Fractured Interbedded Dolomites and Limestones in a Reservoir Analogue: Integrating Carbonate Sedimentology and Structural data from Thin Section to Reservoir Scale*

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Abstract

In low porosity carbonate reservoirs, fracture systems are the main factor controlling the flow of hydrocarbons. Good examples are the Apulian fractured carbonate fields of the Basilicata area (southern Italy), and the major on-shore carbonate reservoirs in Western Europe. There, hydrocarbons are hosted in interstratified limestones and dolomites of upper Lower to Upper Cretaceous age. The occurrence of fractures at various scales in these fields is well documented by FMI logs. However, a profound geological model to explain the distribution of fracture sets and their relative impact on fluid flow in the reservoir is not evidenced, and any study conducted directly on drilling cores presents significant limitations related to observable fracture scales. To overcome such limitations, in the last years a growing interest for geometrical reservoir analogues accrued. The aim of this study is to clarify the role of different geological parameters such as lithology, crystal size and bed thickness, which contribute to the development of stratabound and non-stratabound fracture networks in a carbonate succession that can be considered a good reservoir analogue for the Basilicata oilfields.

The study area – Monte Chianello – is located in the southern Apennines. The outcropping succession comprises a 1200 m thick sequence of Cretaceous shallow water carbonates characterized by an alternation of dolomitic and calcareous beds, with variable textures and crystal sizes. Comparing non-stratabound fracture density determined from thin sections and acetate peels, when intragranular microcracks, that are common in dolomite crystals, are not taken into account, higher values result for limestones with respect to dolomites; on the contrary when all fractures (microcracks included) are considered for the estimation, both lithologies show same fracture density values. Dolomites exhibit an inverse relationship between crystal size and fracture density (microcracks excluded), well described by a power law. However, numerous fracture

counts on single-bed scan lines provide clear evidence that, generally, bed thickness is the dominating parameter controlling stratabound fracture distribution within the studied outcrops, regardless of lithology and crystal size.

