# Karst-fractured reservoirs : diagenesis & petrophysical features.

## Analogous reservoir: Santayi aquifer (Mallorca, Spain)

**Supervisor: Jean Louis Cappelli**



TOTAL

# Outline

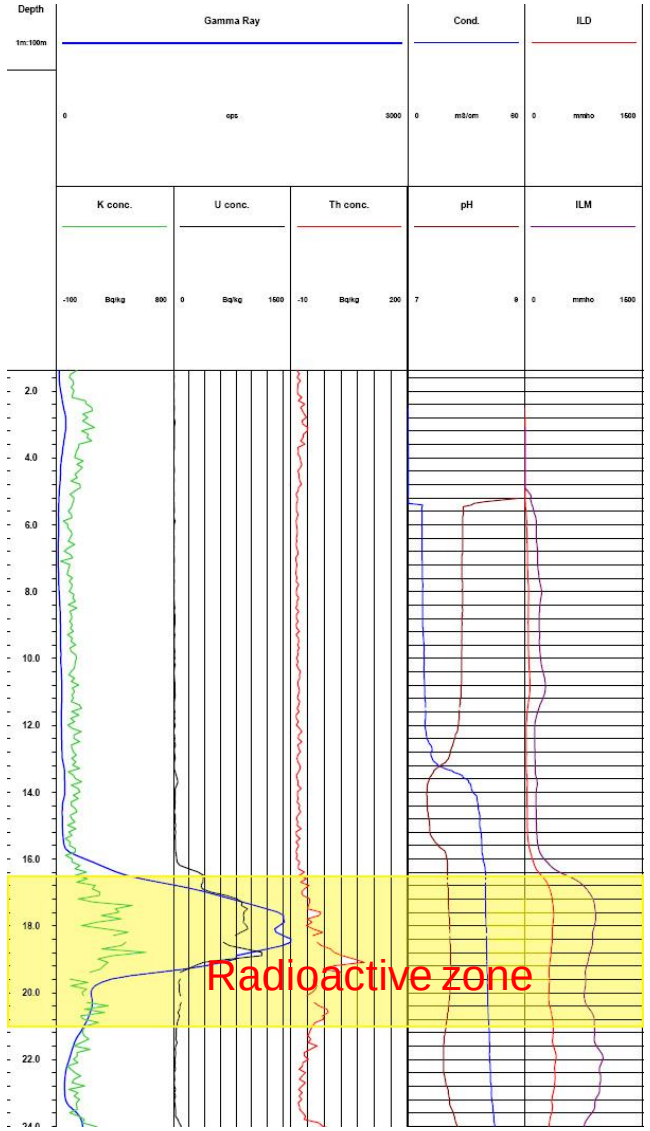
- **Results of previous studies in Font Sant region**
- **Objectives**
- **Workflow**
- **Location of Font Sant aquifer**
- **Geological settings**
- **Well localization: S23/S26/S27**
- **Facies description of core**
- **Origin of Unit 2 and unit 3**
- **Karst-fractured reservoir: Santayi aquifer**
  - ✓ Configuration of the aquifer
  - ✓ Karst features
- **Virtual petrophysical analysis**
- **Conclusion**



TOTAL

# Results of previous studies in Font Sant region

- Geo/hydrothermal activity recorded
- Presence of particular zone in depth, characterized in term of:
  - ✓ Geophysics by a high radioactivity
  - ✓ Lithofacies by coarse crystals of calcite




**Conclusion**

The anomaly corresponds probably to:
a filled-paleokarst created by a radioactive zone

geo/hydrothermal fluids flow throughout an eventual fault

# Objectives

✓ **Provide criteria showing :**

Existence of a fault associated to geo/hydrothermal fluid circulation

✓ **If there are no criteria of fault and hydrothermalism :**

Define the nature of this large filled paleokarst: meteoric or mixing zone

**Main objectives:**

✓ Define the nature of distinct karst development : meteoric or burial !?

✓ Analyze and characterize the impacts of diagenesis processes related to karst impact on petrophysical parameters of the aquifer.

✓ Role of fractures on the quality of the Font Sant aquifer



TOTAL

# Workflow

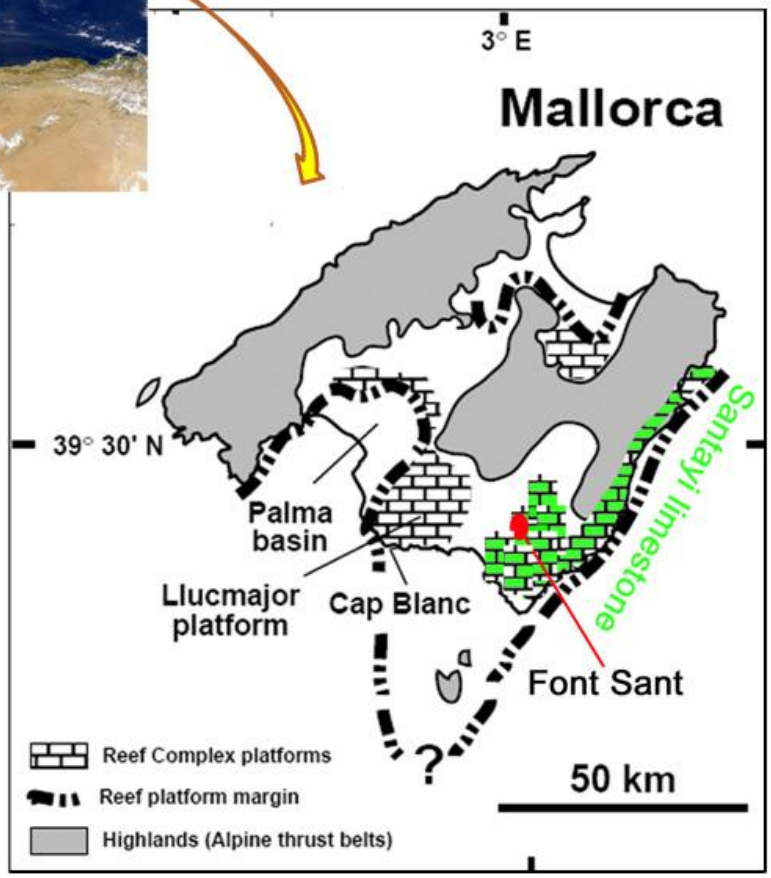
- ✓ Mallorca fieldwork : Logging + Inter-well triangulation
- ✓ Core analysis :
  - Fitting to gather and orientation of the core fragment
  - Scanning: acquisition, virtual petrophysical treatment from Amira software
  - Thin section and plug sampling.
- ✓ Macro-Sedimentological/Structural description of cores
  - Directly from cores
  - from X-Ray images
- ✓ Mirco- facies description from thin sections
- ✓ Borehole data analyses
- ✓ Diagenesis analyses from :
  - Thin sections
  - Cathodoluminescence miscroscopy
  - Stable oxygen and carbon isotopes
- ✓ Inter-well correlation



TOTAL

# Location of Font Sant aquifer

- ✓ Island of Mallorca extends into the western Mediterranean Sea




- ✓ Font Sant located:

In South eastern part of Mallorca

On Santayi platform

# Geological setting

- **Westward migration** of Alboran Microplate,

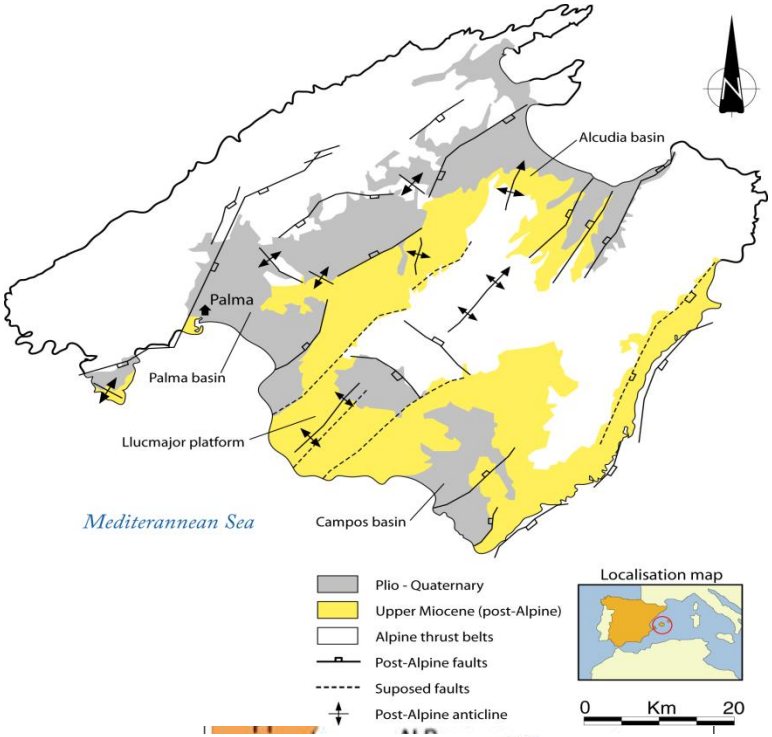
  Oligocene-Middle Miocene in age:

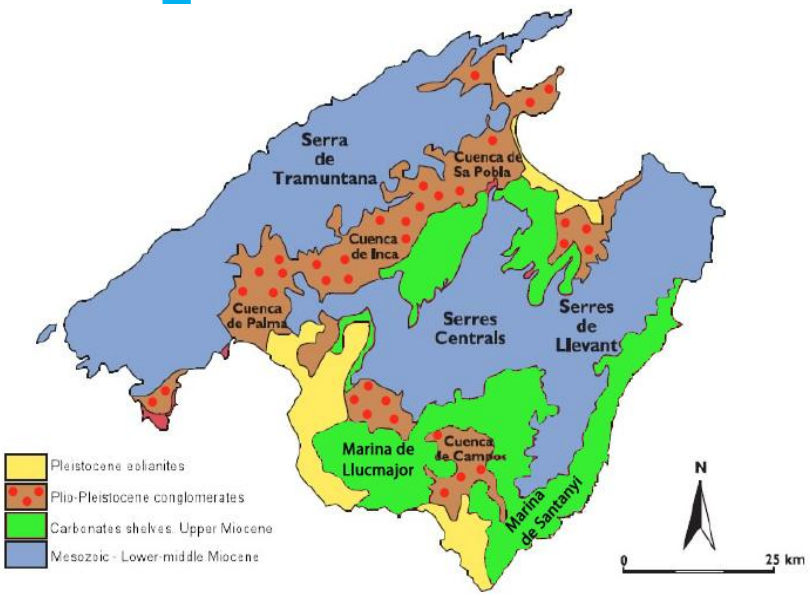
  Clockwise rotation of Mallorca

✓ **Compressive** phase in Mallorca
Establishment of **horst**: Alpine thrust belts

