Porosity Characterization of the Cretaceous Eagle Ford Formation*

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Abstract

Quantifying the pore systems of fine-grained reservoirs is hugely challenging due not only to their extensive textural and mineralogical heterogeneity but also the sub-nanometer to micrometer size of pores. Definition of the reservoir storage and flow system, which underpins effective production, thus requires a very detailed, quantitative understanding of the porosity system and its relationship with rock texture. This work focuses on the Cretaceous Eagle Ford Formation, an organic-rich marl that trends across Texas and which produces around 1 million barrels of oil and 4 bcf of gas per day. In order to understand the nature and evolution of the pore system, we have analysed a set of 46 samples from outcrops and six different wells with maturities of 0.4%, 0.8% and 1.2% Ro. XRD, transmitted and reflected light optical microscopy, EDX and SEM techniques have been used to reconstruct the mineralogical and textural framework in which the porosities occur. Carbonate contents range from 37 to 84% and TOC values from 0.5 to 7.9%.

Petrographic studies show that the organic matter is mainly marine type II and that microfacies vary from finely laminated marls to fossiliferous limestones. The paragenesis of the samples, in particular the diagenesis of carbonate and the generation and micromigration of organic phases, has been determined with BSEM and SEM-EDX. MicroCT of mm-size cores, calibrated with high resolution FIB-SEM, has identified the occurrence and connectivity of the main textural domains (organic matter and porosity, microfossiliferous material, fine-grained argillaceous/carbonate matrix and pyrite), and the nature of the pore system in each domain. In the low maturity samples, the main porosity types are interparticle, enclosed within the argillaceous and coccolithic matrix, whereas in most of the mature samples the pores present a more spherical shape, suggesting that they are mainly situated within the migrated and in-situ OM. Pore systems have been characterised using a combination of high resolution SEM, mercury injection porosimetry and N_2 and CO_2 sorption. Pore sizes, calculated by analysing and combining data between SEM images and gas adsorption, appear to have a bimodal distribution with modes around 10-20 nm and 50-200 nm. Current work, using ESEM, AFM and nano-IR, is focused on understanding the chemical interaction between the fluids and pore surfaces. Calcite crystals simulating the Eagle Ford surfaces were aged in different oils and analysed with the AFM using functionalised tips. The

resulting adhesion maps were then converted in wettability patterns, that change with respect to the different oil molecules on the surfaces, as testified by means of nano-IR analyses.

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Pore system characterization in the Cretaceous Eagle Ford Formation

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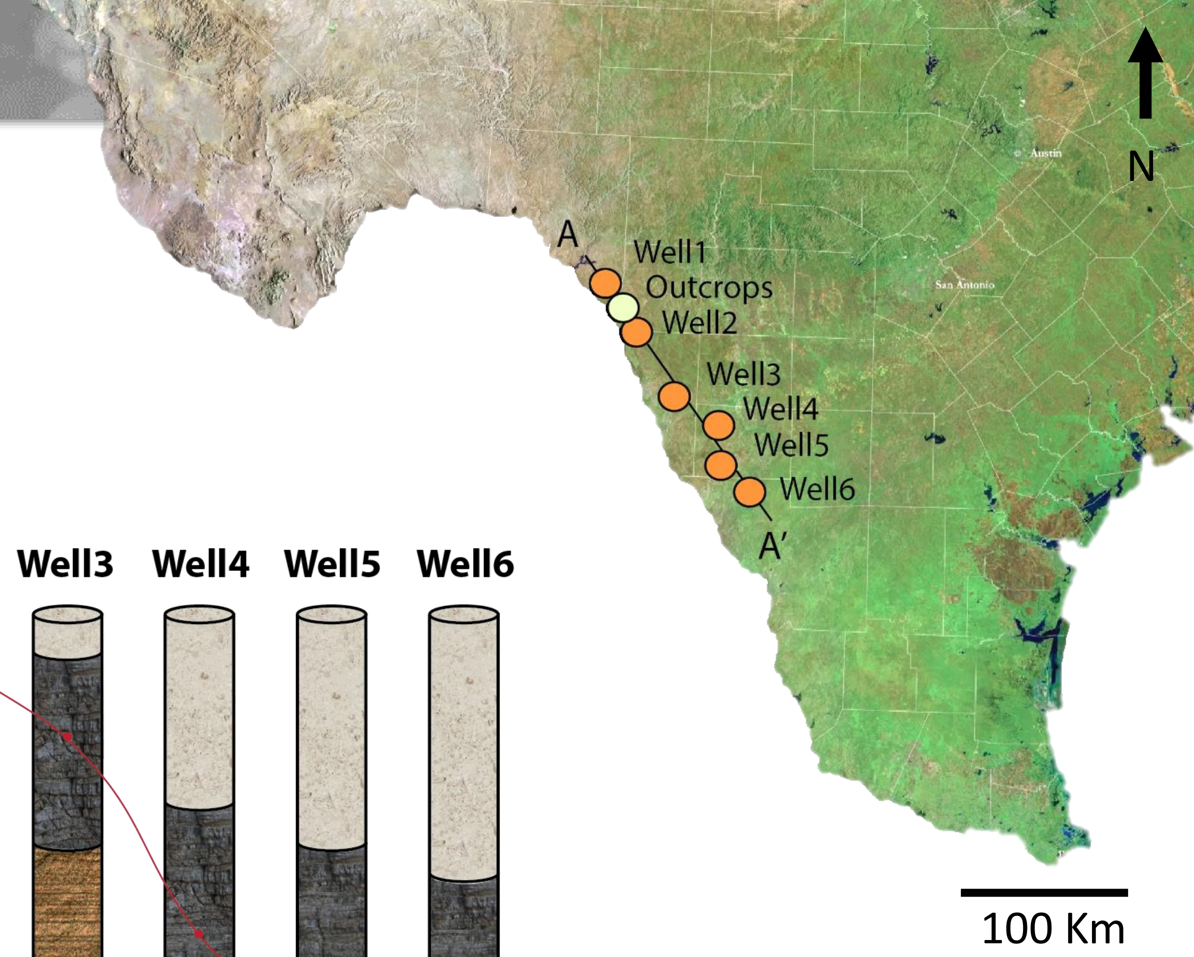
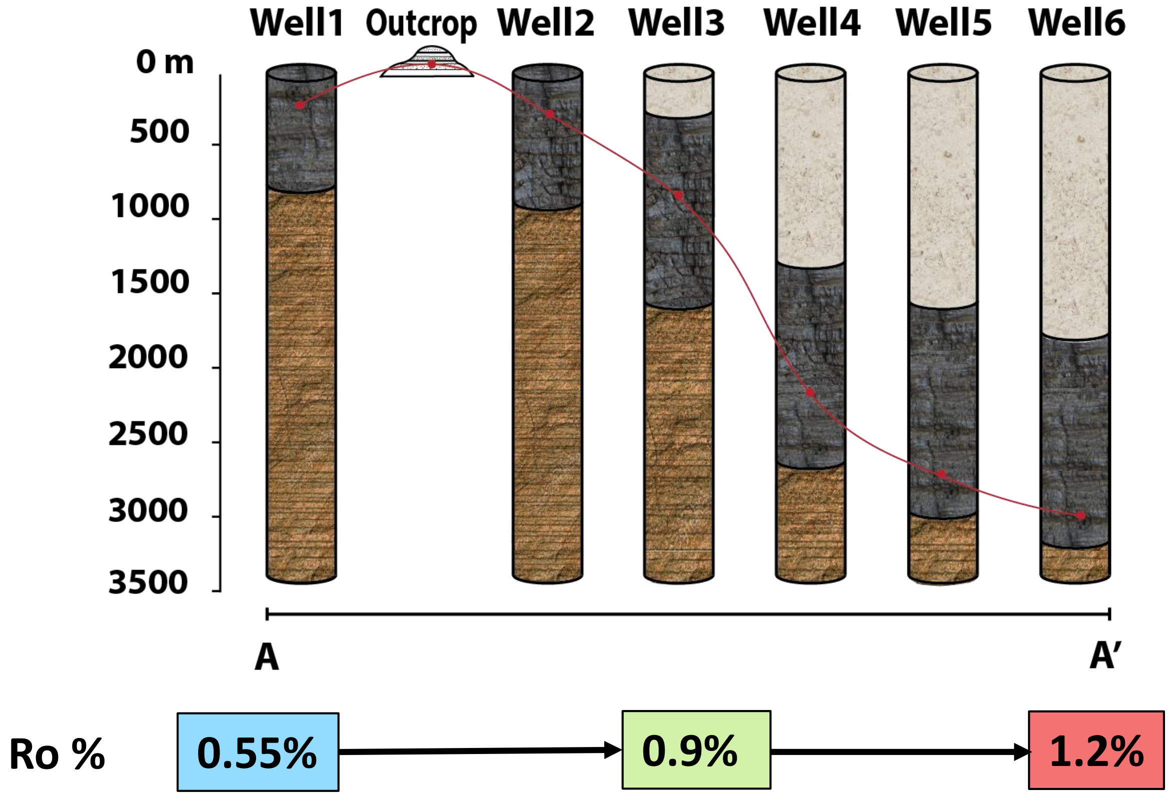
The Eagle Ford Formation

- Carbonate and OM-rich. Deposited in the Gulf of Mexico (Texas) during OAE2.
- SE dip (3 maturity windows).
- Unconventional Play.





Why unconventionals and...why pores?

- Studying pores to understand → Reservoir storage capacity / Fluids behaviour] Enhance the oil and gas recovery

- Heterogeneous, nm to µm pore sizes. → ***Multi-technique characterization***

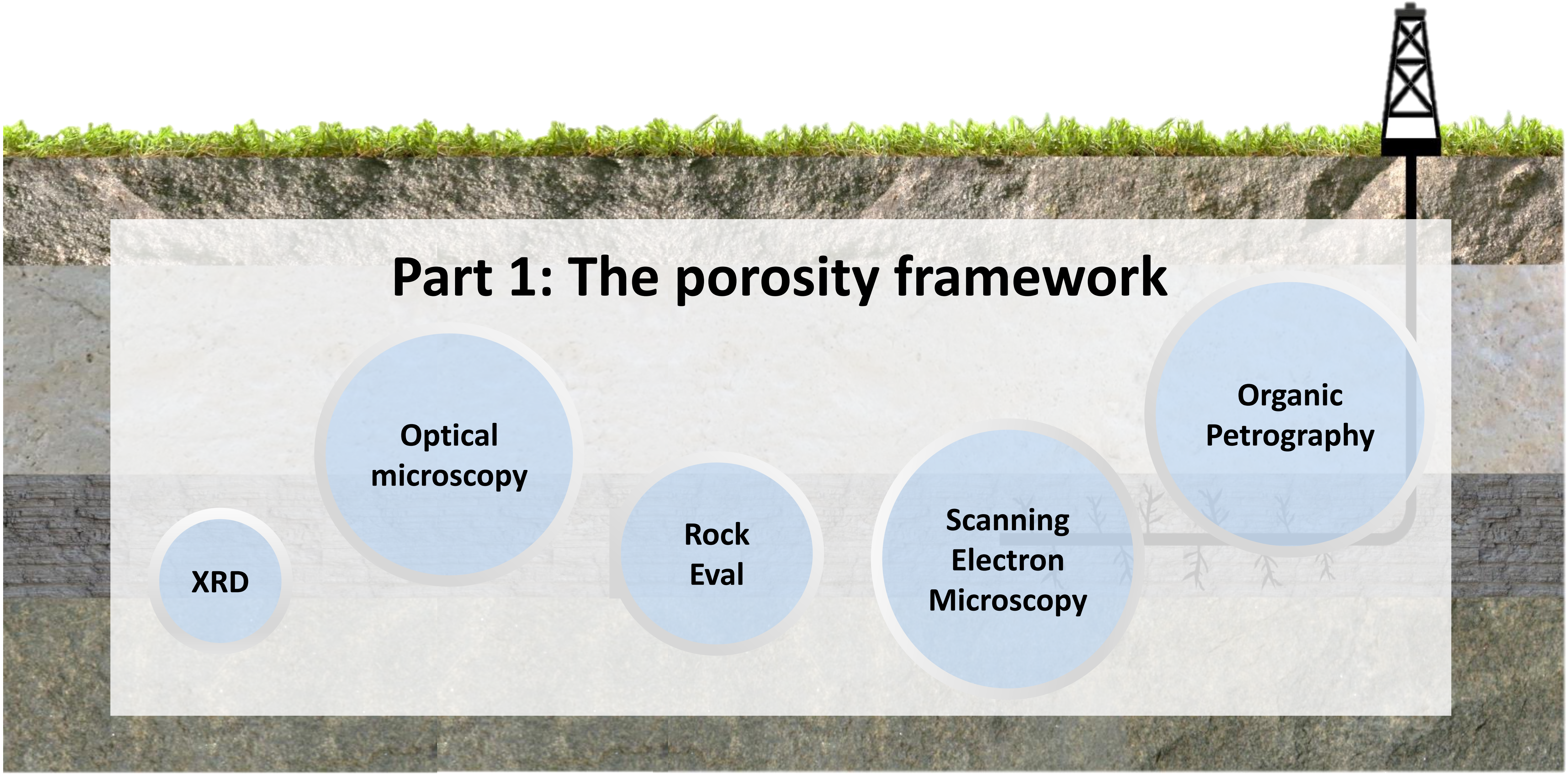
The multi-technique approach

1. Framework in which the porosities were formed: ***mineralogy***
2. Quantitative analysis: ***pore sizes*** and ***connectivity***
3. Chemical analysis*:* ***surface wettability***