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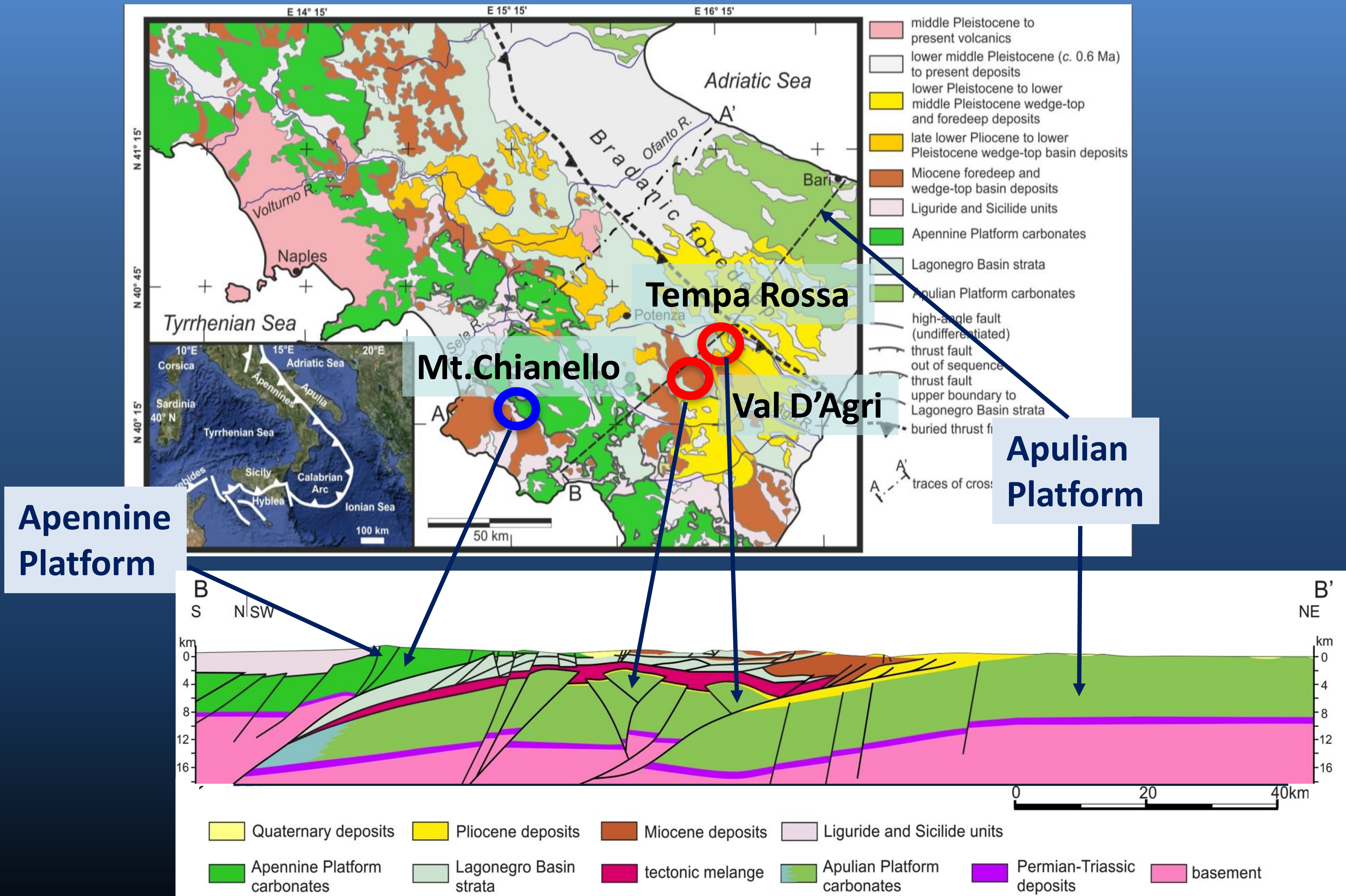