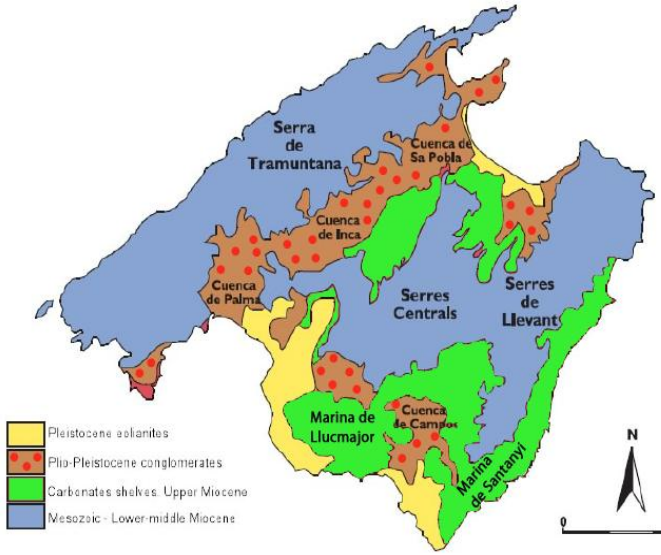
✓ **Exte**

Establishr




Geological map




Geological map

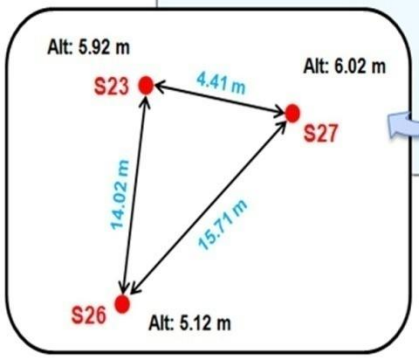


TOTAL

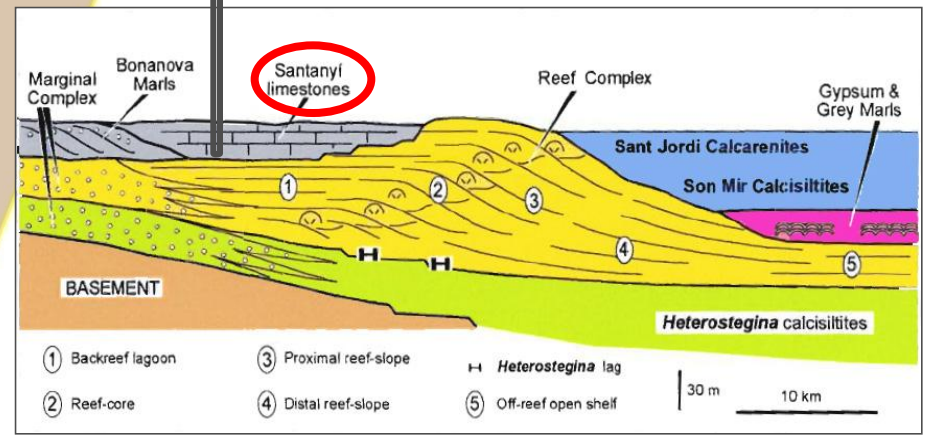
# Well localization: S23/S26/S27

- ✓ Three wells are drilled:


- On Santayi limestone
- In South eastern part of Mallorca


Well




**Data available**

Core: Only S26 and S27 are cored

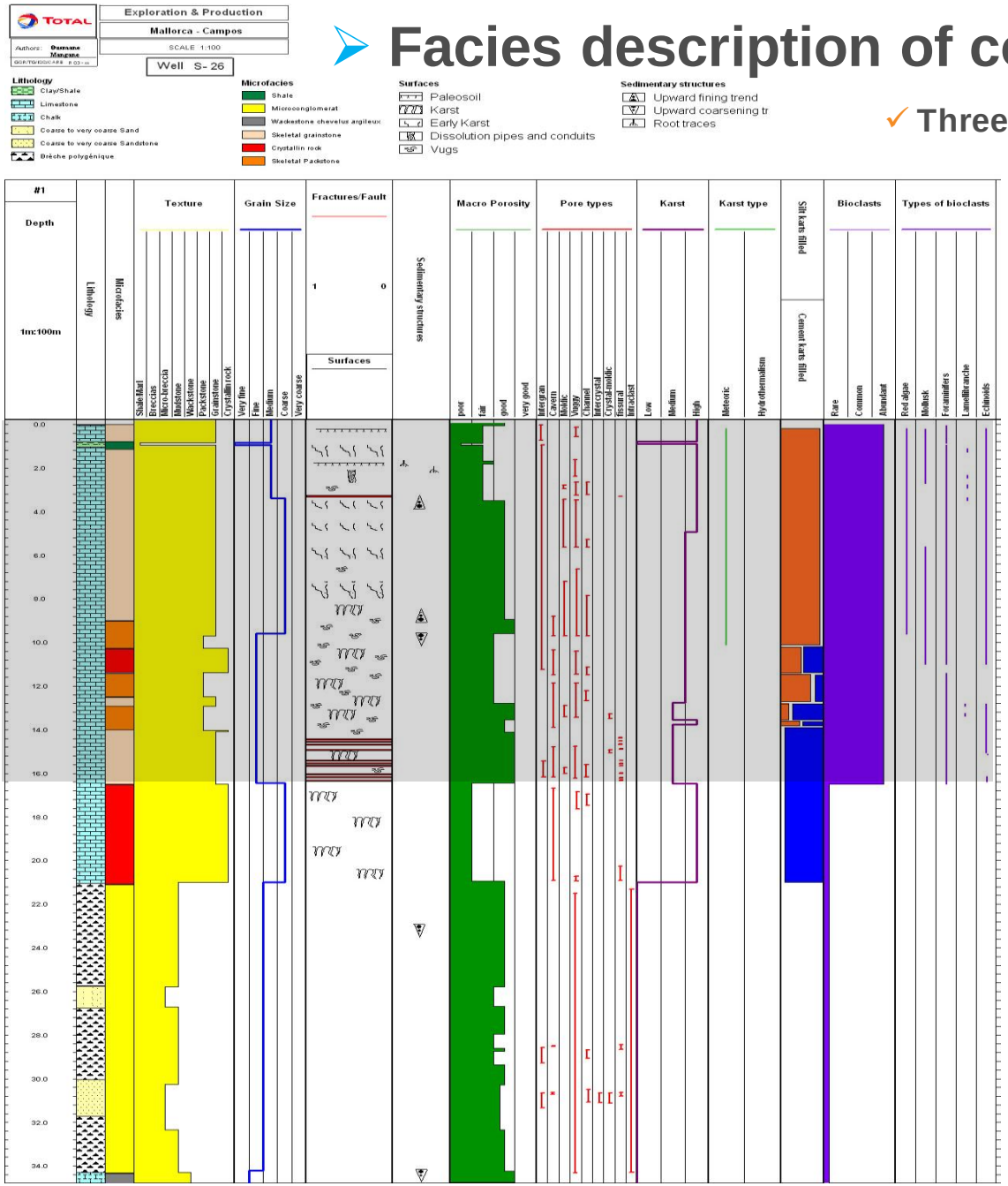
Borehole data: Gr, Ph, C…

Cores are 38 meters in length



TOTAL

# Facies description of core: Case of Well S26




✓ **Three lithofacies units are distinguished:**

**Unit1: Skeletal Packstone/Graisntone**

**Rich in foraminifers**

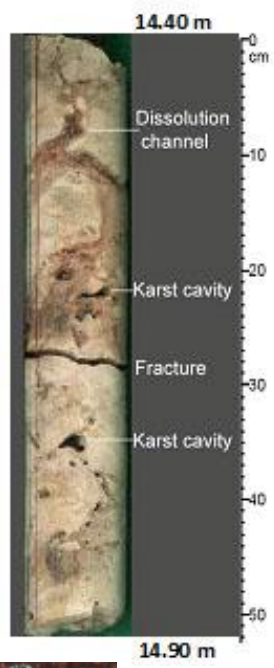
**Karstified**

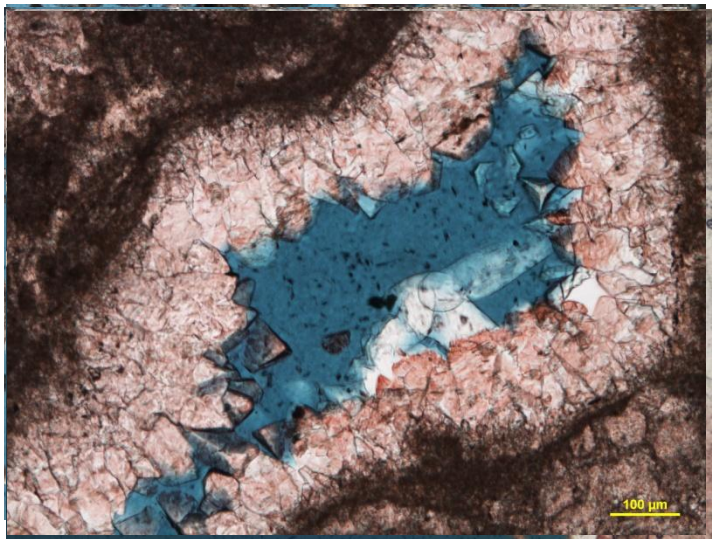
**And**

**Fractured**

# ✓ Unit/ 0.00 to 16.50 m



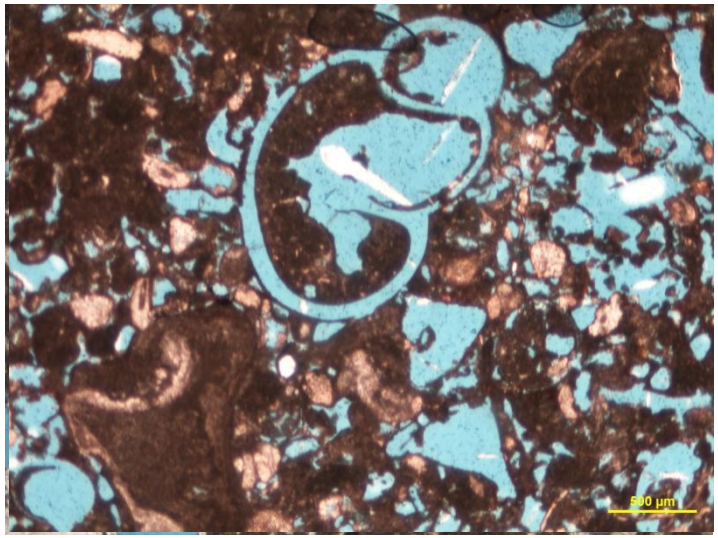



- **Grainstone** rich in foram

Bivalves are common

Porosity: Intergranular, Moldic, vugs

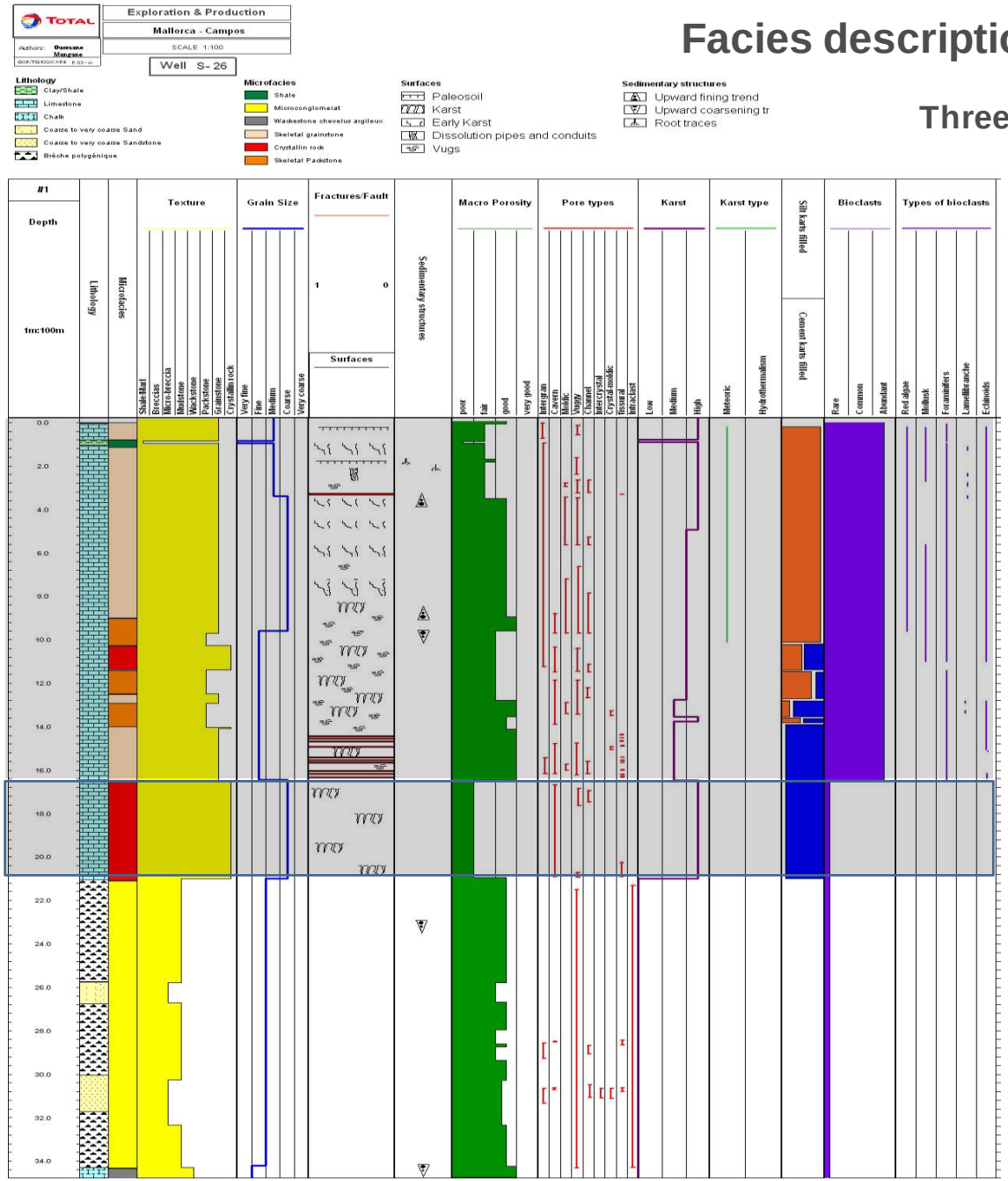



- **Packstone** rich in bivalves

Predominant porosity: Leached porosity

Due to karst action

# Facies description of core: Case of Well S26




## Three lithofacies units are distinguished:

**Unit1: Skeletal Packstone/Graisntone**

**Rich in foraminifers**

**Karstified**

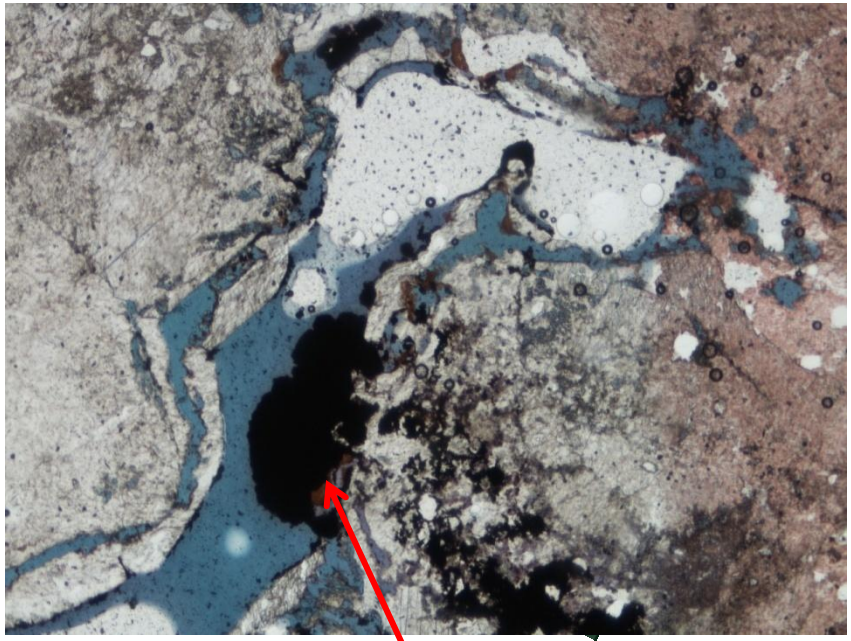
**And**

**Fractured**

**Unit2: Crystalline rock**

**Deformated**

# ✓ Unit2: 16.5 to 21 meters

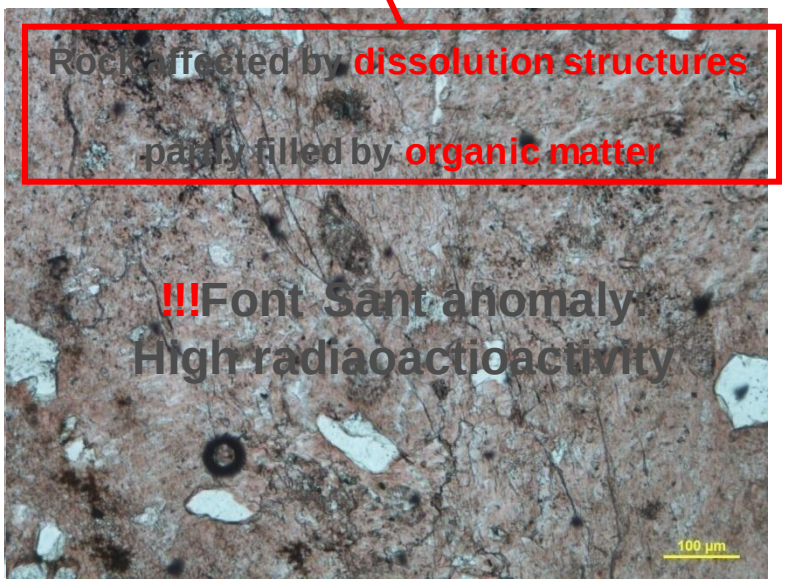


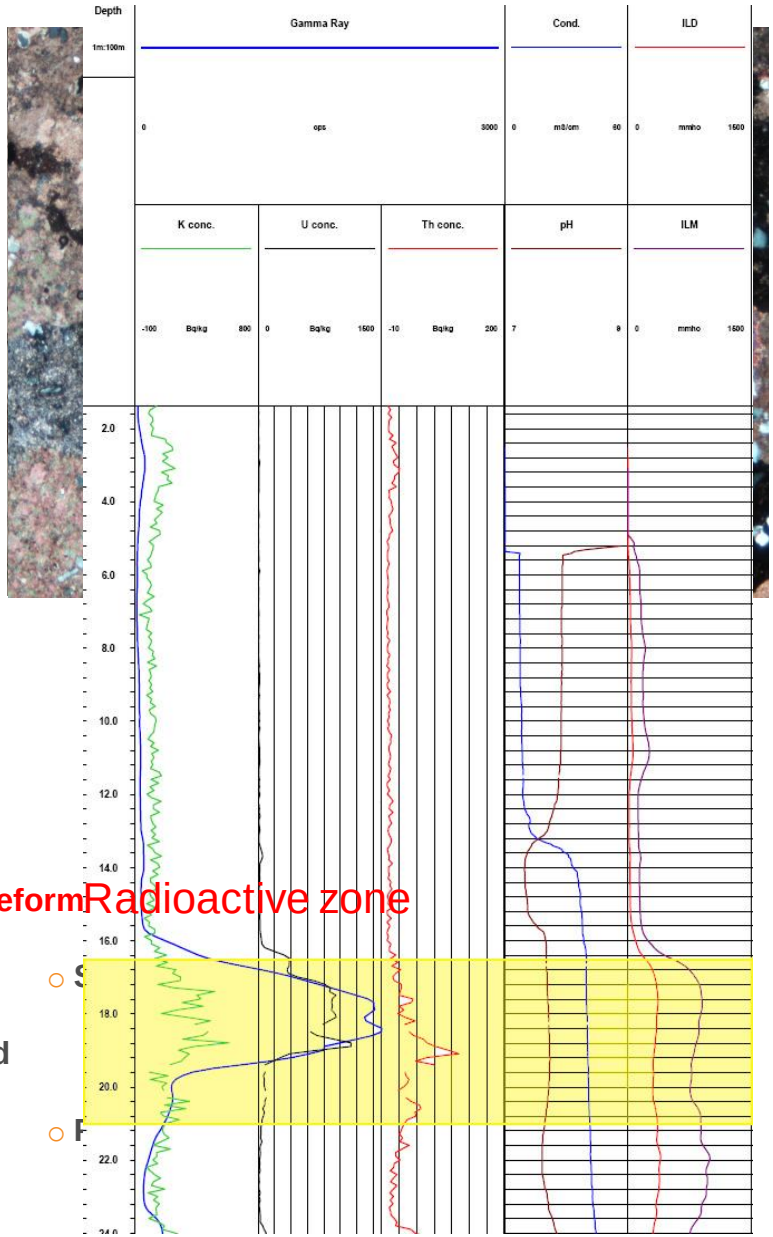
Rock affected by **dissolution structures**