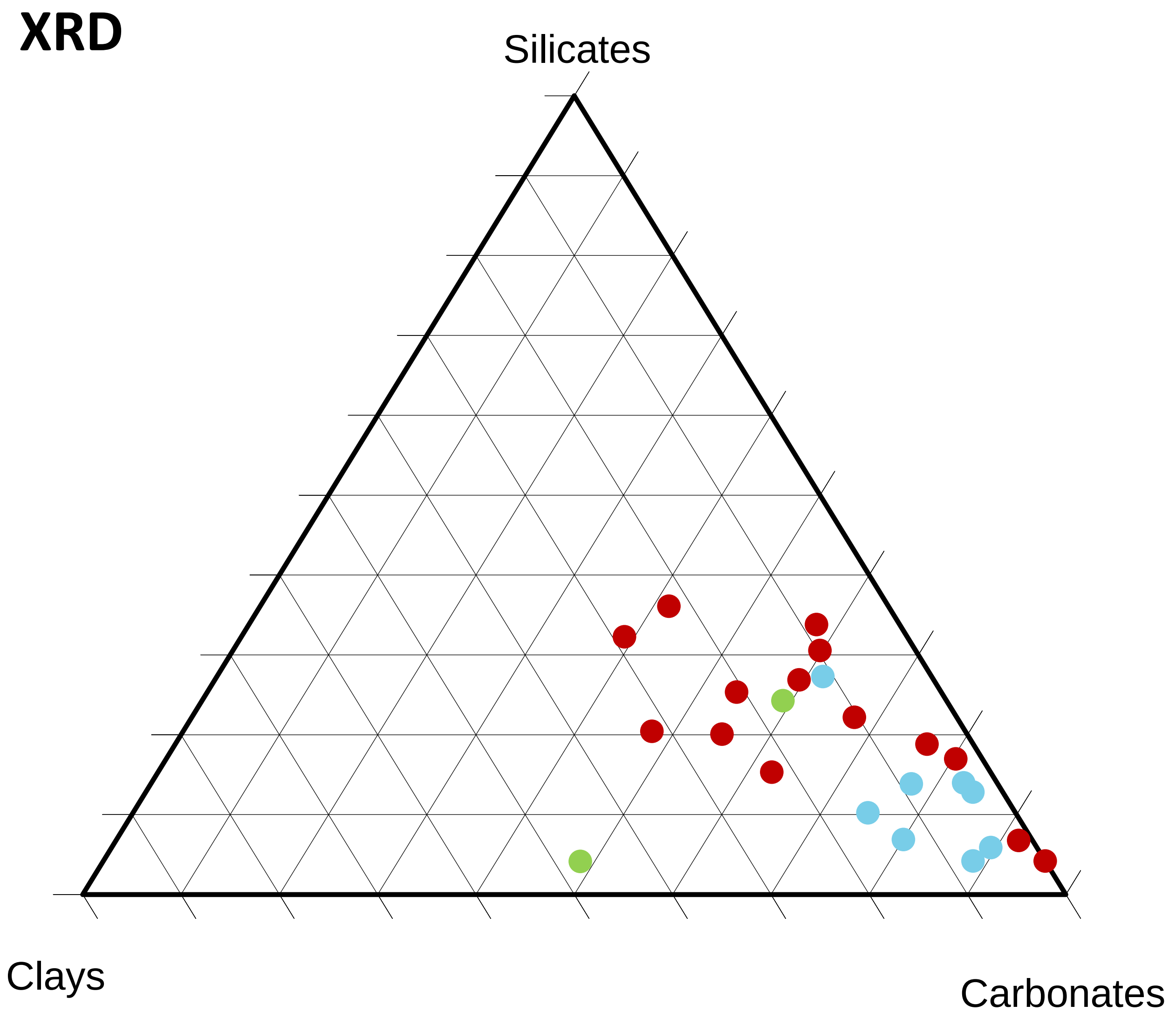
- Where are the hydrocarbons stored?
- Is there a hydrocarbon pathway?