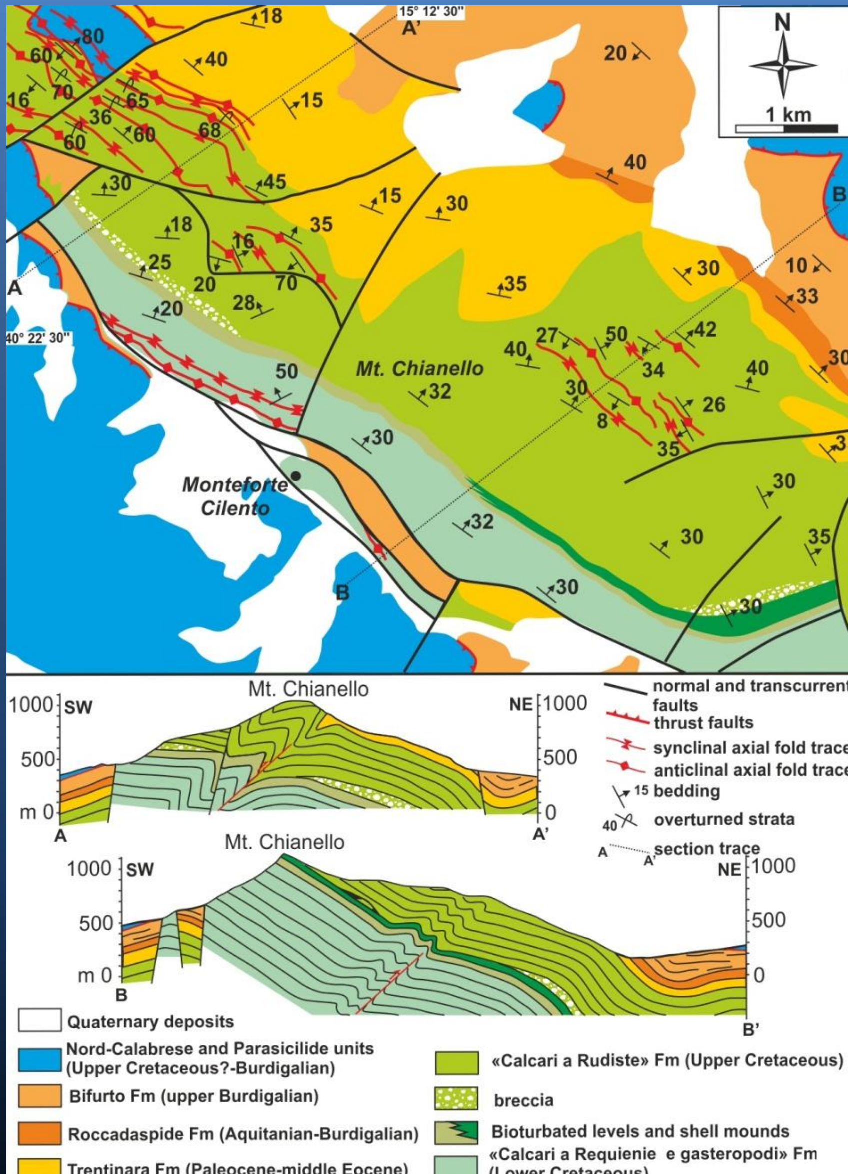
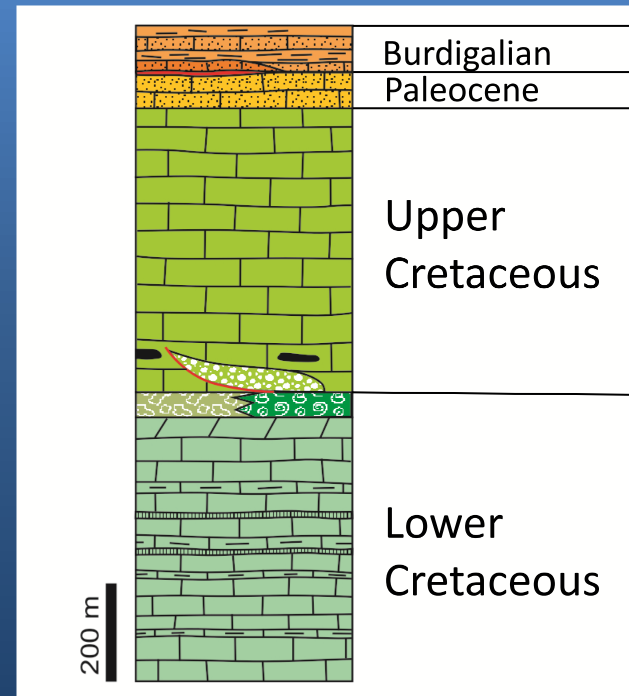
Hydrocarbon reservoirs in southern Apennines

