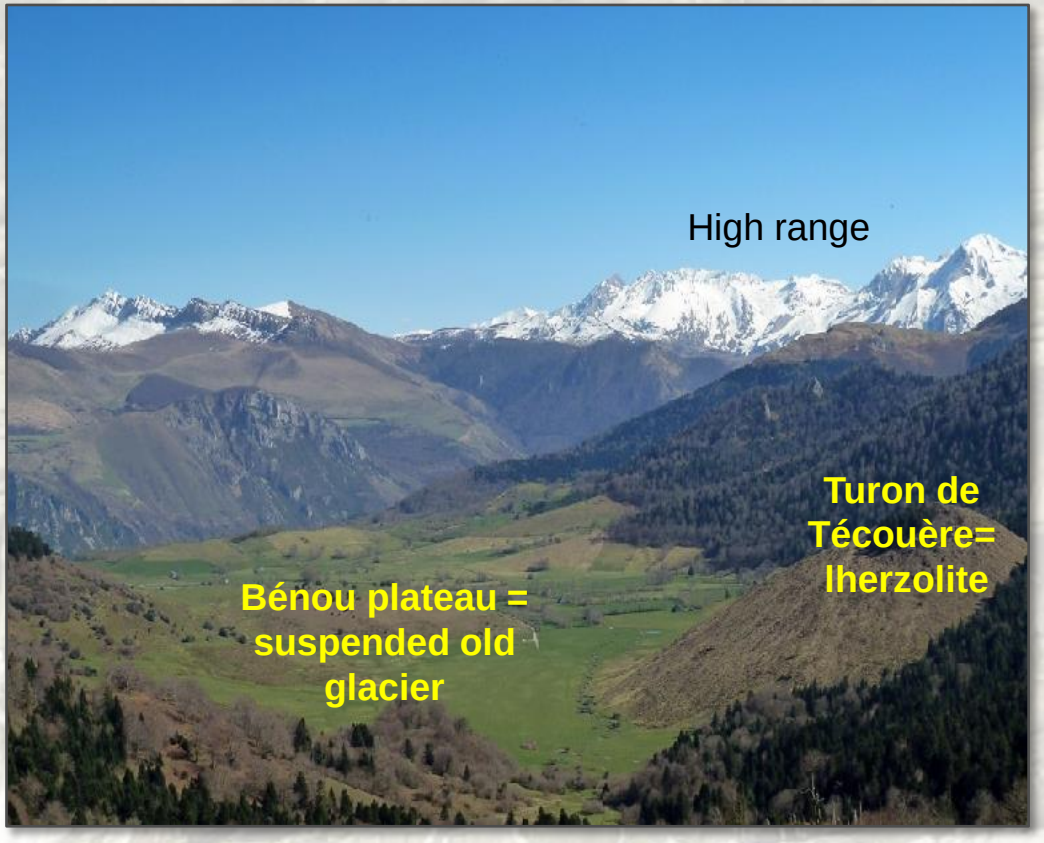


Escurets Peak → Marie Blanque Pass (stop 5)

In the way down from the Escuret peak (1440 m) to the Marie Blanque Pass (1035 m), below the Lons formation we can observe:

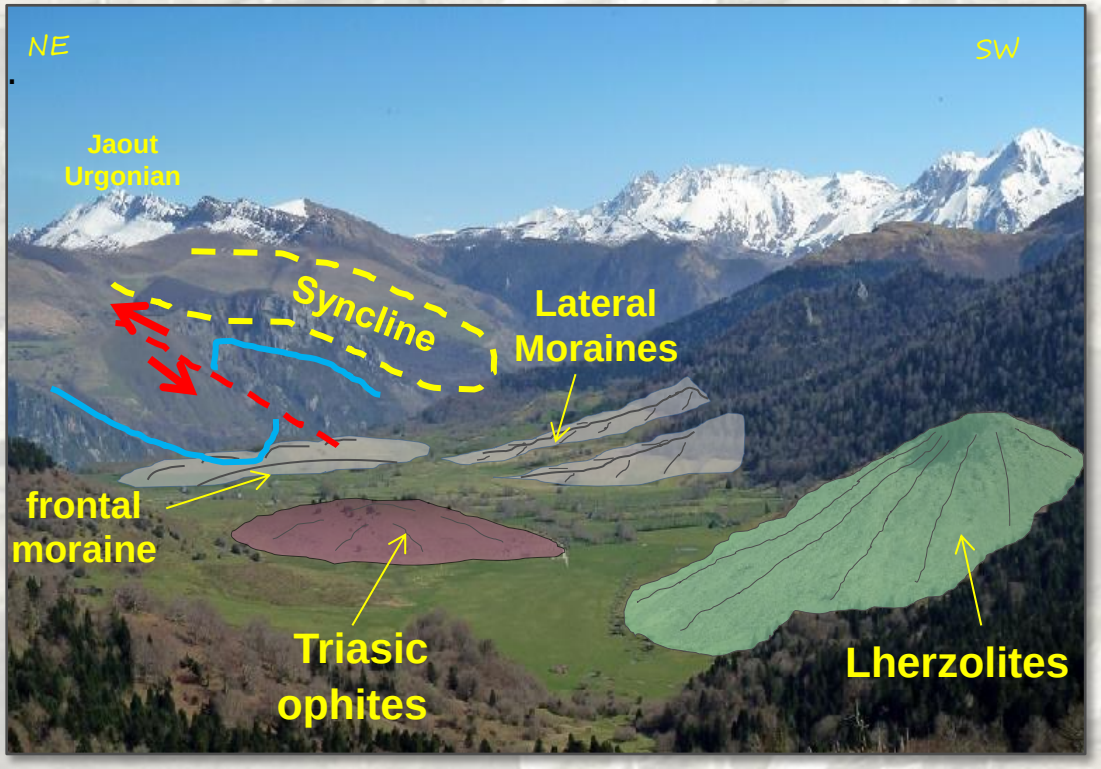
- The Meillon dolomite Formation (also a reservoir at Meillon gas field)). These black domlomites are Middle Jurassic in age.
- Marls and shales of different color, mainly « vine » red, often containing gypsum (Trias)
- Some sharp hills corresponding to triasic ophites or lherzolites magmatic rocks.

From the Escuret peak to the Marie Blanque pass (optional)



Walking down from the Escurets peak, looking towards the Bénou plateau we can observe some typical cone shape hills made of ophites (Triasic volcanic rocks) or lherzolites (= peridotite) an ultra-mafic rock, with a still controversial crustal origin.

In the morphology, we can also see some remanants of glacial moraines, indicating that the Bénou plateau was occupied 20 000 years ago, by a « suspended » glacier over the Ossau main glacier



Typical structures of the « chainons béarnais
Panorama from the Bénou plateau

The observed structures, anticlines, synclines, thrusts
are at a similar (seismic) scale, than the oil and gas fields