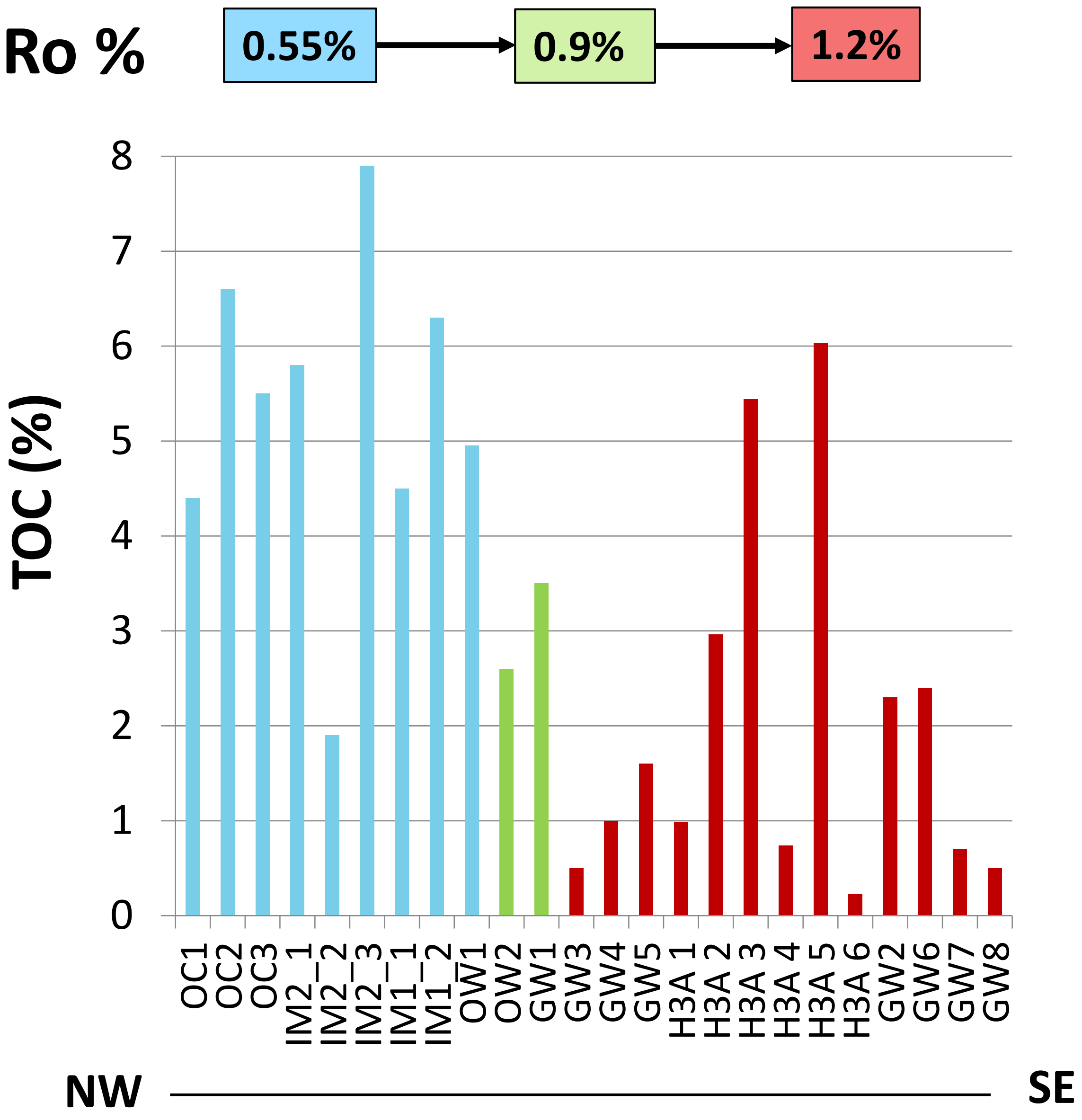
The multi-technique approach

Part 1: The porosity framework



Carbonate and OM-rich samples



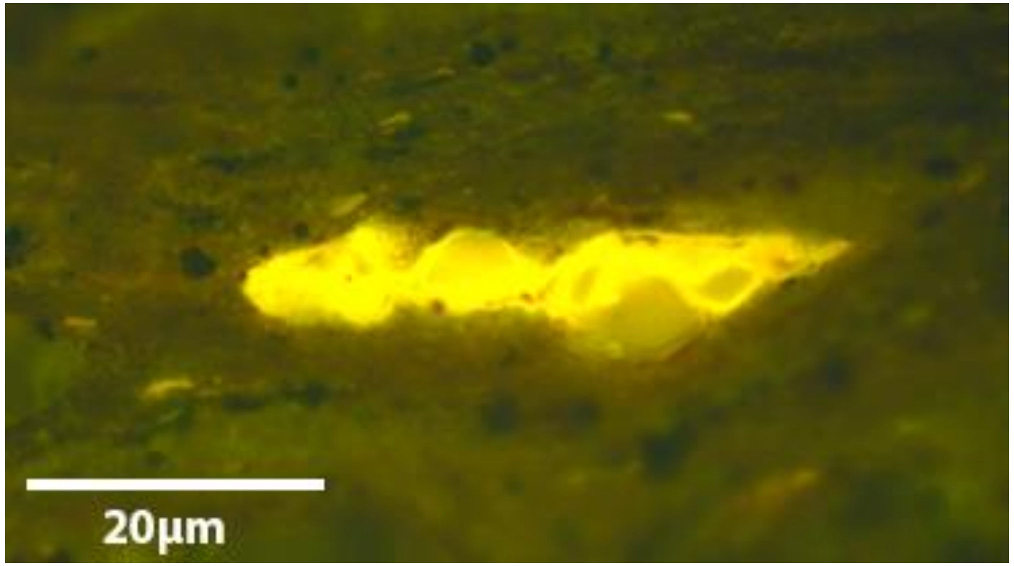


The OM type

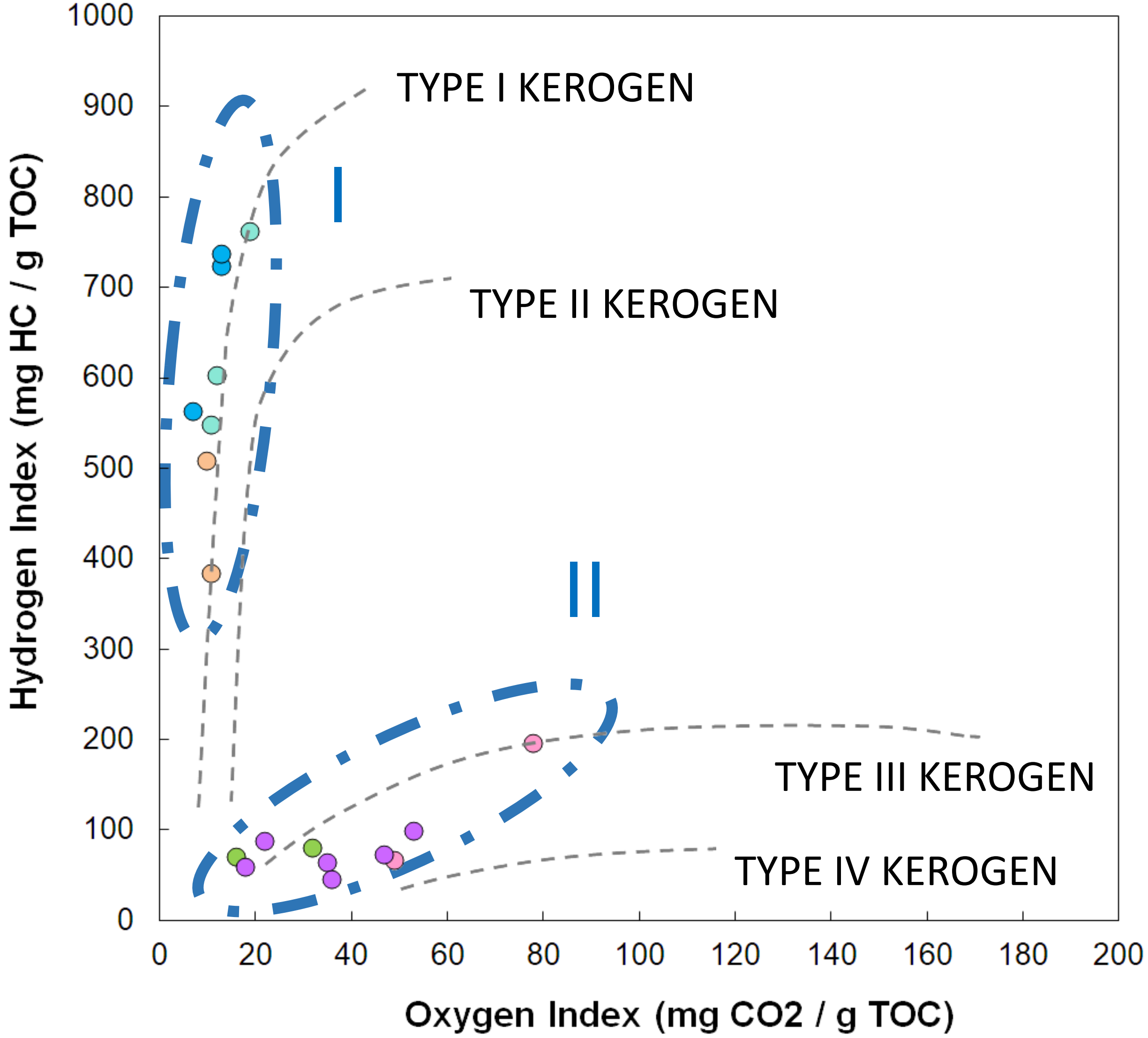
- Group I: immature samples

- Group II: mature samples

Type I-II marine kerogen

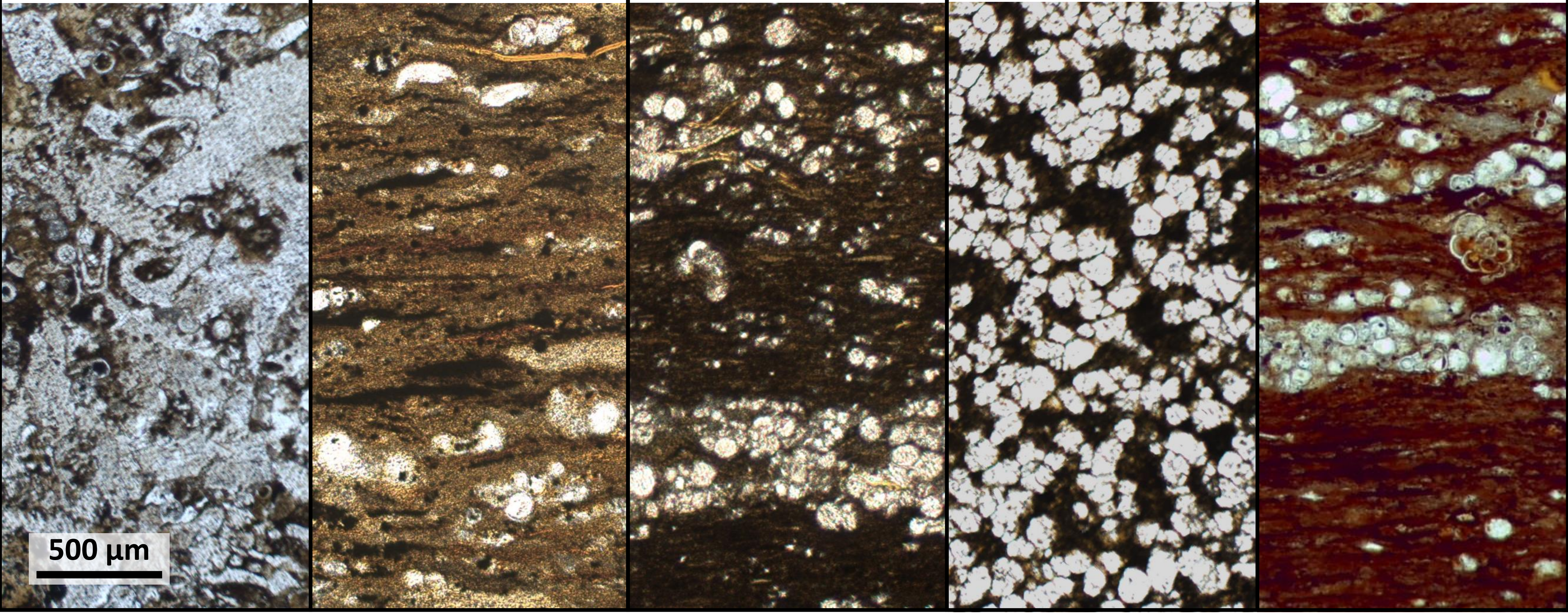


Rock Eval data

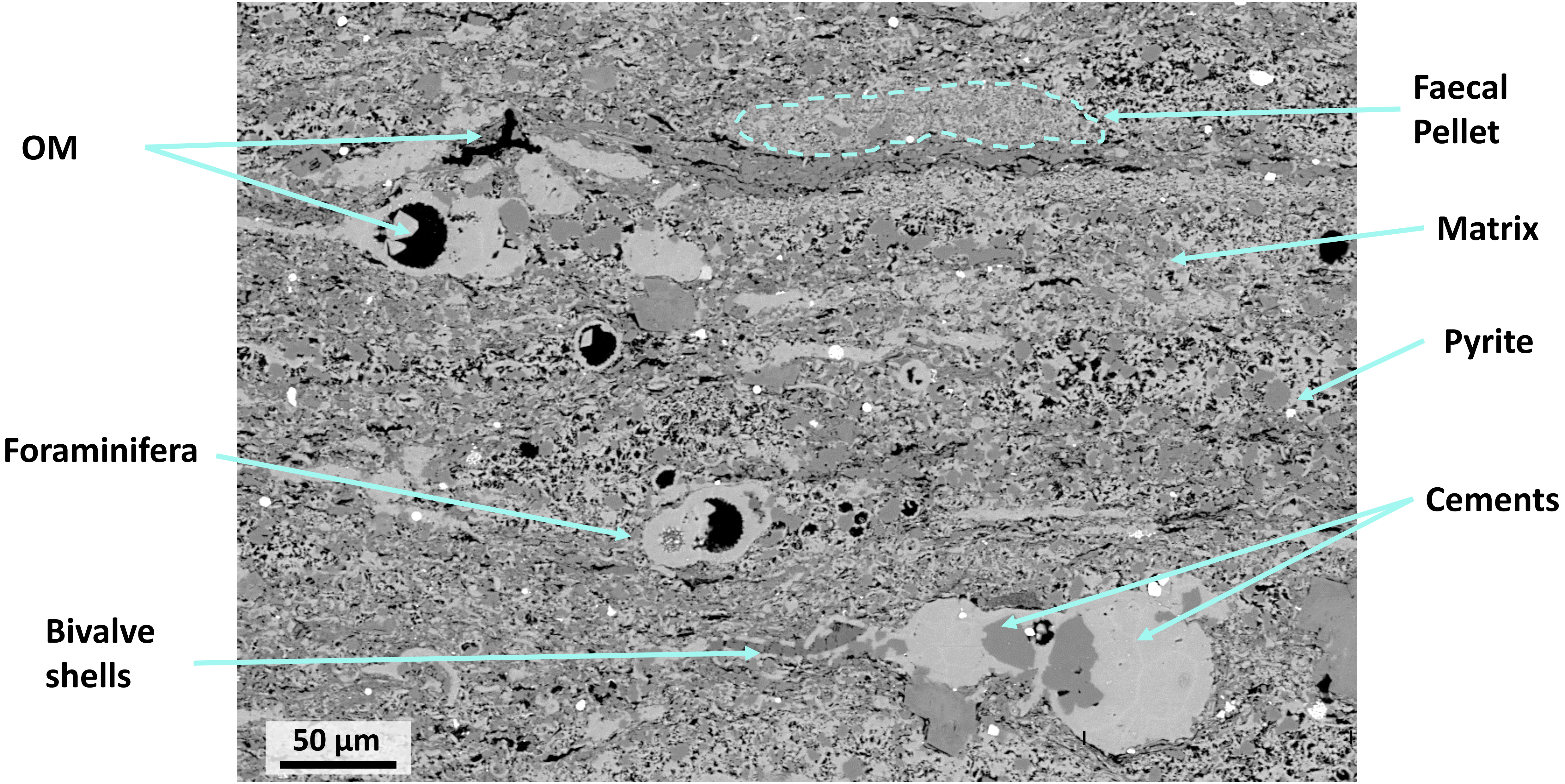


Different microfacies

Packstone	Foraminiferal mudstone (ca-rich)	Foraminiferal mudstone (OM-rich)	Limestone	Foraminiferal mudstone (clay-rich)