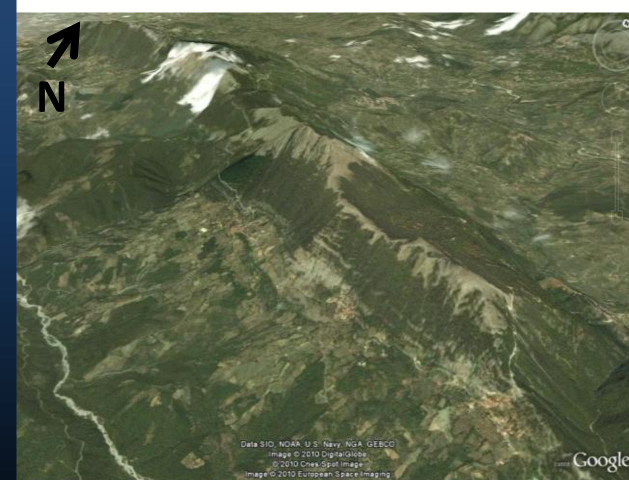


Mazzoli S., Ascione A., Candela S., Iannace A., Megna A., Santini S., Vitale S., 2013. Rend. Online Soc. Geol. It. doi: 10.3301/ROL.2013.XX

Geological setting of Mt. Chianello

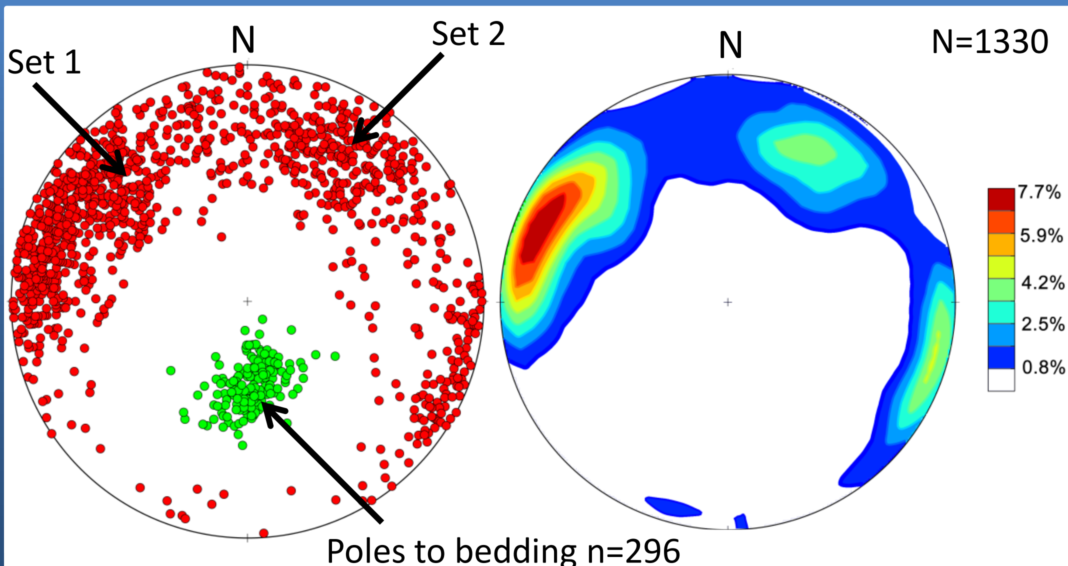


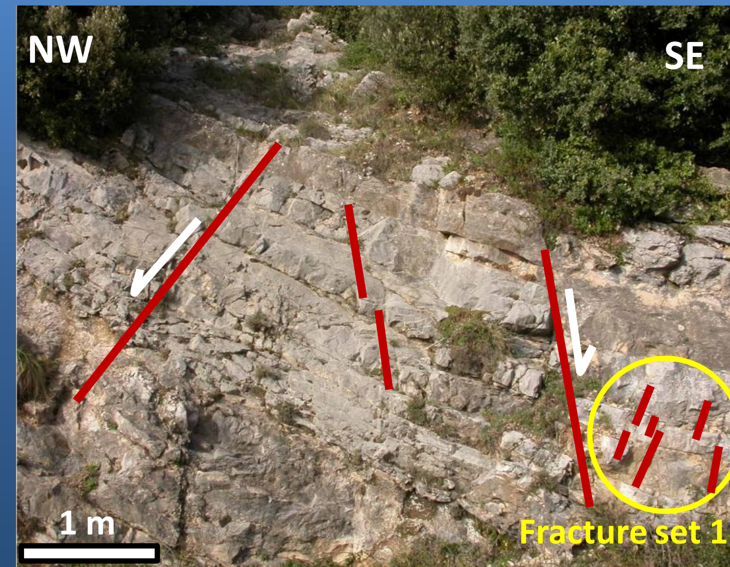