partly filled by **organic matter**

**!!!Font Sant anomaly**

**High radiaoactioactivity**



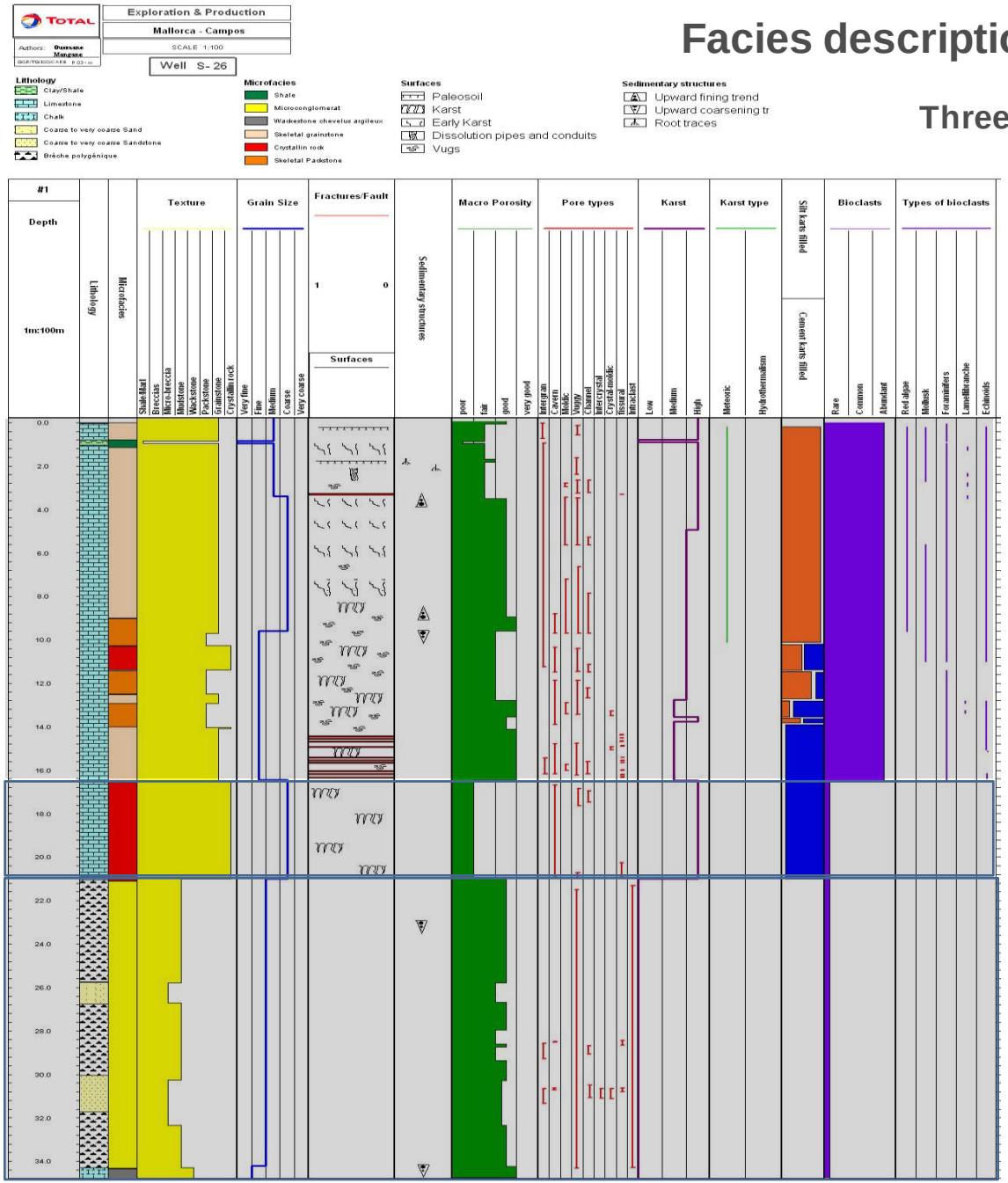




- **Deform**

Radioactive zone

And

# Facies description of core: Case of Well S26




## Three lithofacies units are distinguished:

**Unit1: Skeletal Packstone/Graisntone**

**Rich in foraminifers**

**Karstified**

**And**

**Fractured**

**Unit2: Crystalline rock**

**Deformated**

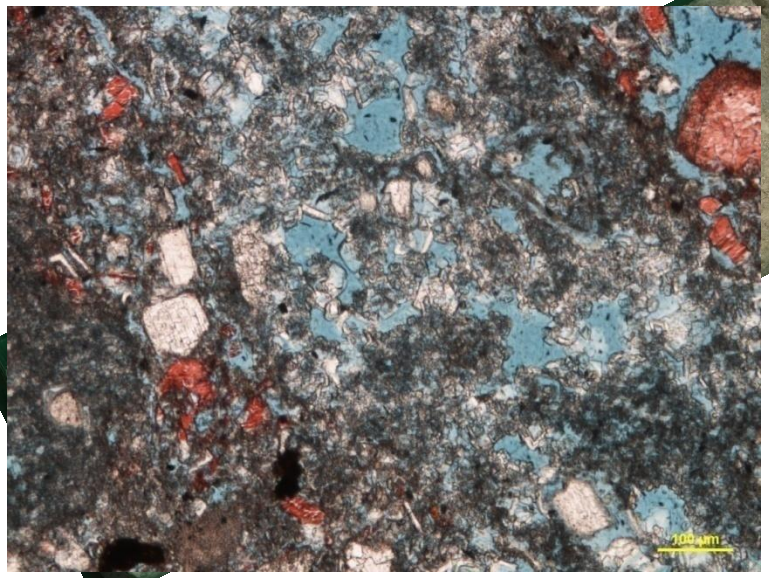
**Unit3:**

**Polygenic breccias**

**13.30 meters thick**

# ✓ Unit3: 21 to 34.30 mete

- Dolomitized layers on breccias



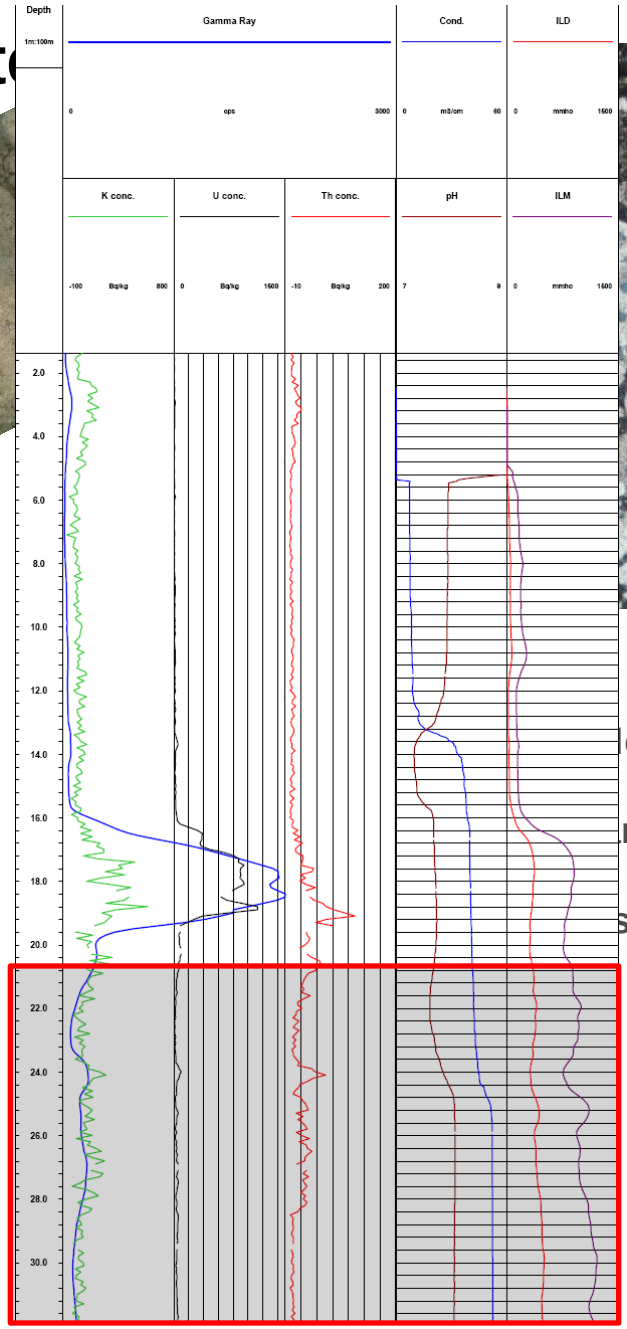
Dolomitized layers:

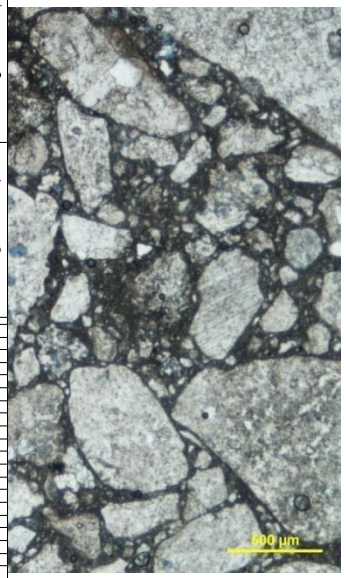
**Type of dolomitization**

Porosity is **good**: Intracrystal + intercrystalline

- Note: Calcite stained in red / Dolomite unstained
- Note the clear rims and cloudy core of dolomite crystals
- Note the **polymodal variability** of the dolomite crystal size

**Replacement dolomitization**




composed of

e and

rtz

st and leached porosity

**Origin of dolomitization**

Note the High conductivity in this zone (Saline water)

Marine-Meteoric Mixing zone



TOTAL

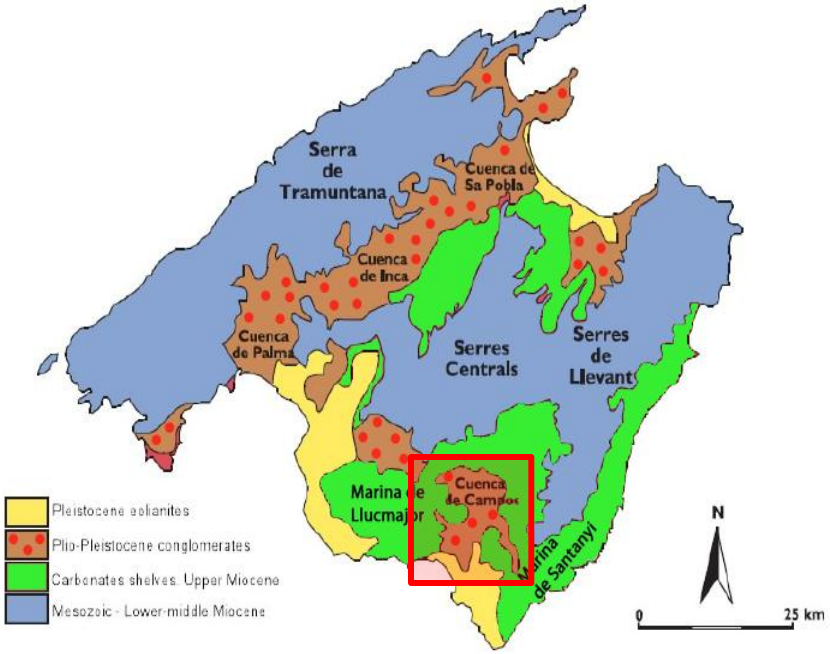
# ✓Origin of Unit 1 and Unit2

**The vertical sequence of lithofacies established is:**

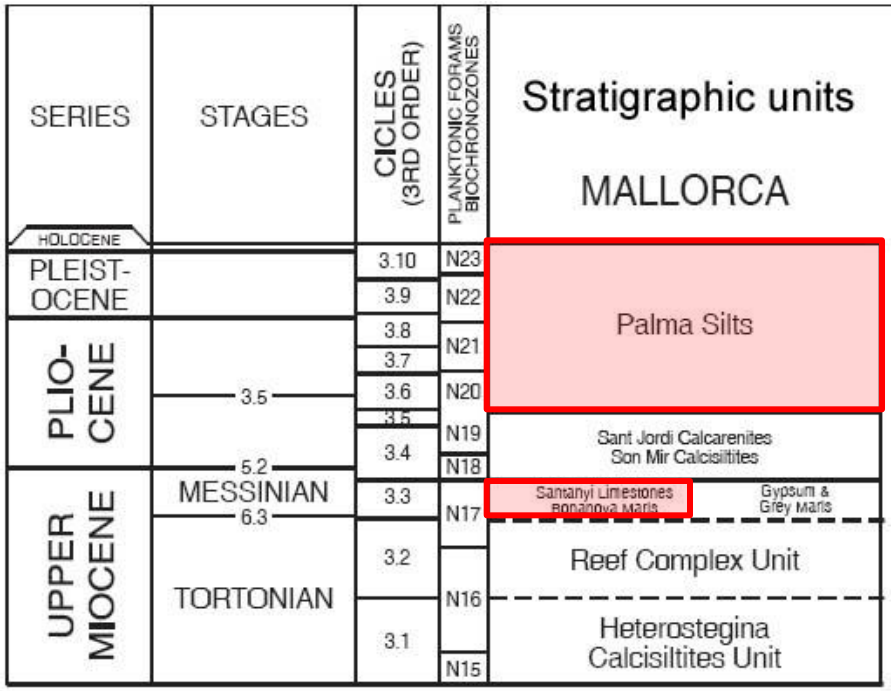
**Regional ?**

**Or**

**Local ?**




Geological map




- **Unit 1**: Bioclastic limestone = **Messinian** Santayi Limestone
- **Unit3**: Polygenic breccias = Pleistocene **alluvial fan deposits**