Different domains



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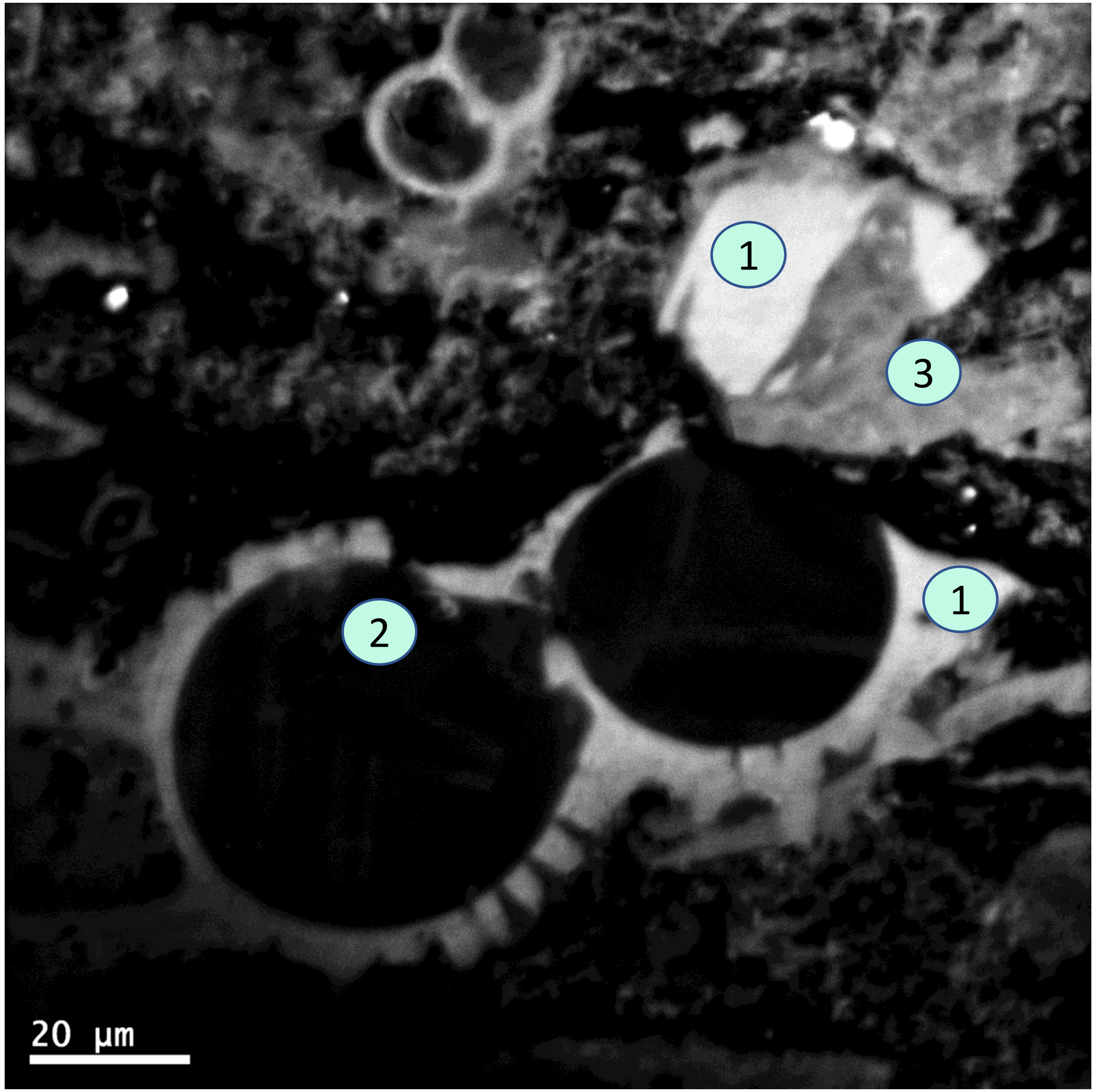
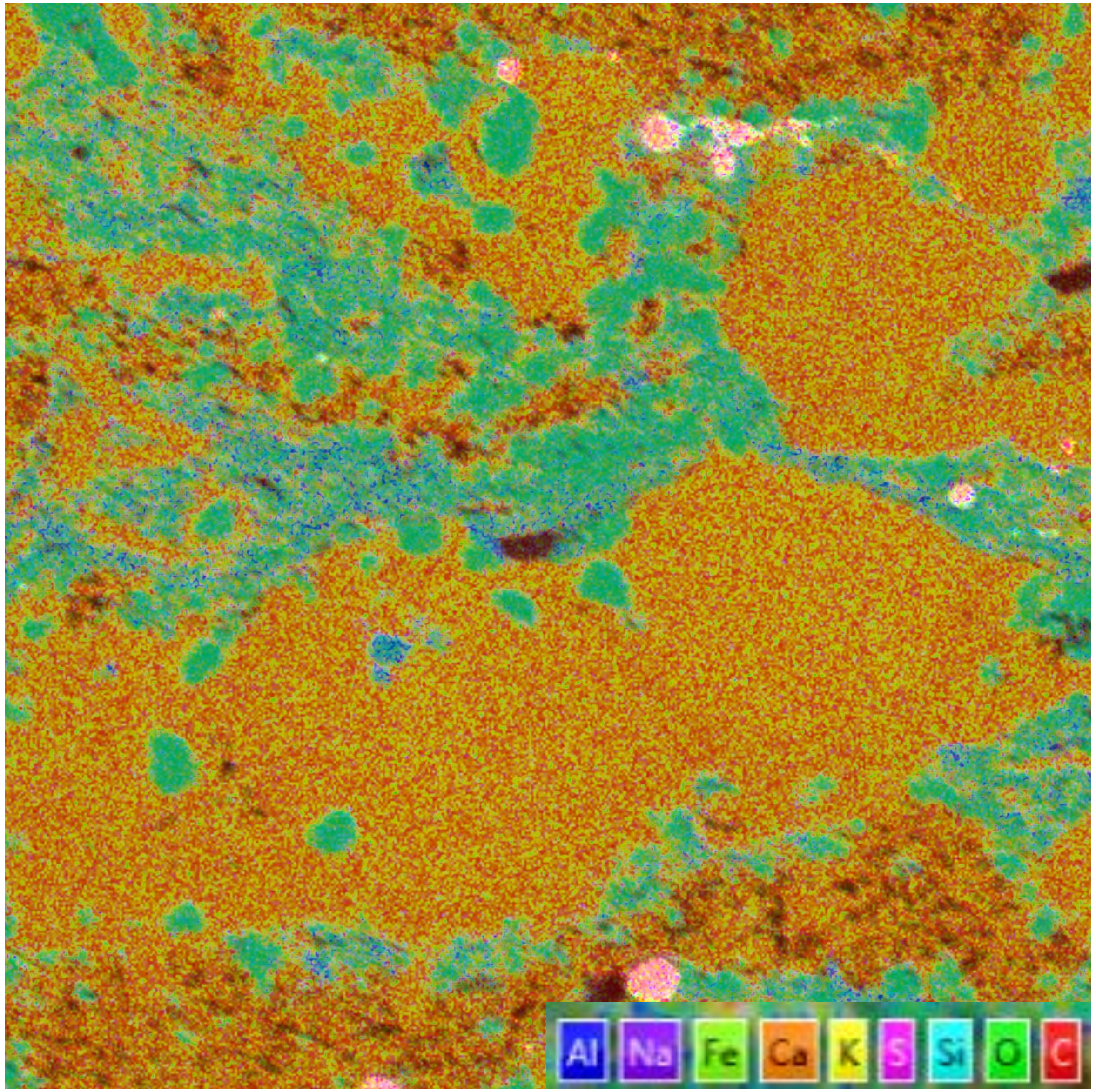
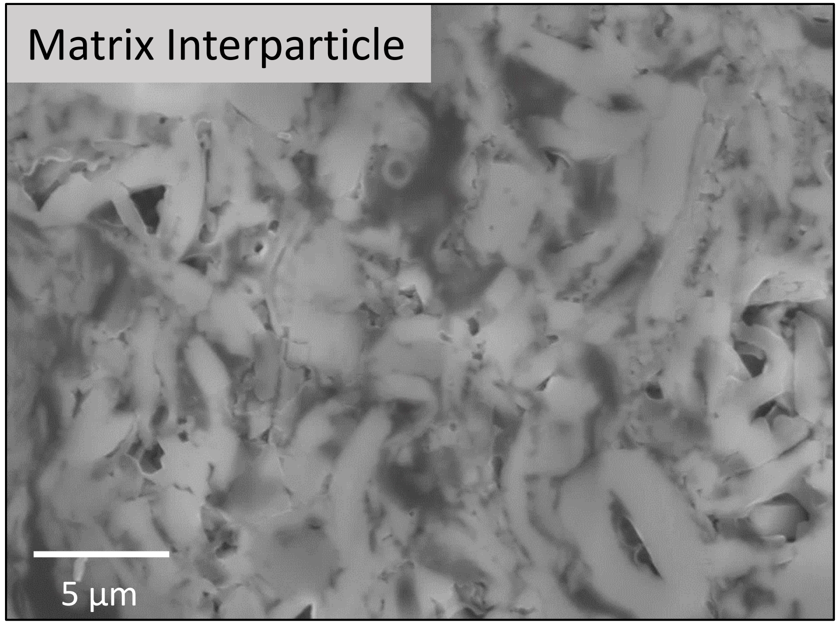
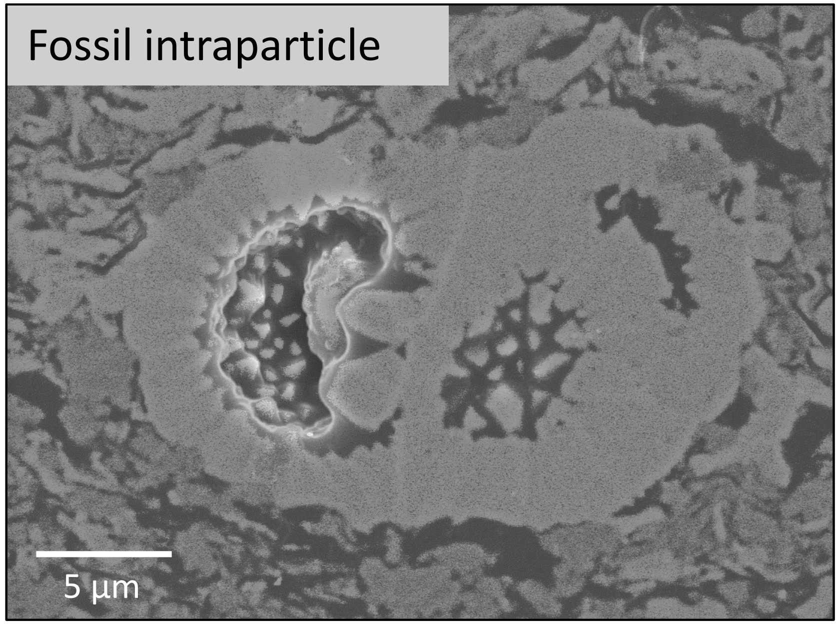
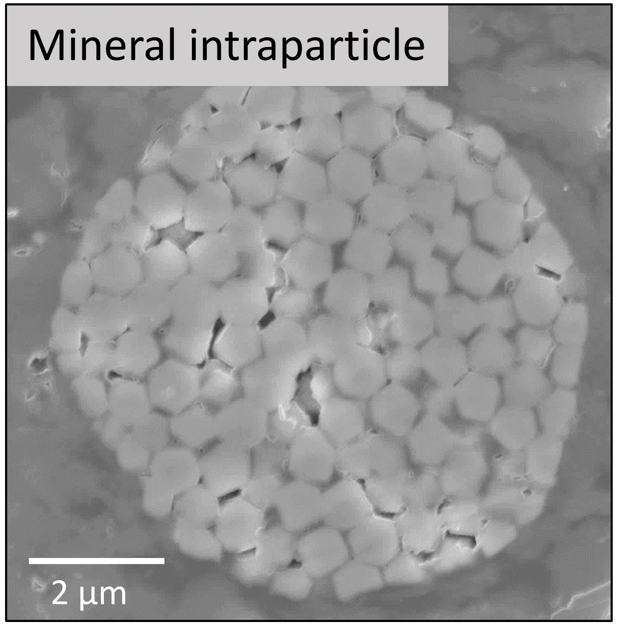