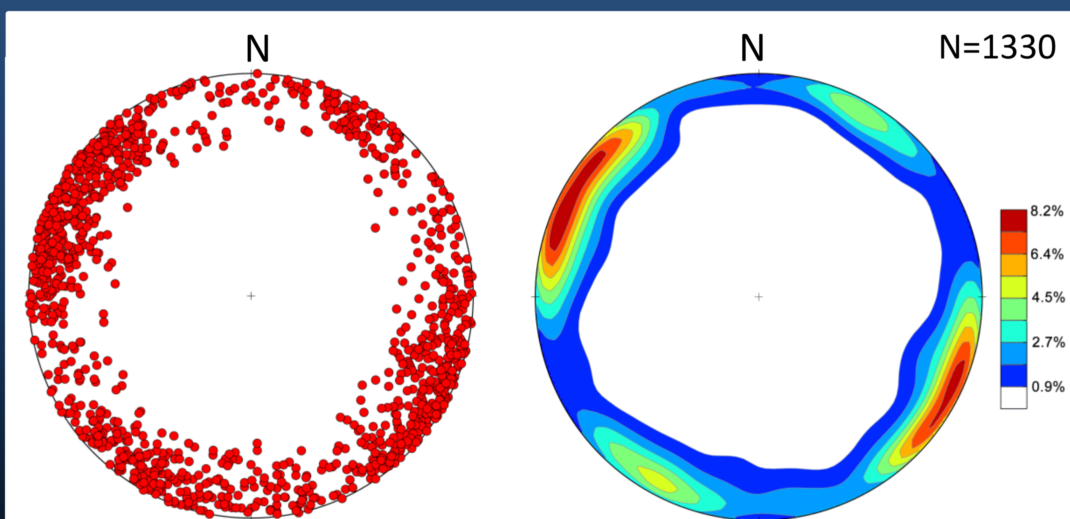


Vitale S., Dati F., Mazzoli S., Ciarcia S., Guerriero V., Iannace A. 2012. Journal of Structural Geology. doi:10.1016/jsg.2012.01.005

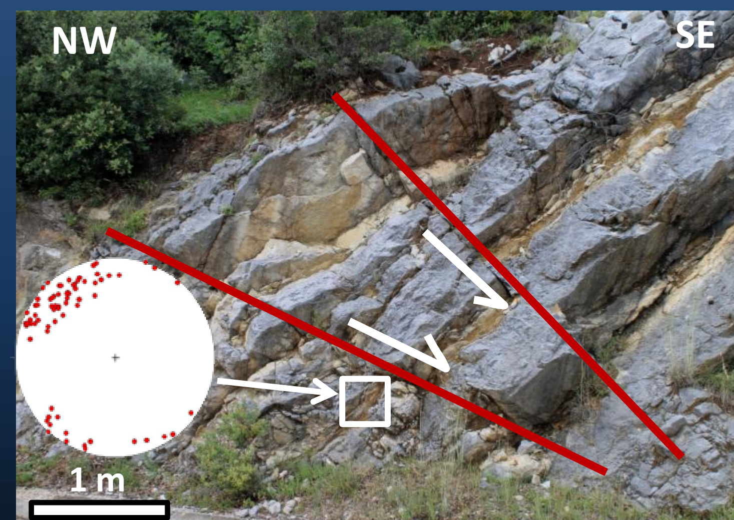
'Background' fracture sets







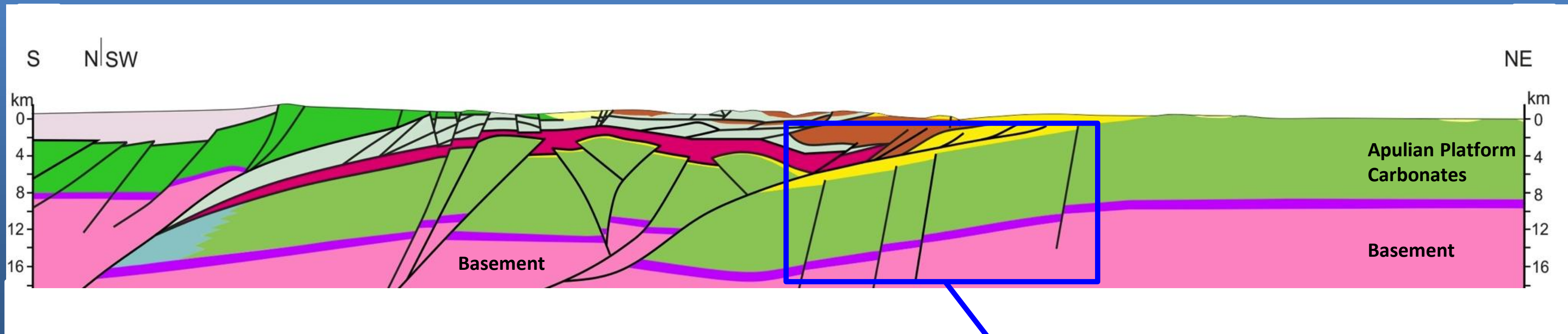
Restored fractures (veins and joints)