  = Palma silstone which **overlay** Santayi limestone
- **Unit2**: **No deposits** in Mallorca **can be assimilated** to

  the coarse crystal of calcite of Unit2

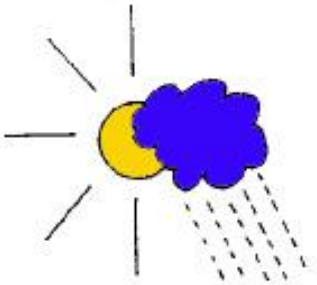


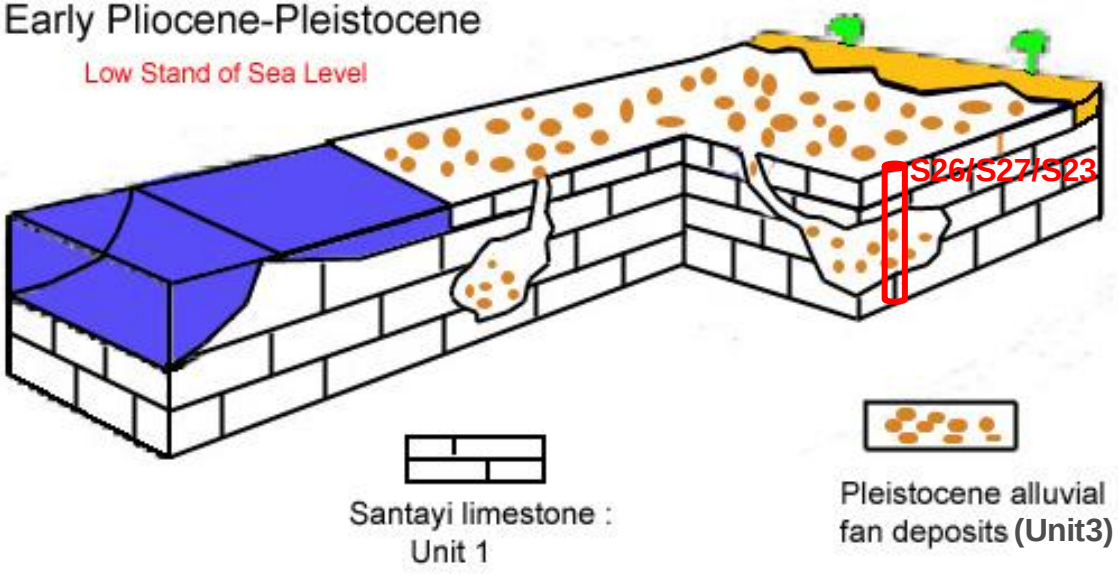
TOTAL

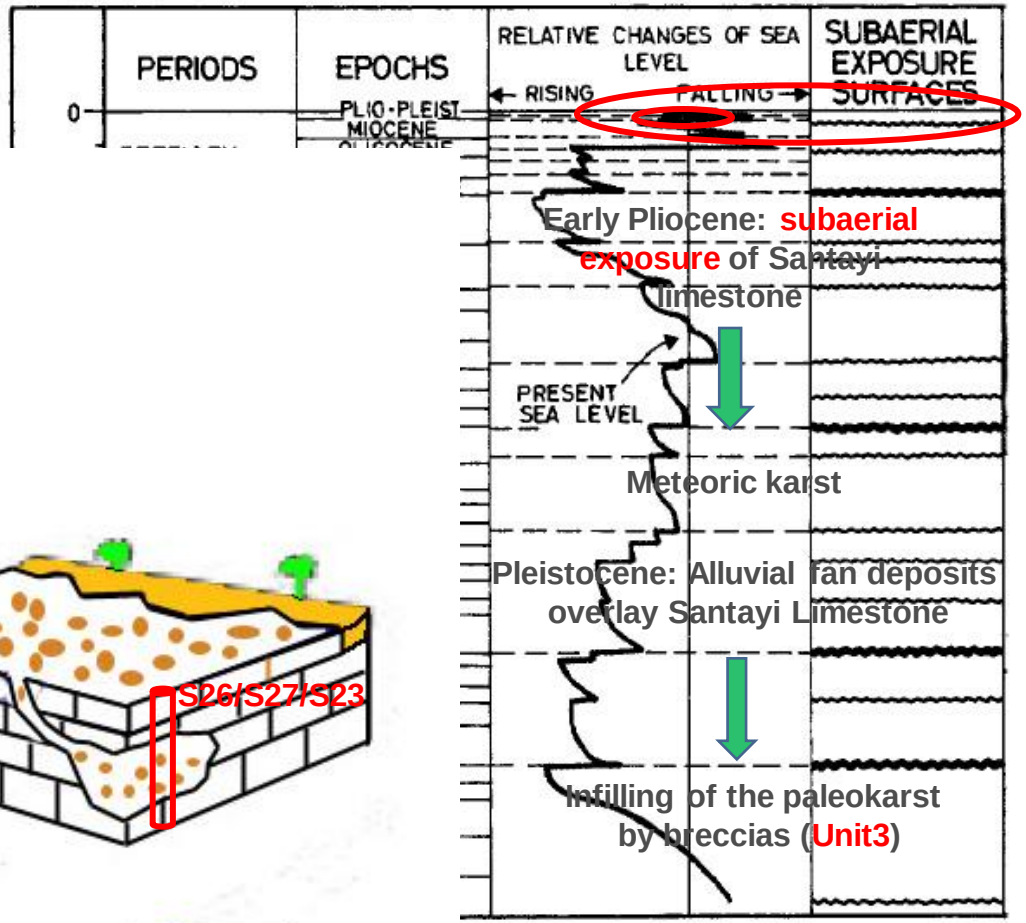
# Origin of Unit 1 and Unit2

## Hypothesis 1: Meteoric filled-paleokarst

**To resume:**





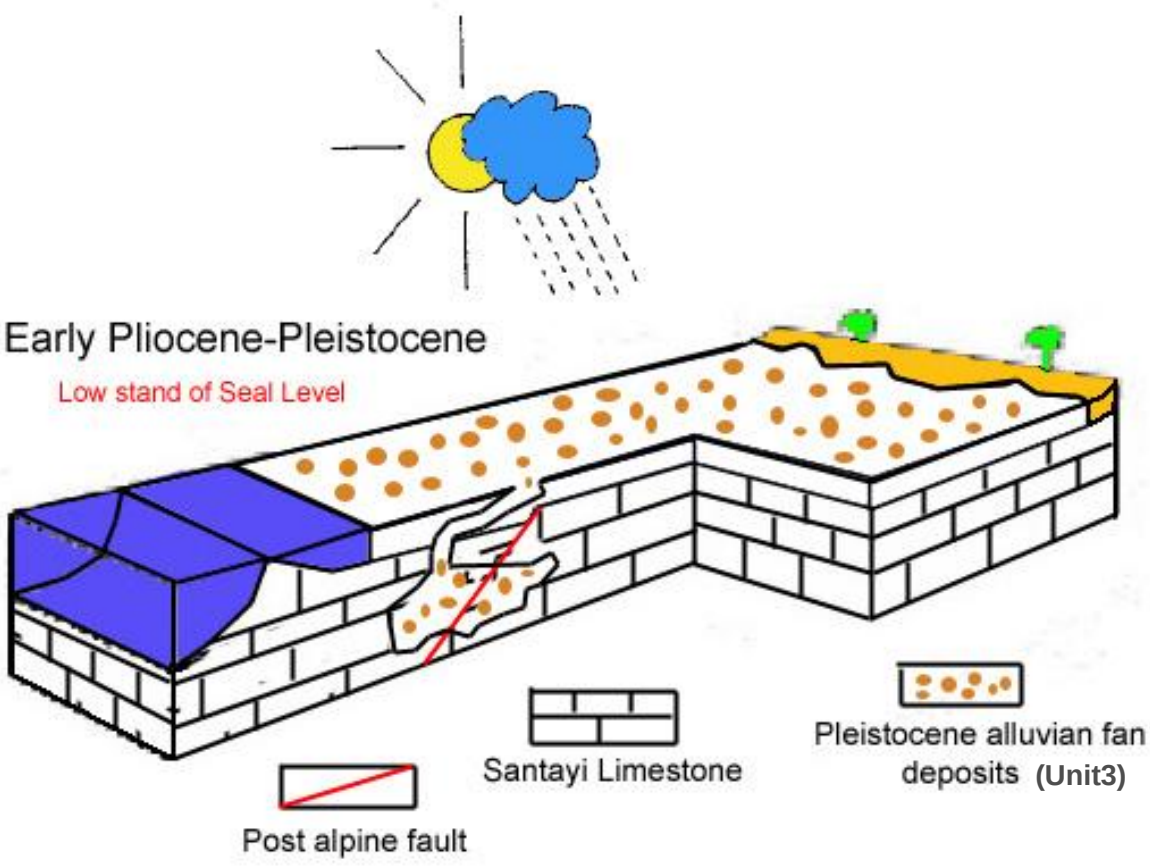




Deposit of transgressive unit: Santayi Limestone – Unit 1



TOTAL

# Hypothesis 2: Hydrothermal karst

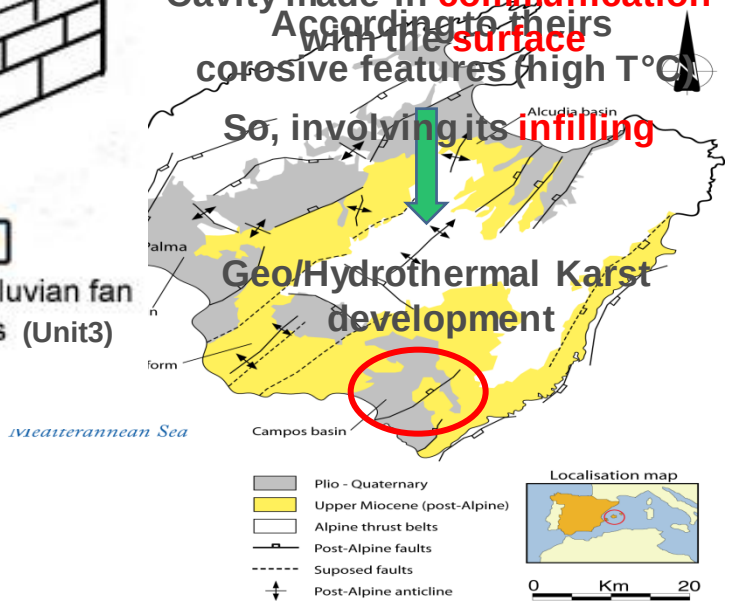



Sanatyi limestone
Miocene: subaerial exposure episode
**Consider that** Fault reaches the Font ant source affected by **Fault**:

Post-Alpine fault created
Hydrothermal karst resumed during the **Meteoric** karstification
Geo/hydrothermal fluid flow through the fault:
of the Island

Cavity made in **communication** with the **surface**
According to theirs corosive features (high T°C)
So, involving its **infilling**

**Geo/Hydrothermal Karst development**



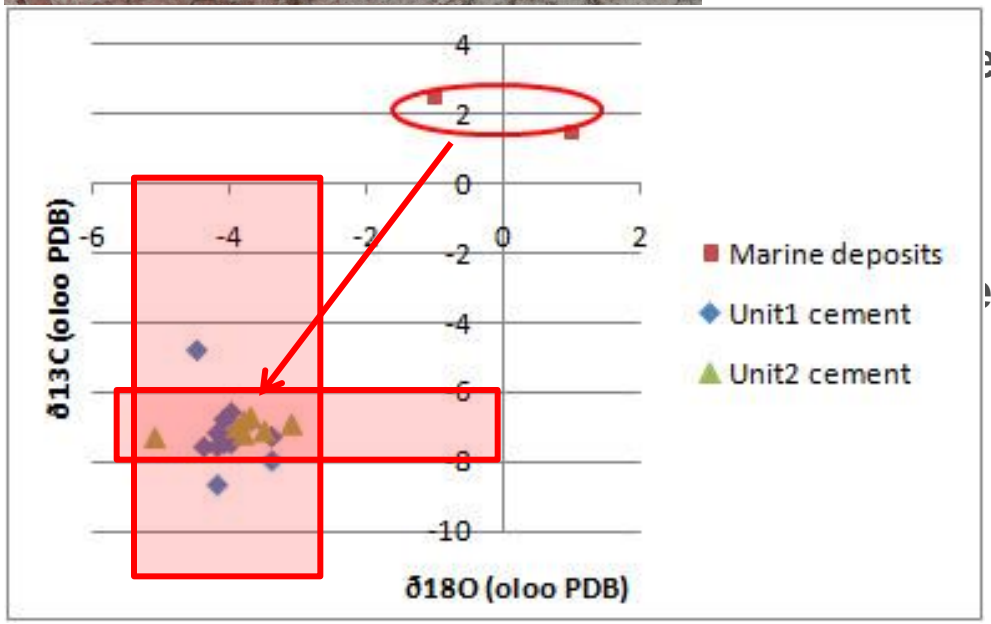

Geological and structural map



TOTAL

# Residual void filled by coarse crystal of calcite

Stable Ox and Carb isotopic analyses




Note the transversal shifting of

eteoric ?

Miocene marine deposits

To slightly lighter $^{18}O/^{16}O$ (-3.1,-5.1)

ermal ?

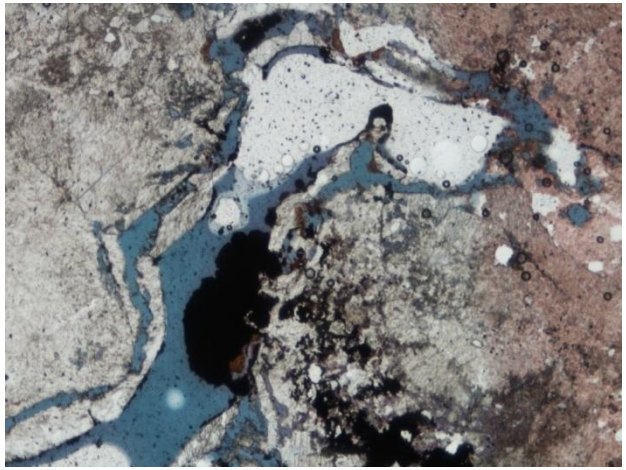
Meteoric diagenesis ?

To Substantially lighter $^{13}C/^{12}C$ (-6.7, -7.3)