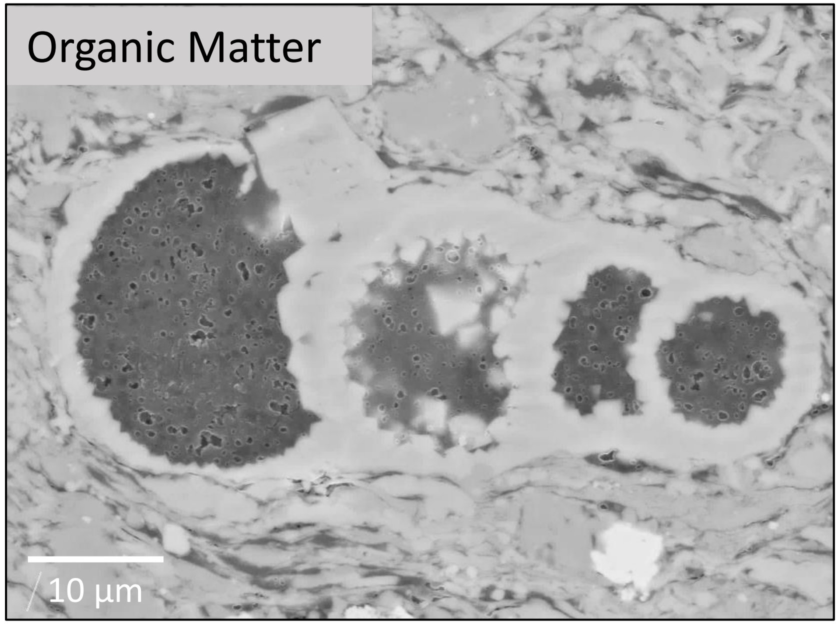


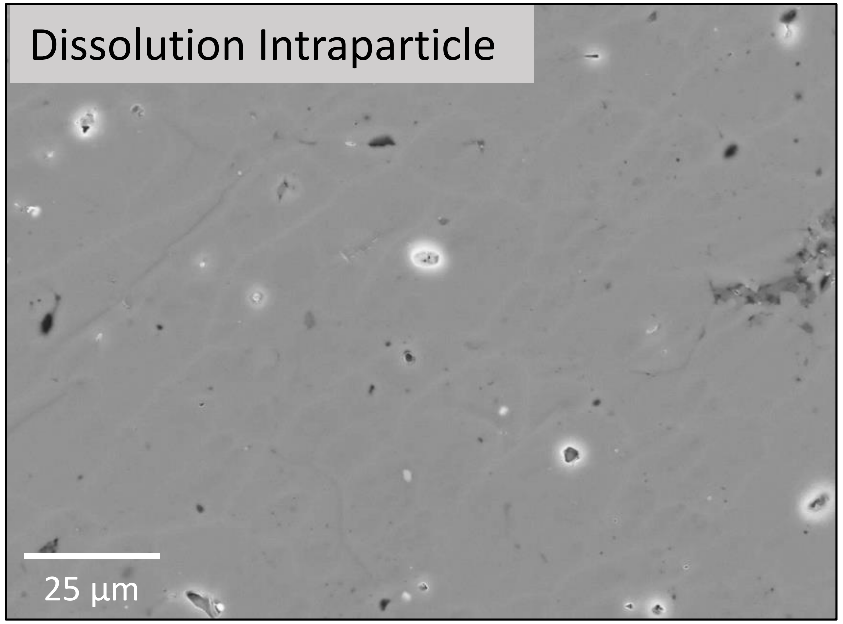
The different porosity types











Part 2: The porosity quantification

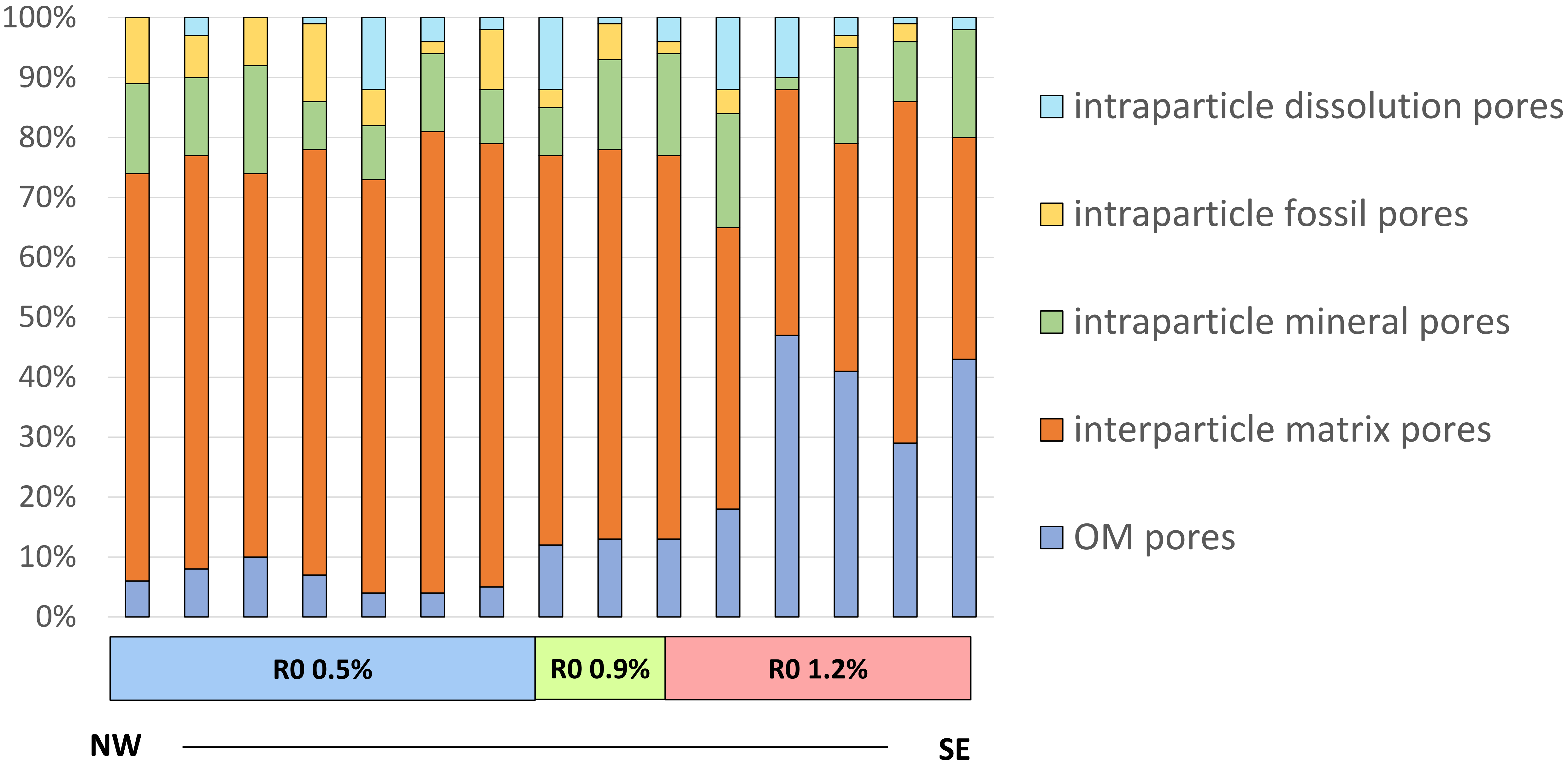
Mercury Injection Porosimeter

Gas adsorption

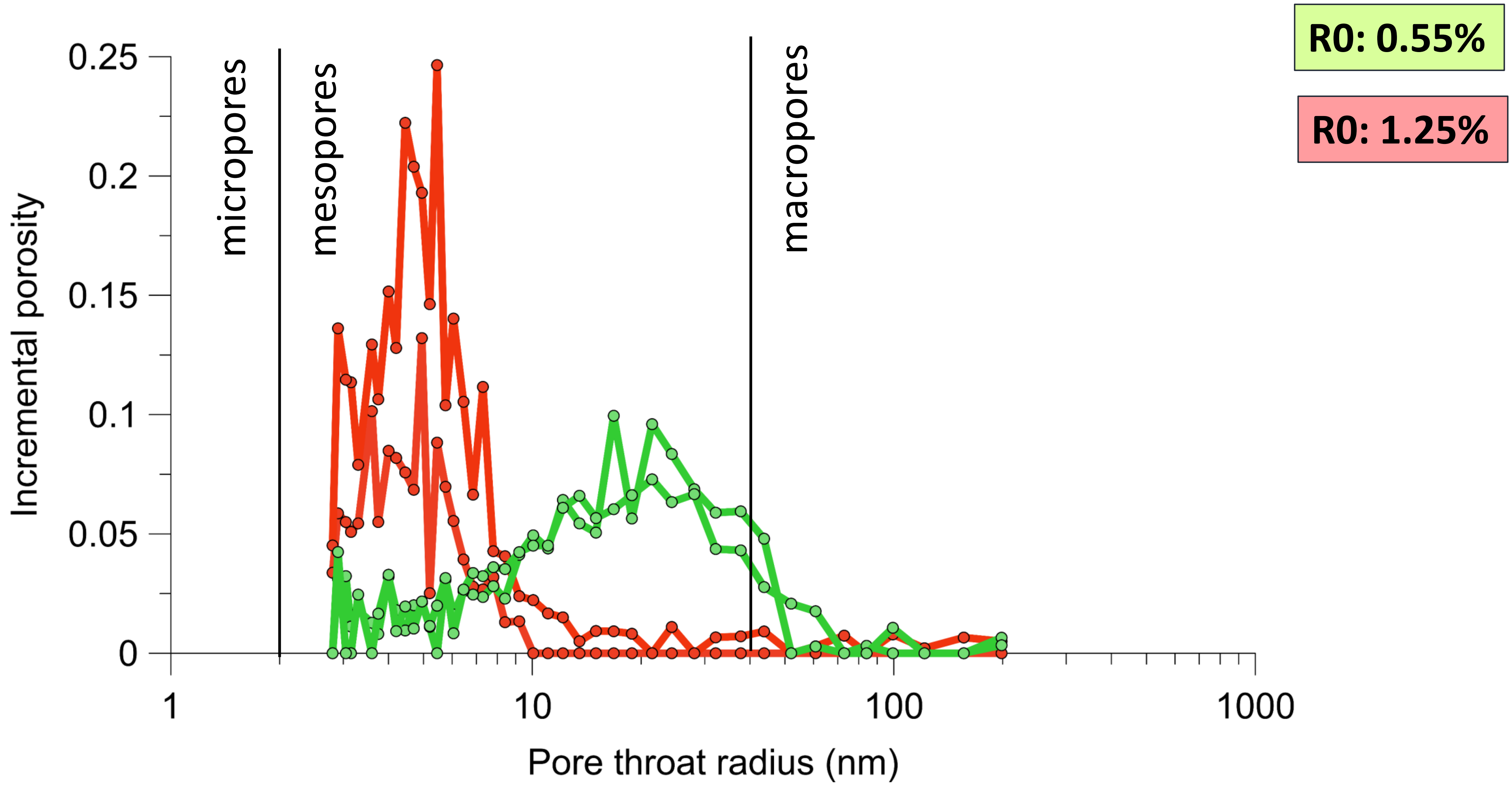
Scanning Electron Microscope

Focussed Ion Beam

The porosity quantification using the SEM

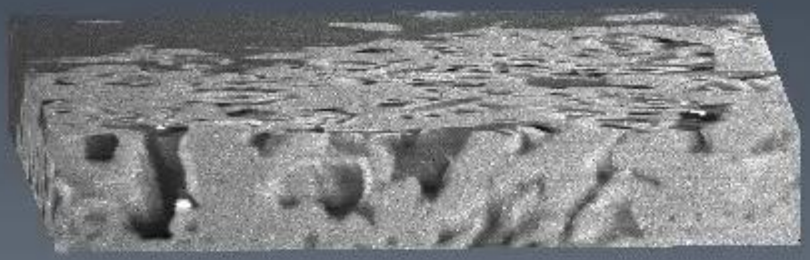


The pore size distribution using the MICP



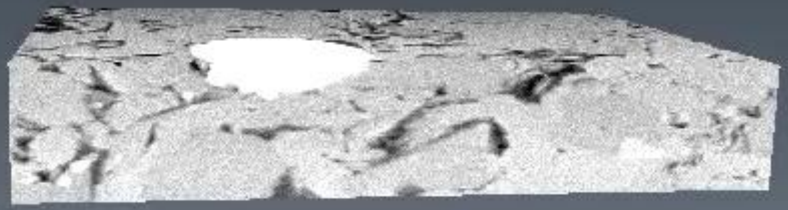
The pore types and connectivity in 3D: the FIB