Restored joints

Vitale S., Dati F., Mazzoli S., Ciarcia S., Guerriero V., Iannace A. 2012. Journal of Structural Geology. doi:10.1016/jsg.2012.01.005

Modern setting of pre-thrusting normal fault development



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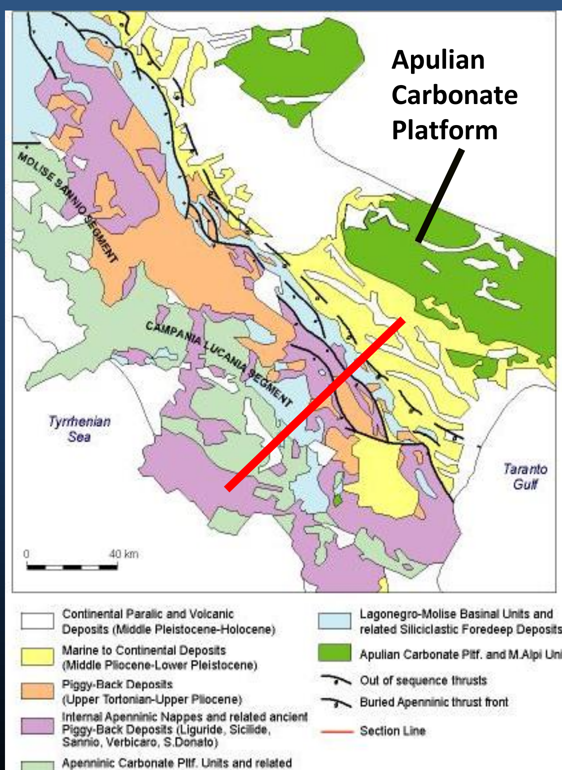