Referring to AAPG Memo 77,

this type of shifting is typically an

effect of Meteoric alteration

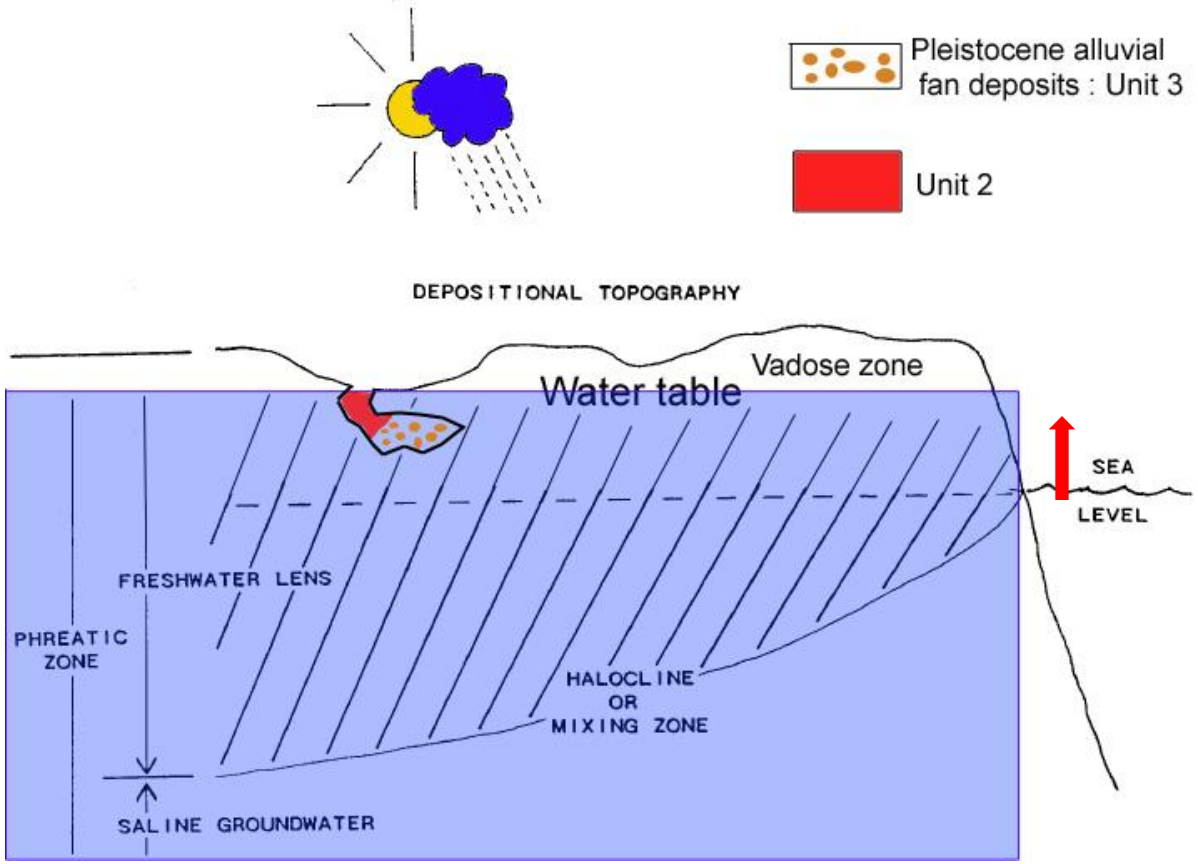


Organic matter



TOTAL

# Infilling process of the coarse crystal

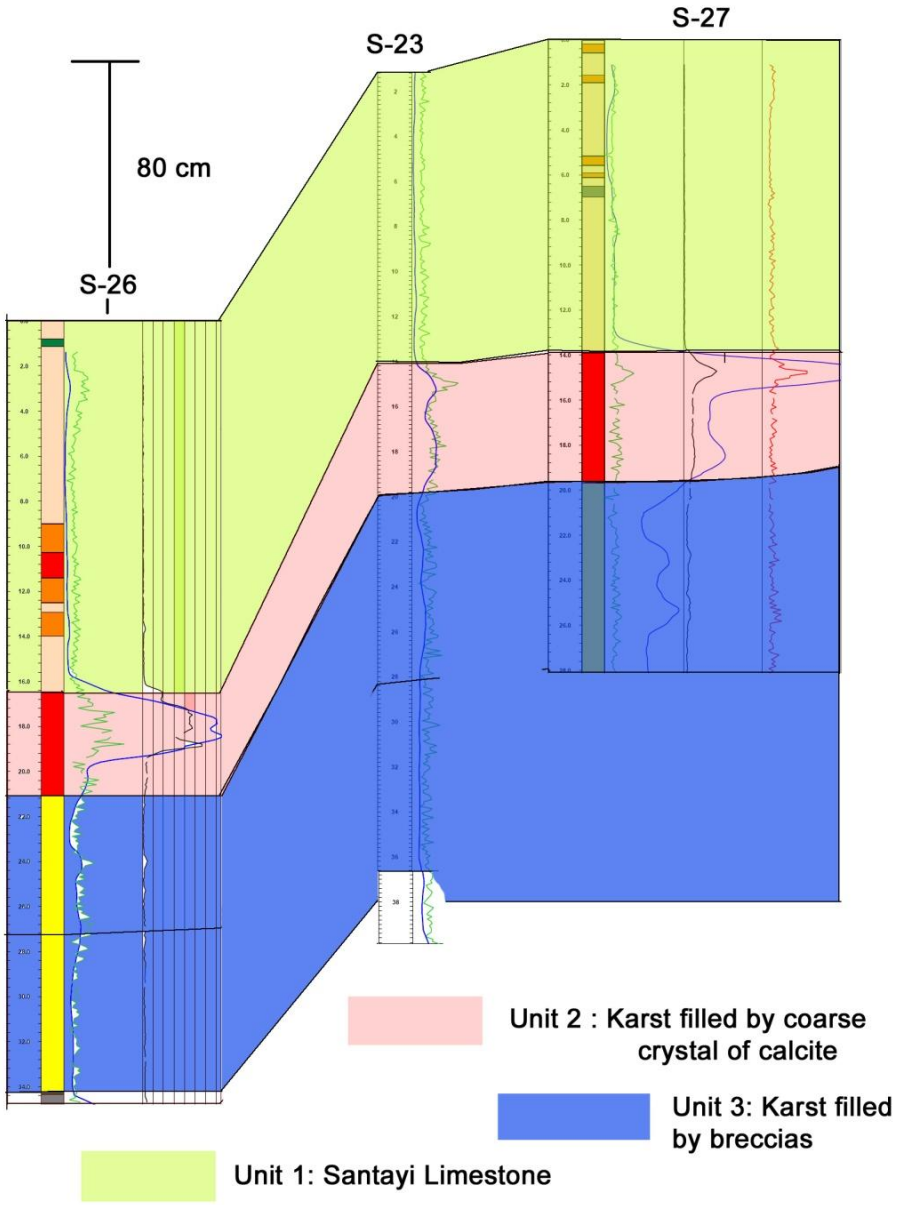



**Recharge of Font sant aquifer: Rise of the water table**

**Paleokarst submerged in Saturated zone**

**Reprecipitations of coarse crystal of calcite In large residual void**

# Font Sant filled-Paleokarst




**Santayi limestone (Unit1)**

**affected**

**by Paleokarst filled by**

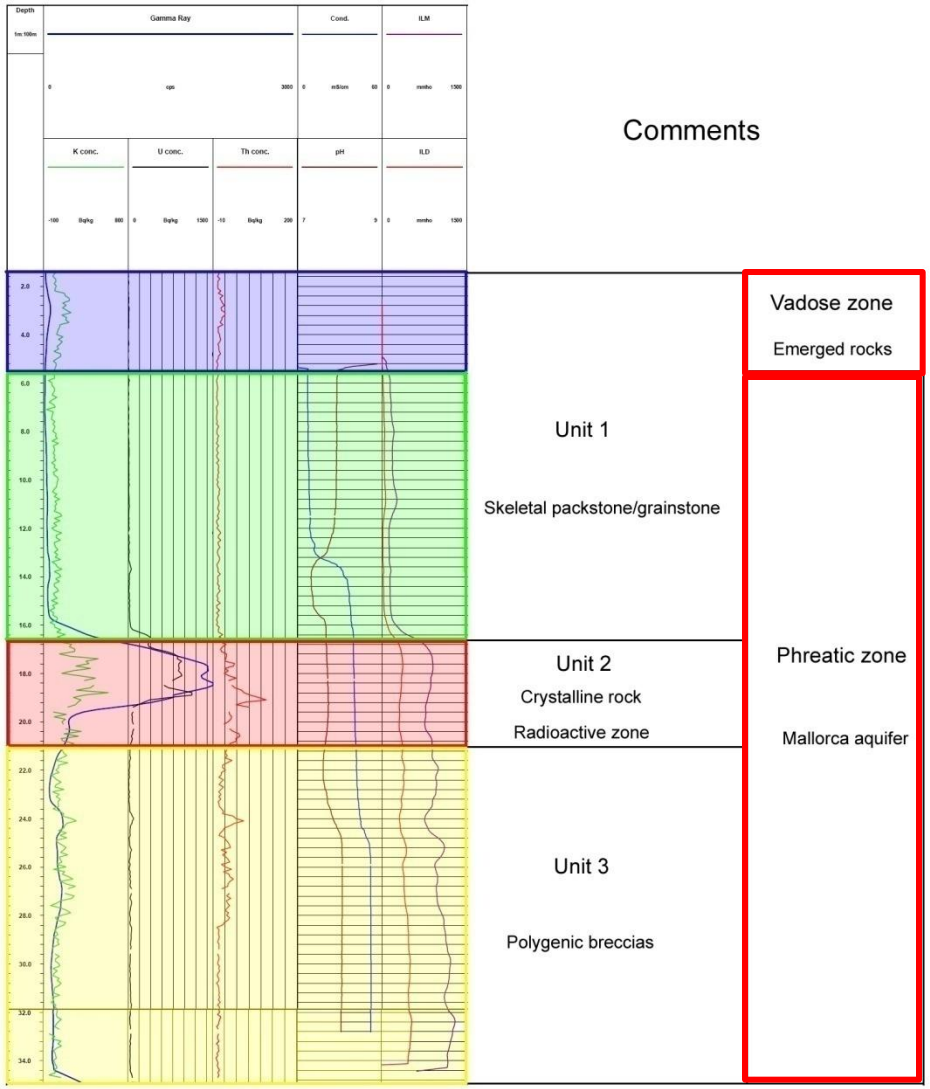
**Coarse crystal of calcite (Unit2)**

**And**

**Breccias (Unit3)**

# Karst-fractured reservoir: Santayi aquifer

## ✓ Configuration of the aquifer




**Ph and Conductivity are only evaluated in the aquifer**

**Zone where Ph and Cd are not available**

**=**

**Vadose zone**

**Water table at :**

**5.40 m (WellS26)**

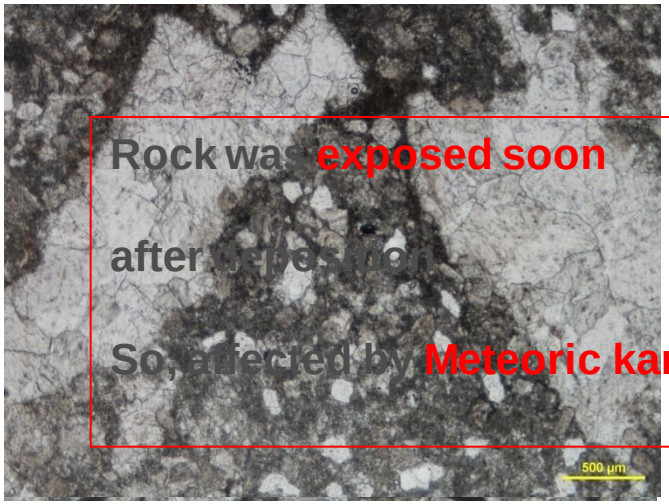
**6.10 m (Well S27)**

**Phreatic environment**

# ✓ Karst features

**Dissolution** structures

in Phreatic area




Rock was **exposed soon**

after deposition

So, affected by **Meteoric karst** action.

Predominant porosity due to

**Extensive cementation**

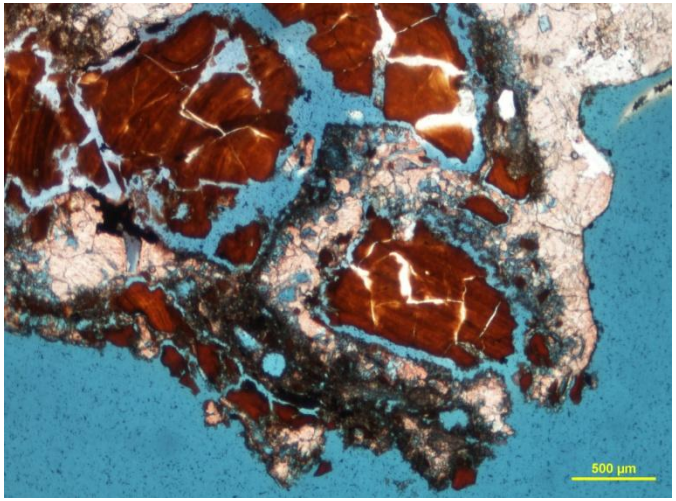
**Leached porosity**

Mixing of **chemically-distinct** water

Due to **Meteoric** karst action

Porosity is generally very **poor**

Fluctuation of the water table




**Reprecipitation** processes

Structure **reduced** by

late **growth of calcite**

From **surcharged** meteoric fluid

or by **red clay**

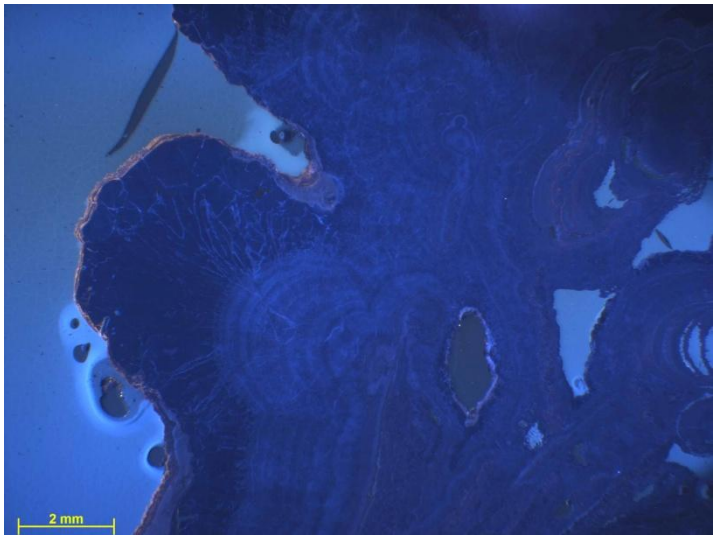
(Paleosoil materials)