R0: 0.55%



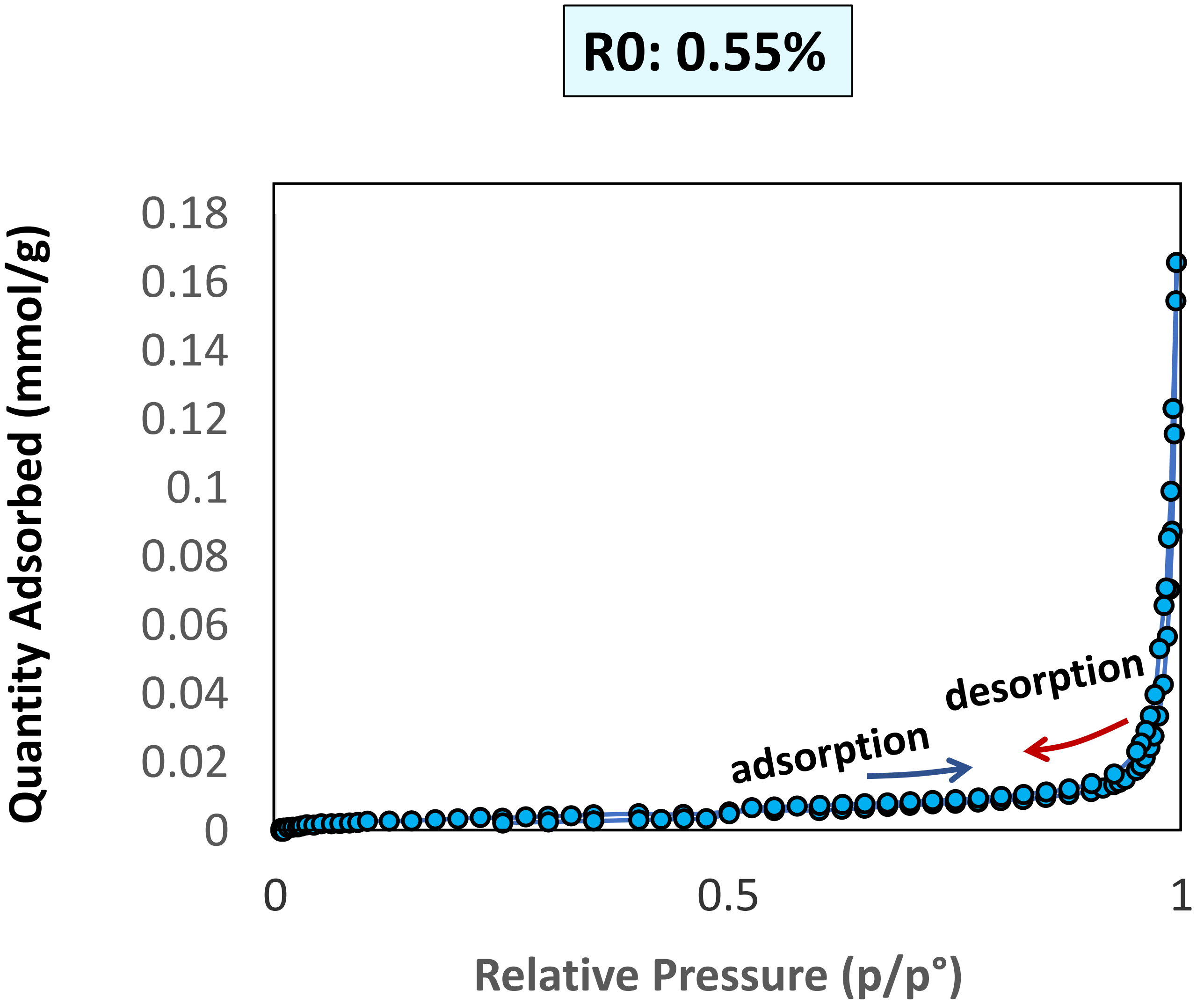
5 µm

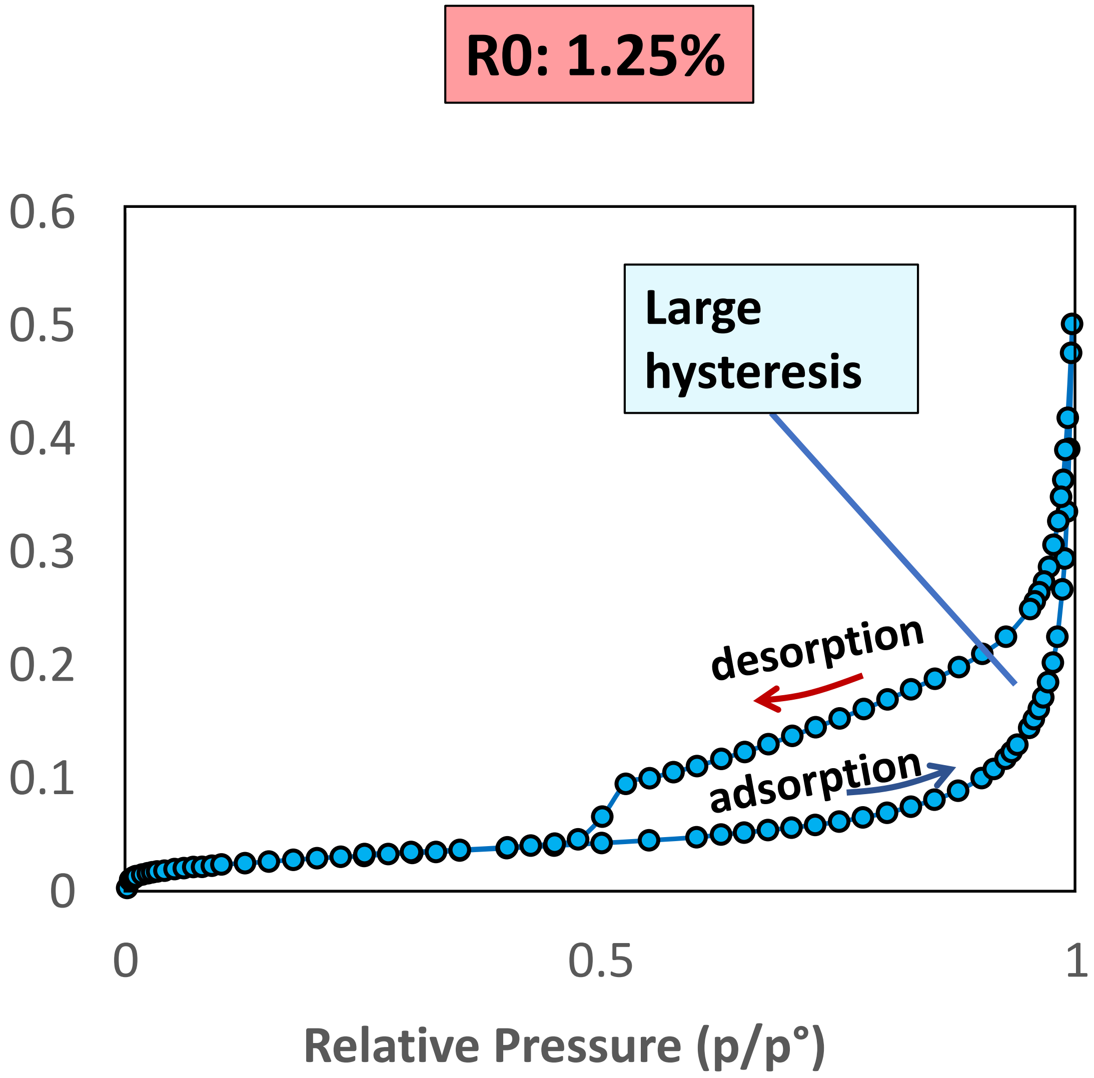
R0: 1.25%



5 µm

The pore network using the Gas Adsorption (N2)





Part 3: The pore surface chemistry

Environmental Scanning Electron Microscope

Atomic Force Microscope

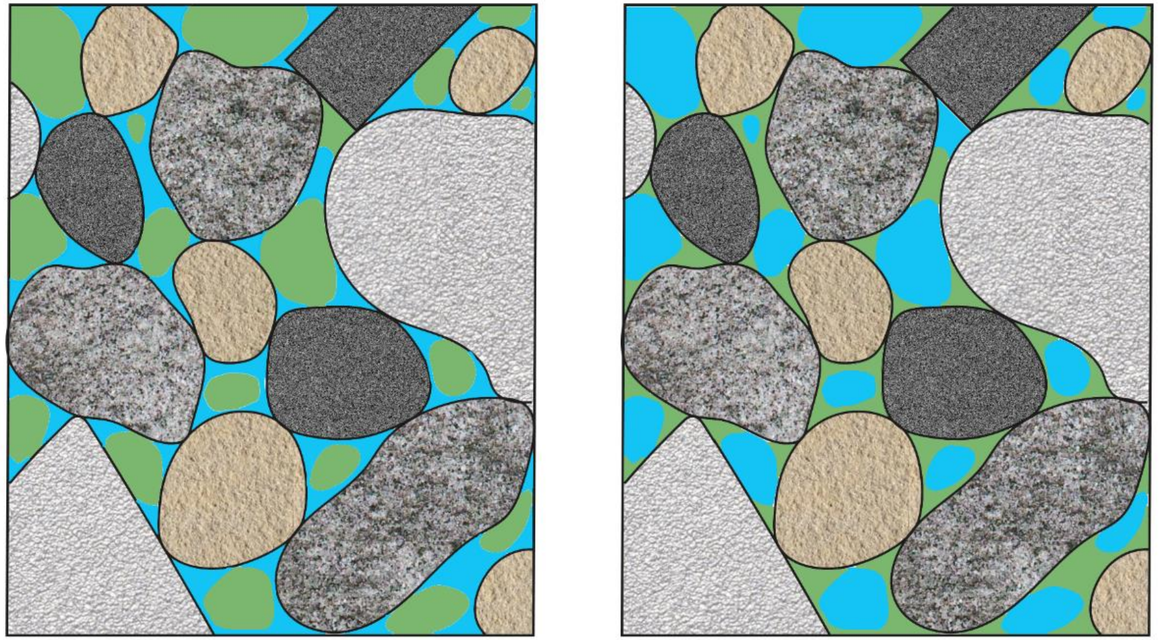
Atomic Force Microscope + NanoIR

The wettability

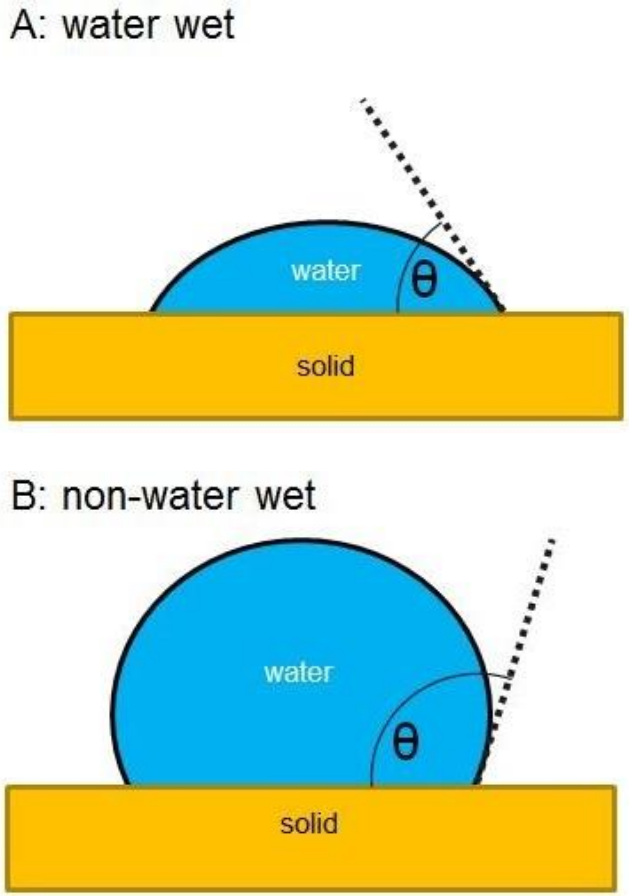
- It is the preference of a solid to be in contact with a fluid rather than another.
- A rock (or a mineral) in a reservoir can be water-wet or oil-wet.