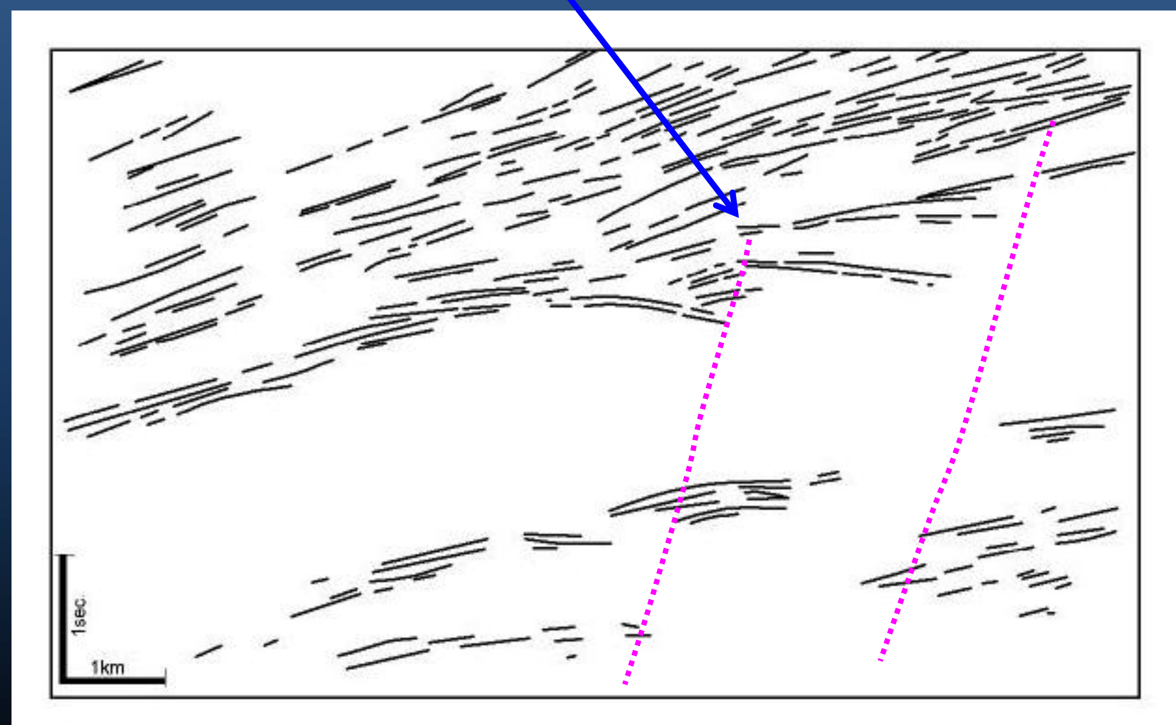

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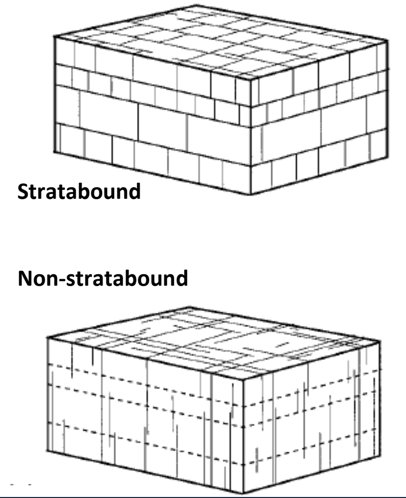
Multi-scale fracture analysis

‘Background’ fracture systems

- 3D Virtual Outcrop (reservoir scale)
- Single bed scan line (outcrop scale)
- Micro scan lines on acetate peels
- Micro scan lines on thin sections