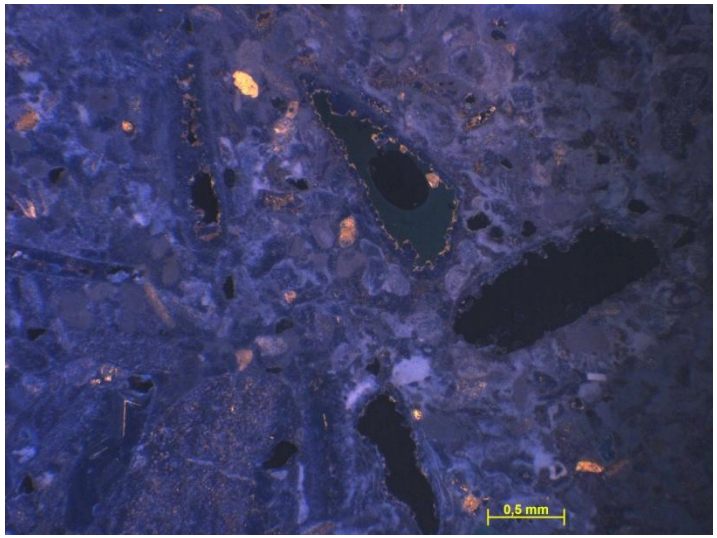
TOTAL

# ✓ Karst features

❖ Meteoric Diagenesis




Karst cavity partly occluded by gravitational cement




Extensive cementation in phreatic zone

Note the **nonluminescence** of cement

That response is typically assigned to

**oxidizing** environment,

as **meteoric** environment

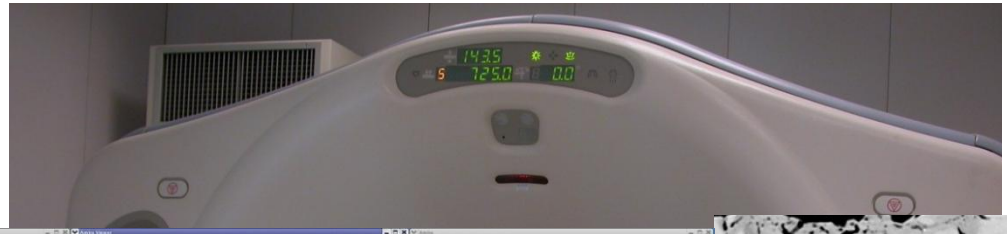
In which reduced forms of both

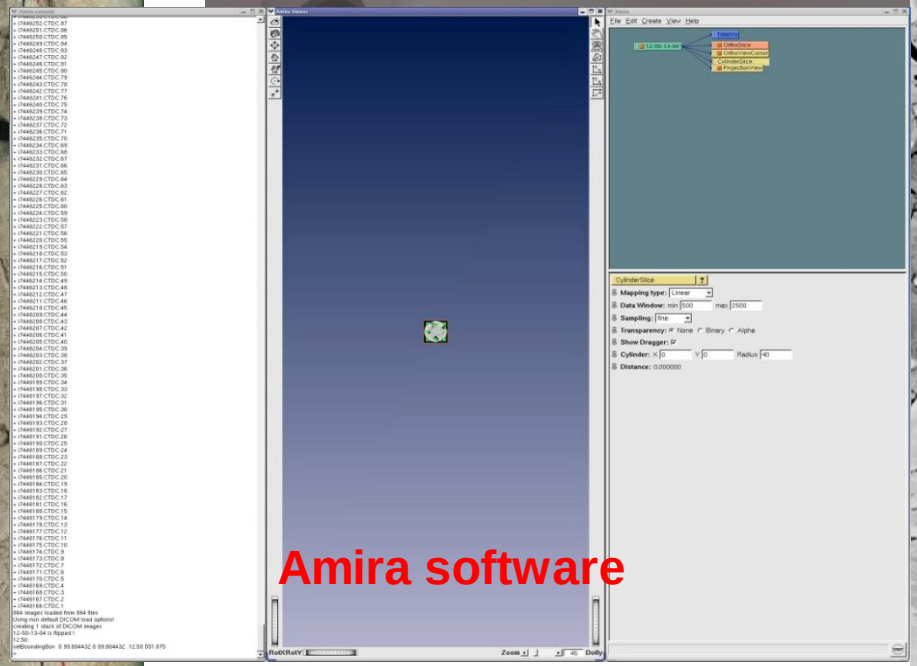
**Mn and Fe** are unavailable



TOTAL

# Virtual petrophysical analysis






3D X-Ray Tomography Image

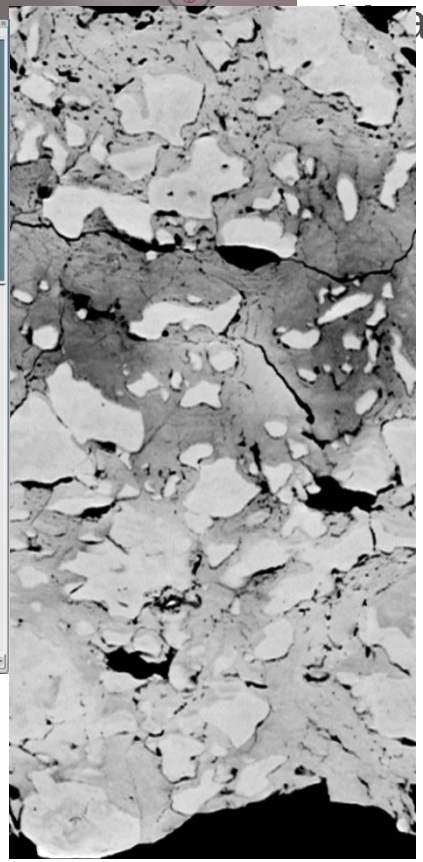
**Petrophysical** treatment

## Methodology

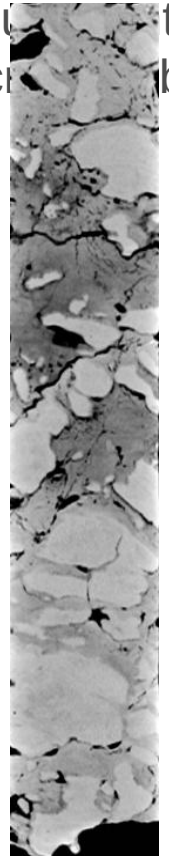
X-ray Density

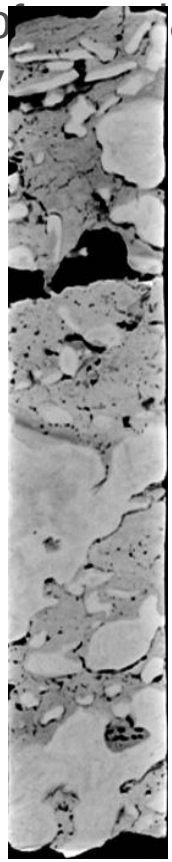
as t o als

cr by



Raw

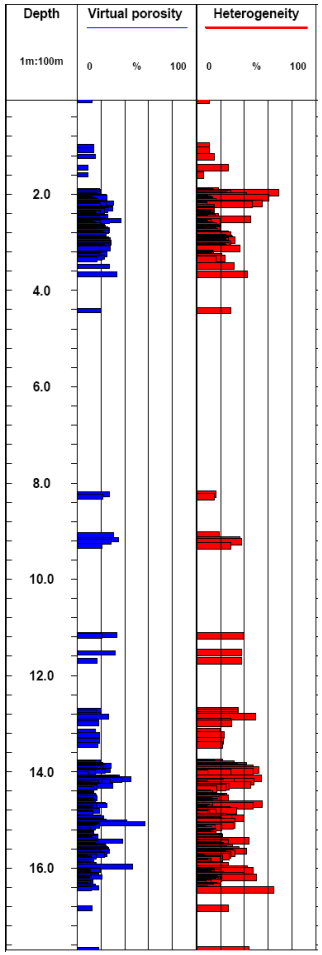


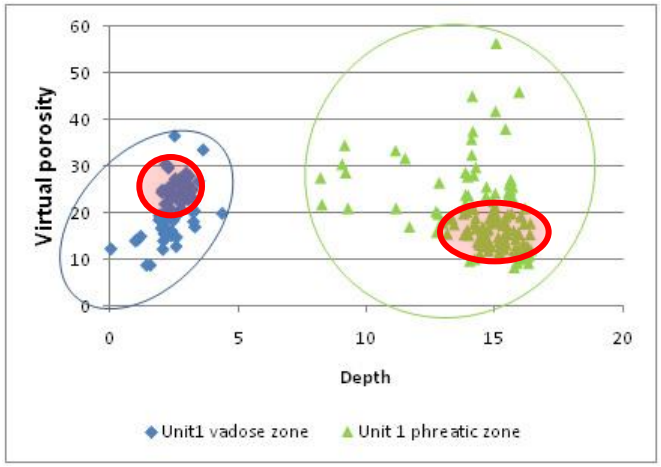


Strikes

TOTAL

# ✓ Results




- Porosity in Phreatic environment
  - Values range of porosity
  - is ten percent lower than
  - the porosity in vadose zone
- In vadose zone: 8.8% to 36.5%
- In phreatic zone: 9.9% to 30.5%

This low in porosity reflects

the extensive cementation

In both environment, porosity in that environment is very variable

Dissolution structure are reduced by gravitational cement (dog tooth, stalactite)

Or paleosoil materials.

- Although some peaks of porosity are regular
- Its porosity is fair to mean ??
- Primary porosity commonly modified during meteoric diagenesis (Reprecipitation of stable carbonate)

Karst reservoir as

Existence of dissolution structure

heterogeneous reservoir

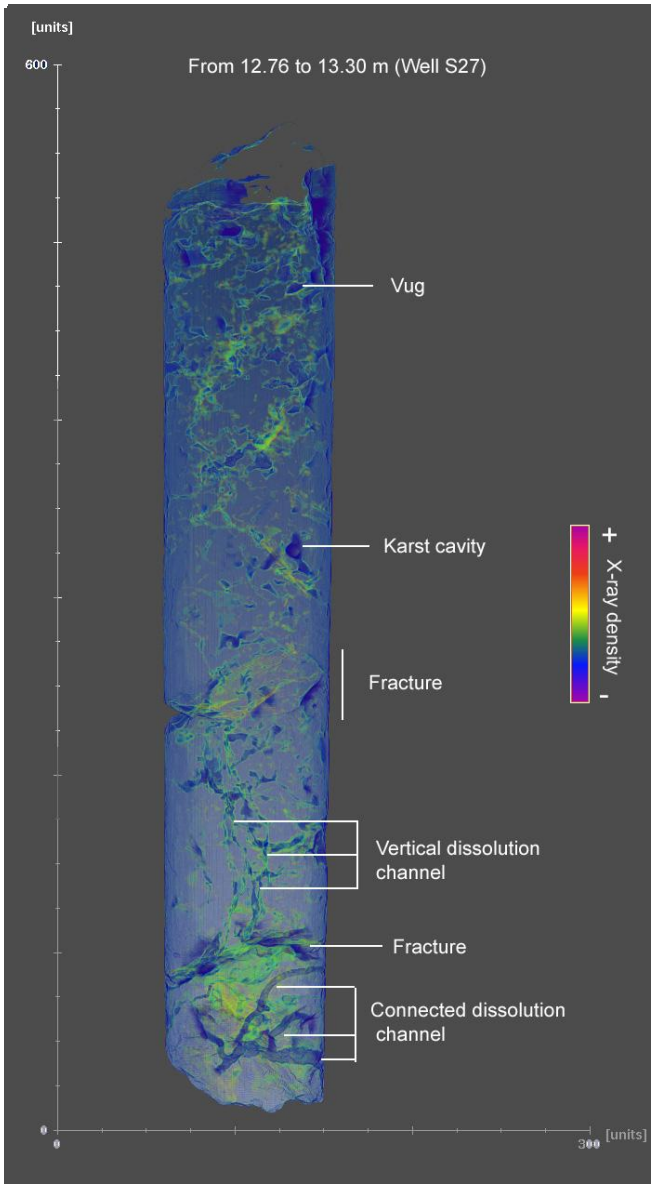
In that environment,

So it is soon subaerial exposed



TOTAL

# Visualisation of the Porous network




Dissolution structures can sometimes show a good connectivity

Moldic and vuggy pores have a strong effect on permeability

Permeability reductions through cementation of interconnected primary pores structures depends on

Potential of connectivity of these pores through solution enlargement of fractures

Degree of alteration increases

And on

In addition note the control of karst development by fracture types of dissolution pores



TOTAL

# Conclusion

Anomaly in Font Sant corresponds

to a Filled Paleokarst (Unit 2 and 3), Early Pliocene in age

Origin of this paleokarst is Meteoric

Infilling is Pleistocene in age

Karst-fractured reservoir as

heterogeneous reservoir

In term of

Porosity and Permeability

Heterogeneity mainly controlled by

diagenesis process

related to karst action

Predominant porosity in karst reservoir is

Dissolution porosity
(Moldic, Channel, vugs, caverns)

Fractures can highly ameliorate

the quality of karst reservoirs

Increase of permeability

And Porosity
(karst development from fractures)



TOTAL

# Perspectives

Evidently, This investigation is realized on

the superficial part of karst reservoir (First thirteen meters)

The nature of Font Sant anomaly

(coarse crystal of calcite) is Meteoric

✓ It is now interesting to drill more in depth

✓ But origin of paleokarst can be meteoric

or hydrothermal resumed by meteoric

✓ So, it will be interesting, in Font Sant aquifer, to analyze and characterizing

the nature of karst development (hydrothermal, salt water)

✓ To realize a detailed structural map

Realized measures of temperature And

chemic analyses their impact on quality of the reservoir

To confirm or invalidate the hydrothermal hypothesis

Thank you for your attention