Water

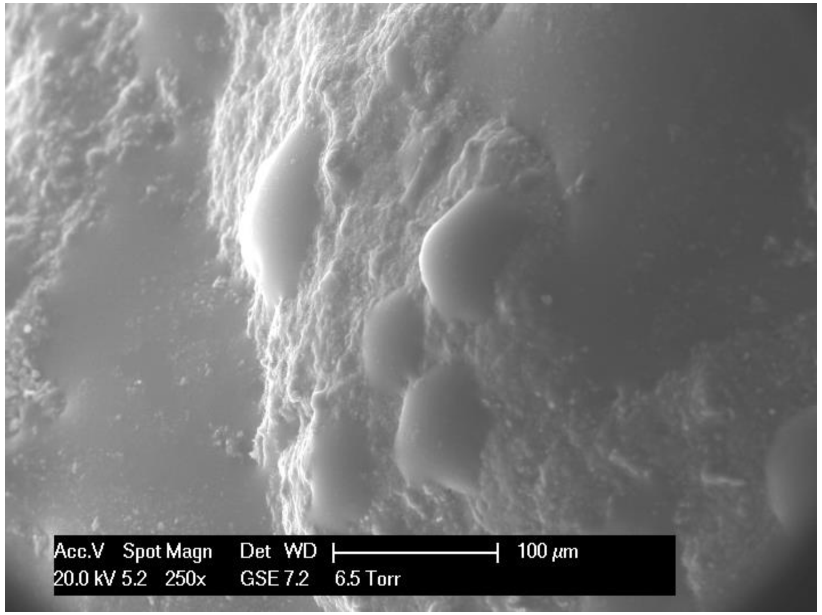
Oil

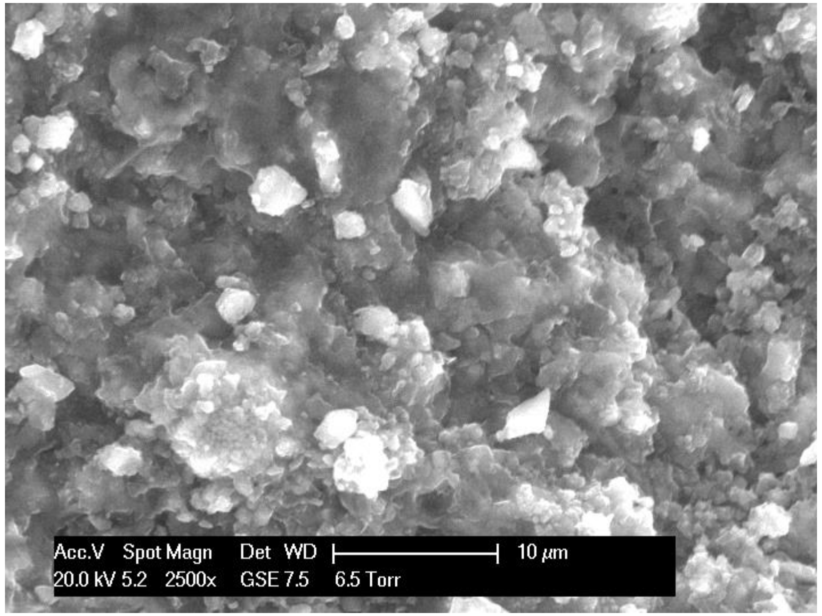


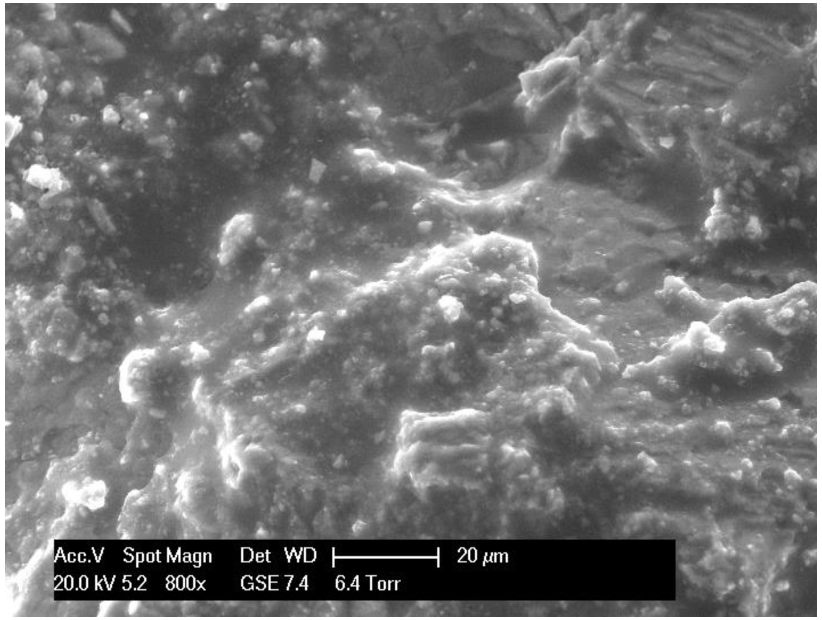
Water-wet Oil-wet

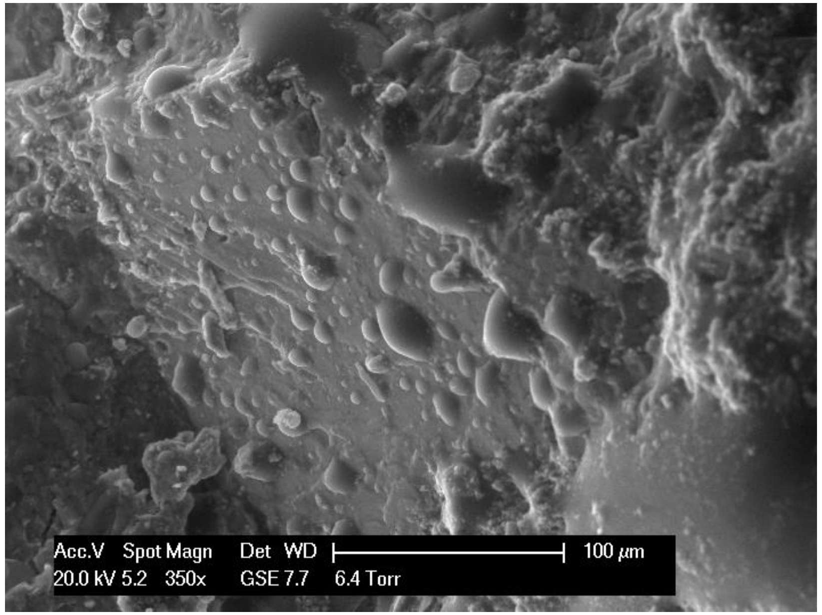


The wettability at the microscale: ESEM



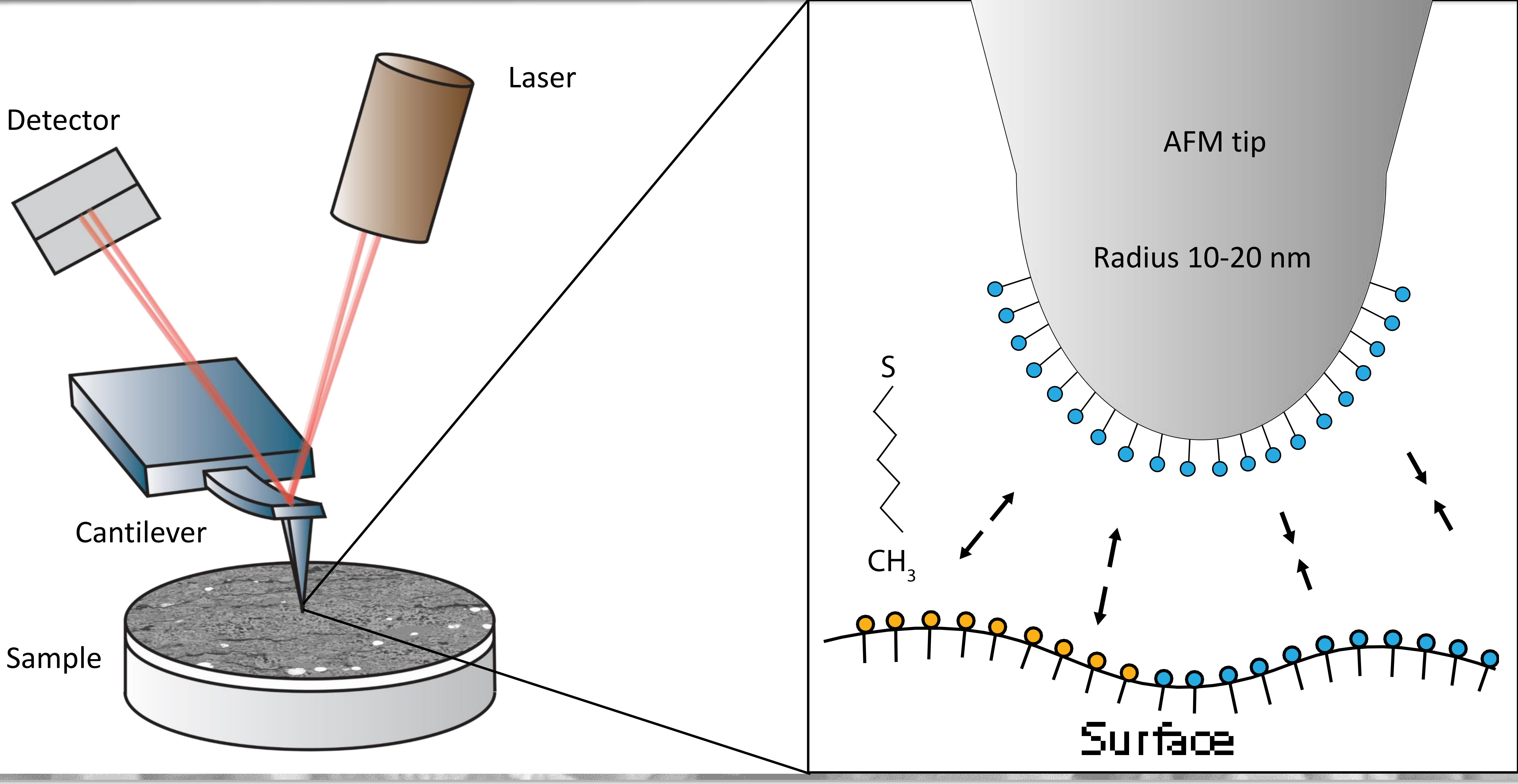




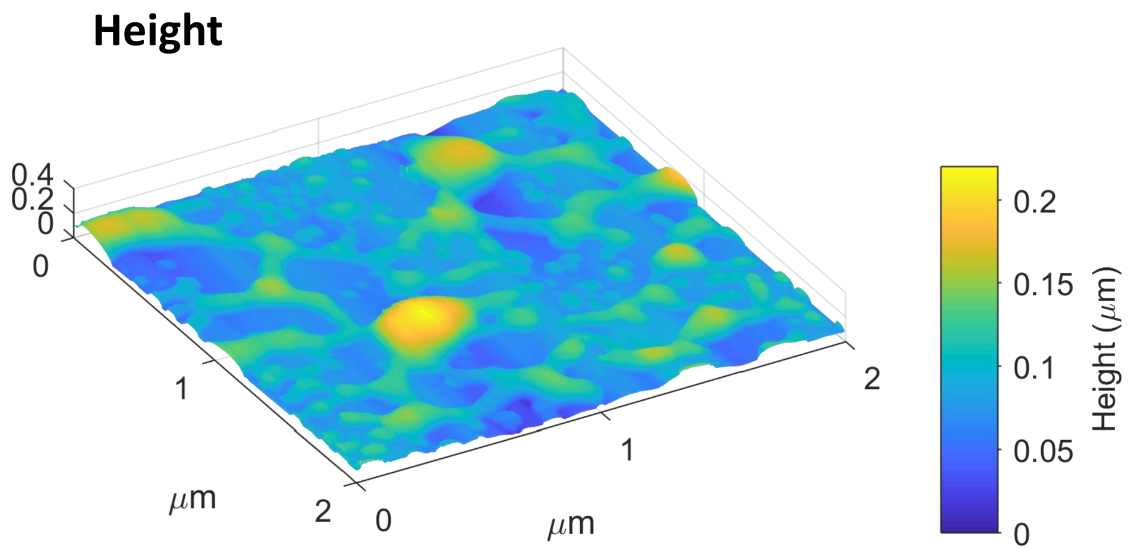


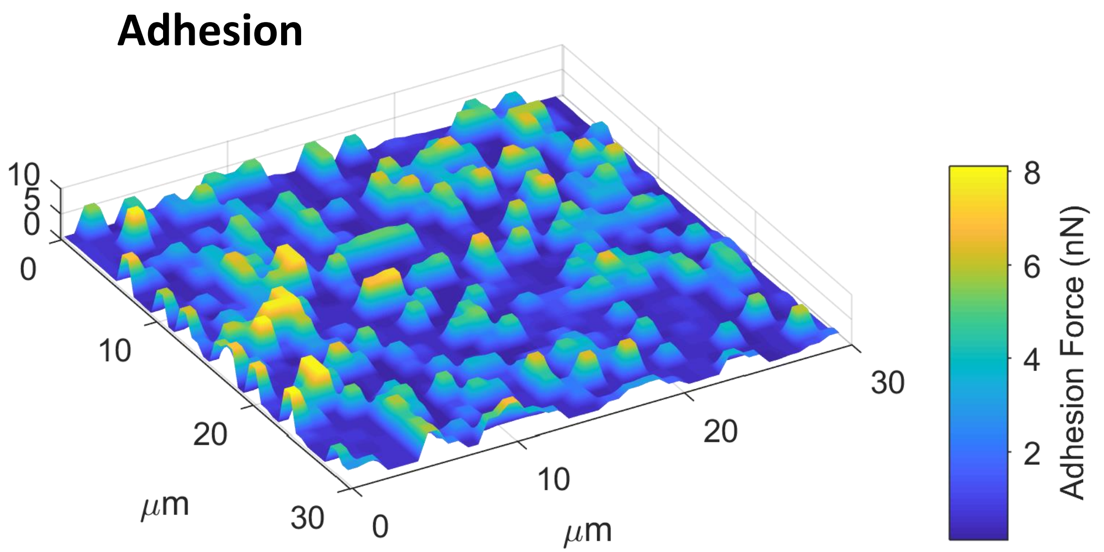
- Mixed-wet
- Carbonates, quartz and pyrite are less hydrophobic than clays

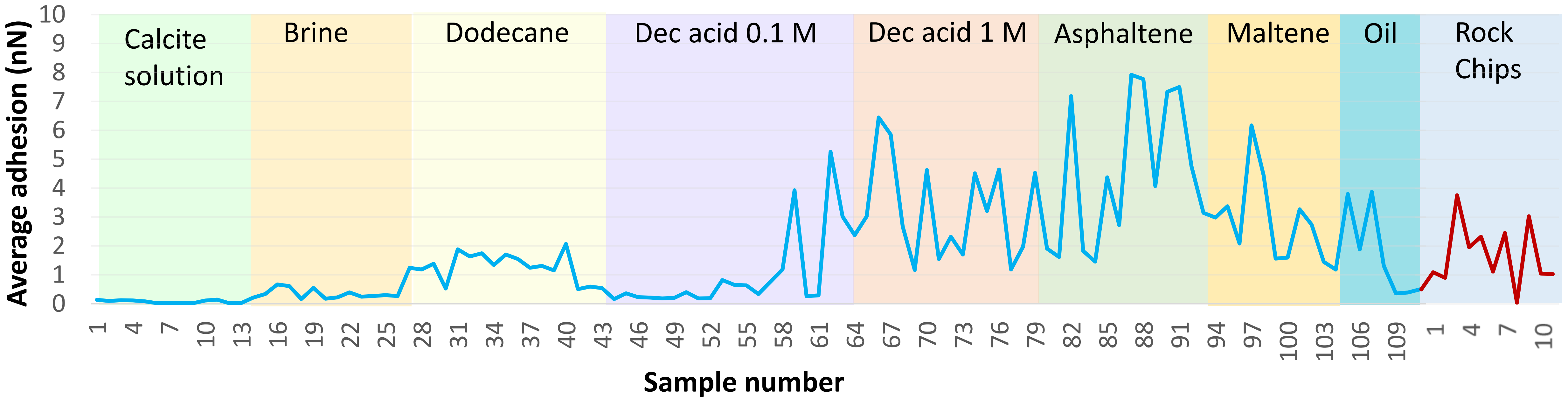
The wettability at the nanoscale: CFM



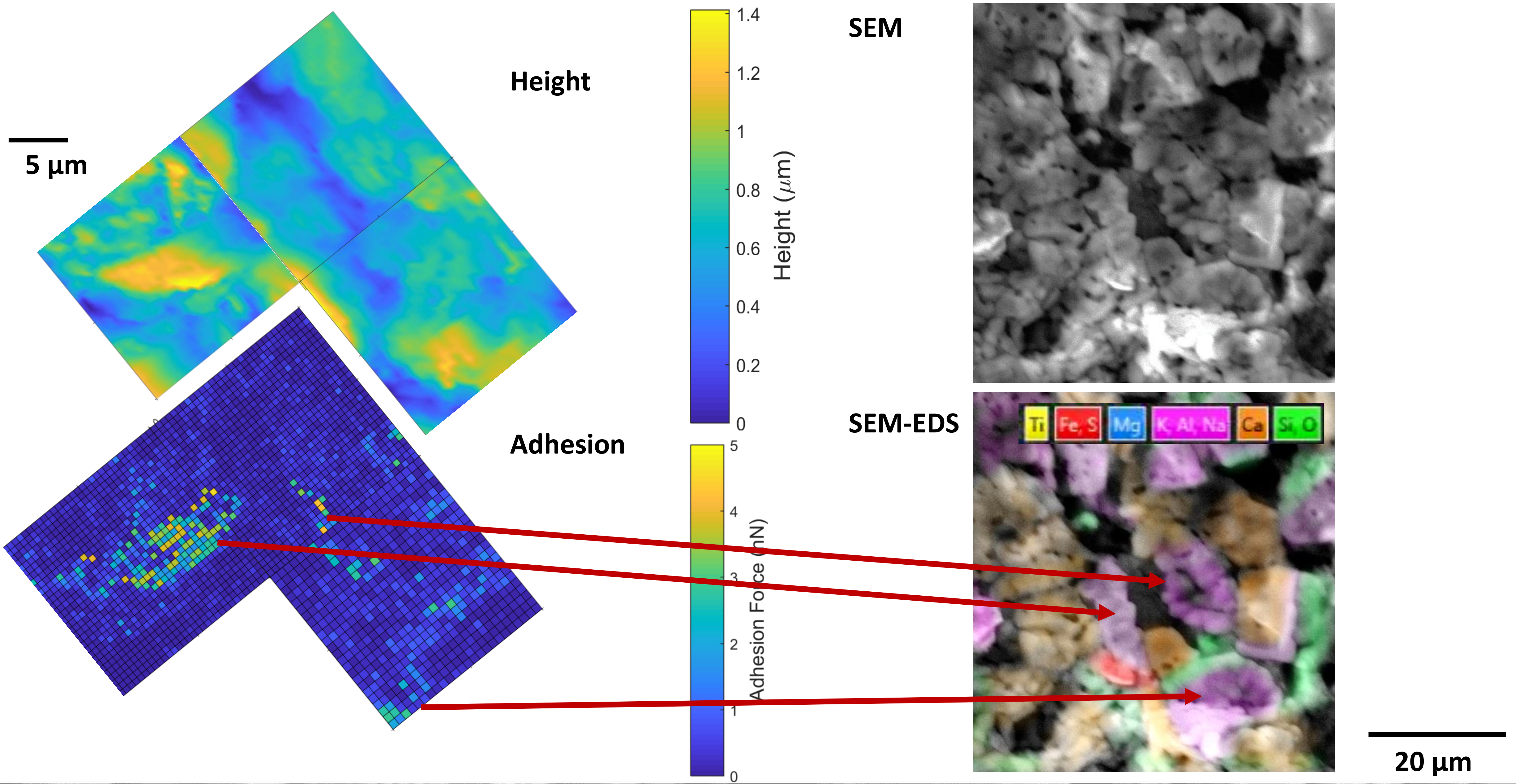
The wettability: CFM on Calcite



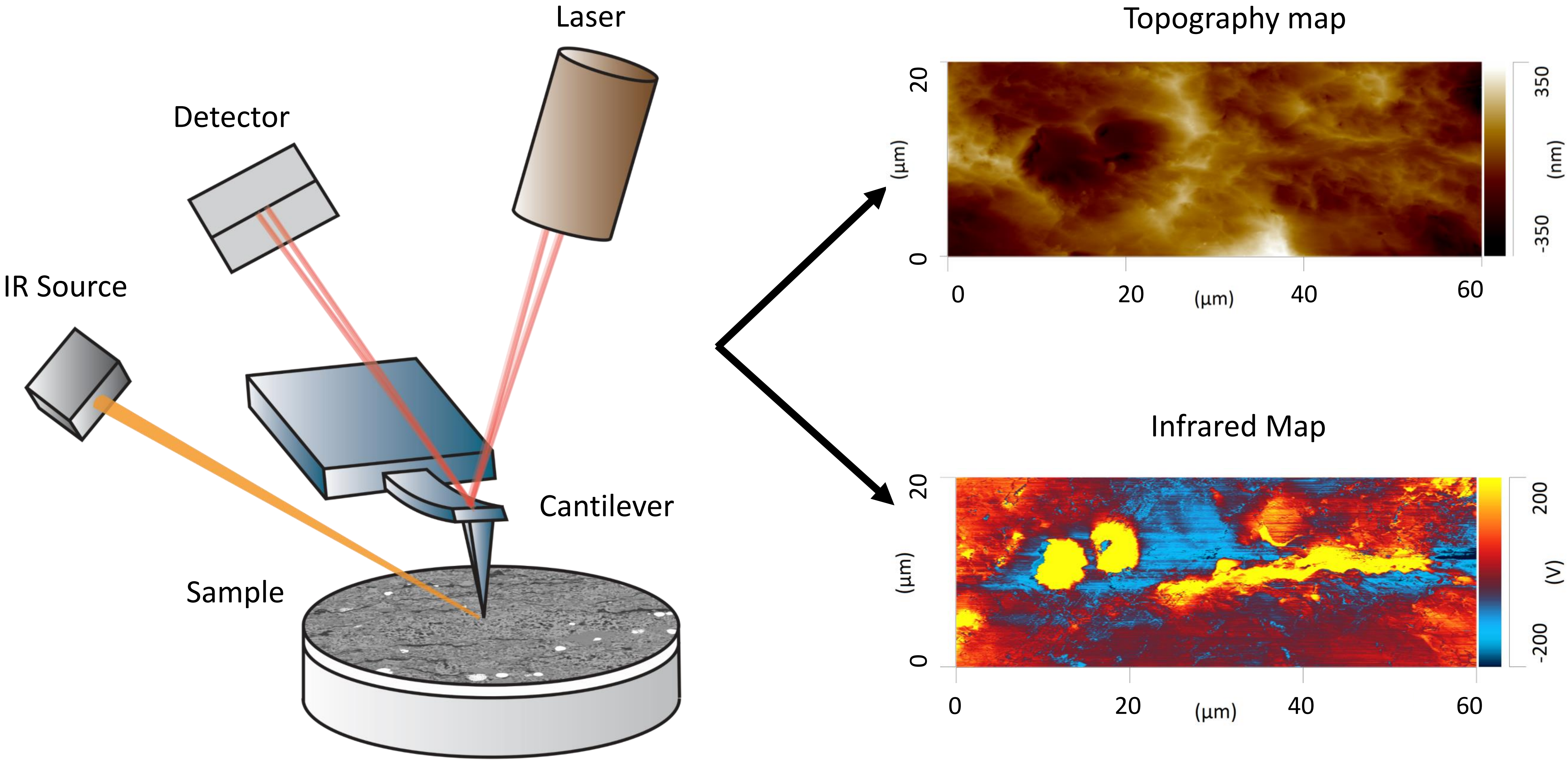




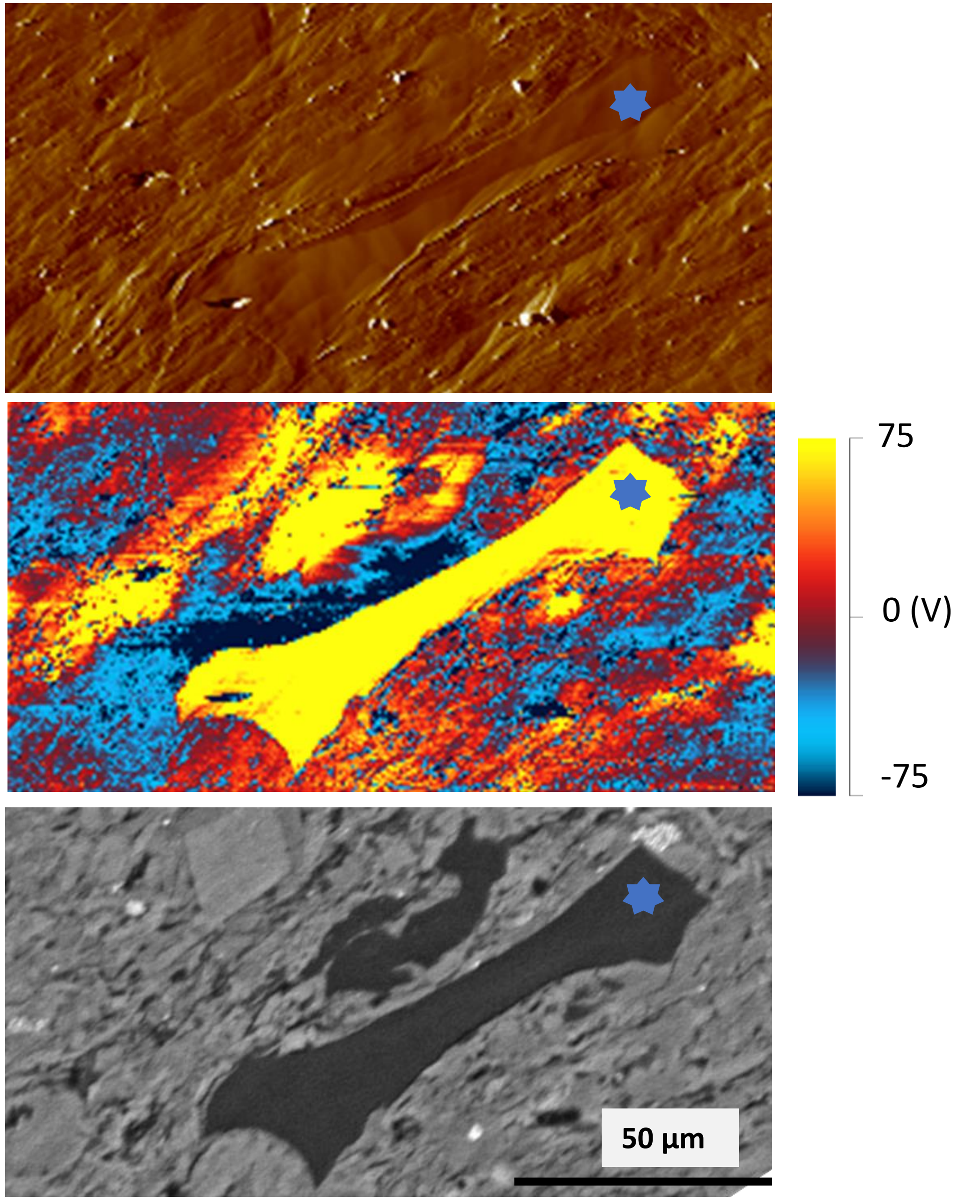
The wettability: CFM on rock chips

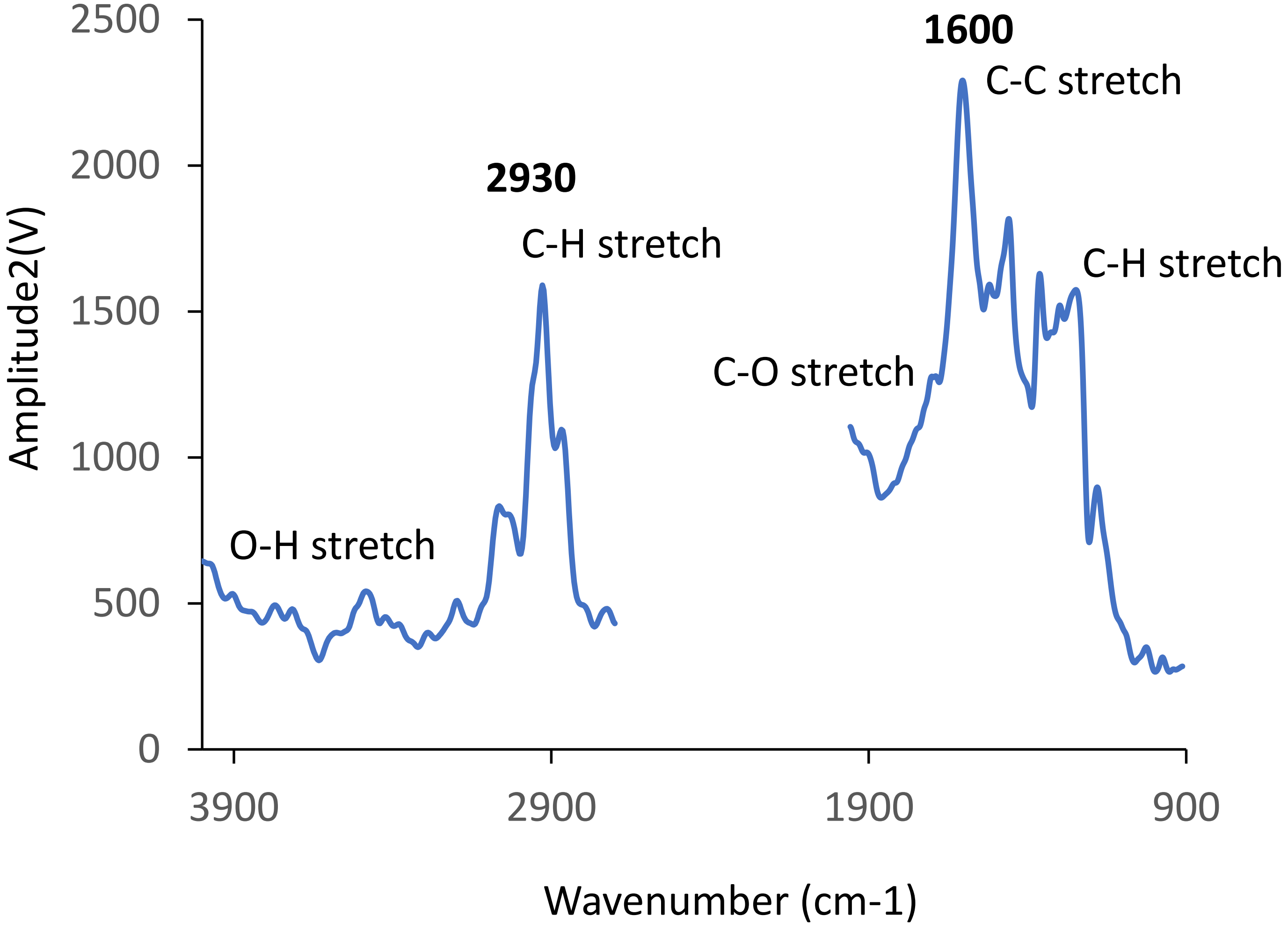


The wettability: AFM-IR



The wettability: AFM-IR





Conclusions

- The samples are **carbonate** and **OM-rich** and are highly **hetereogeneous**.
- The pores change with the increase in maturity. Pores become **smaller**, more **circular**…more **OM-related**.
- Studies using different techniques suggest that the porosity at low maturities is mainly formed by **interparticle matrix mesopores**.
- The **pore system network at high maturities is complex**. Mesopores connected by smaller pore throats.
- The **wettability** of a pore surface varies with the **type of fluid** (higher molecular weight = more Oil-wet surfaces) and with the **mineralogy** of the surface.

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