Single-bed scan line

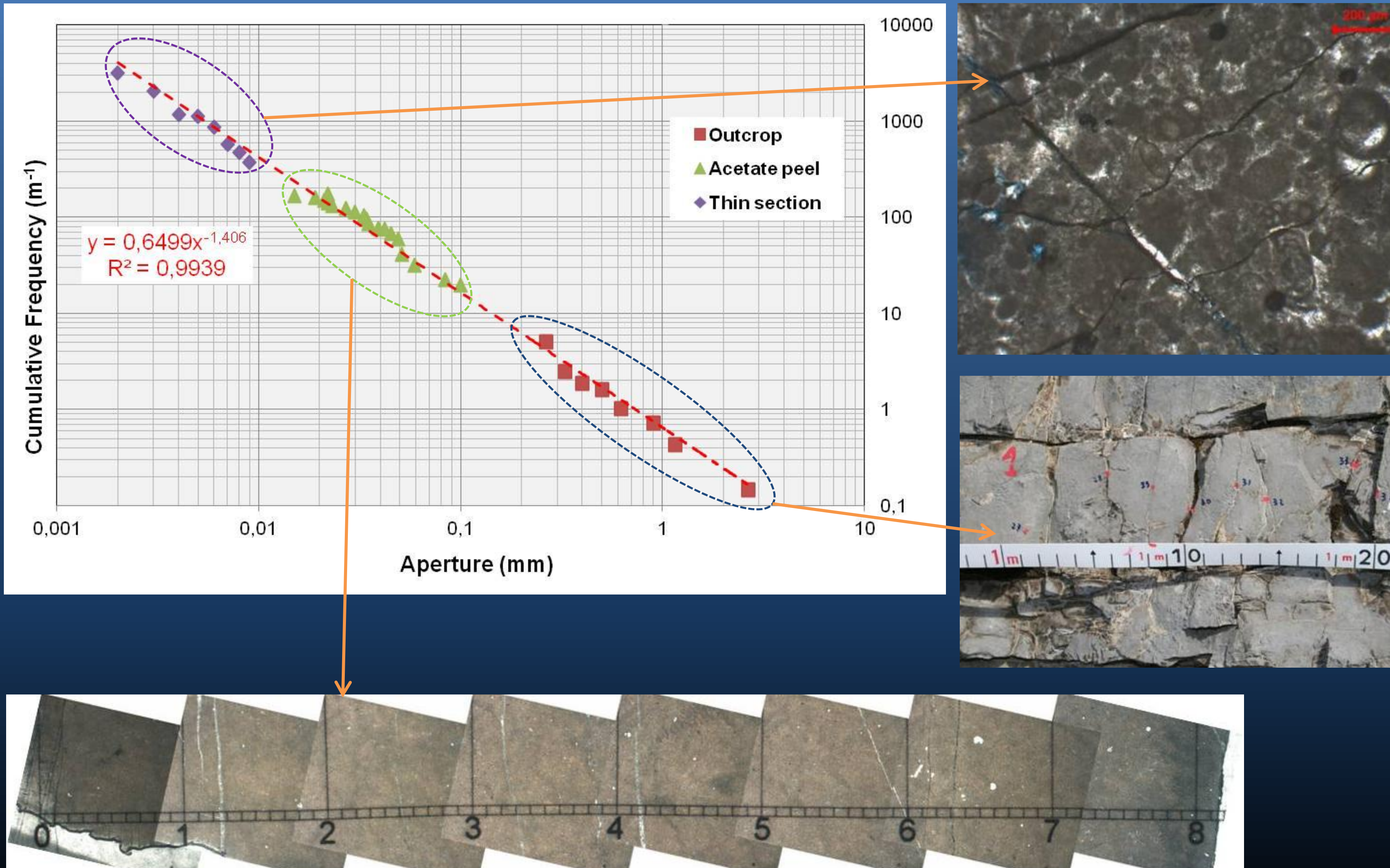
(a) Stratabound joints
(b) Non-Stratabound joints



From Odling et al. (1999)

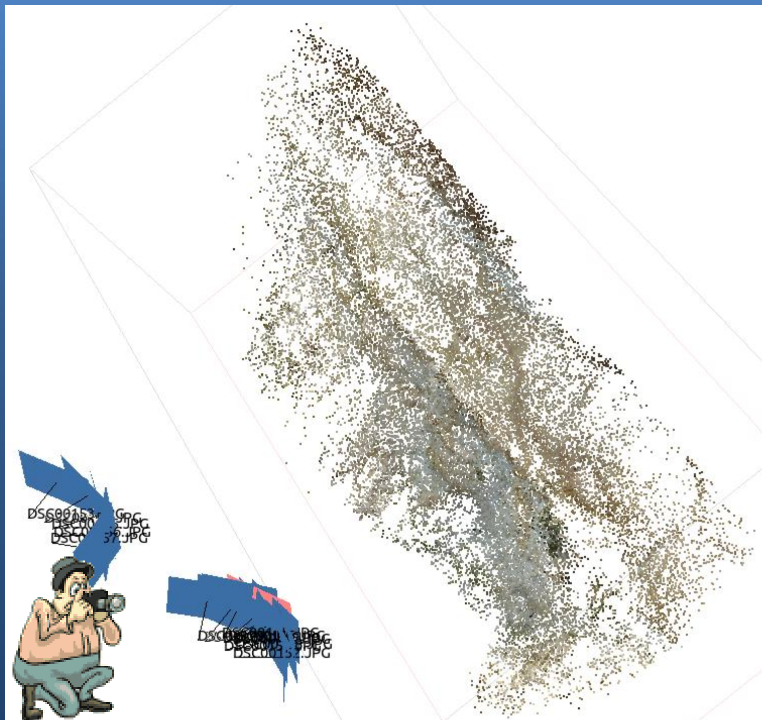
Multi-scale fracture analysis

'Background' fracture systems

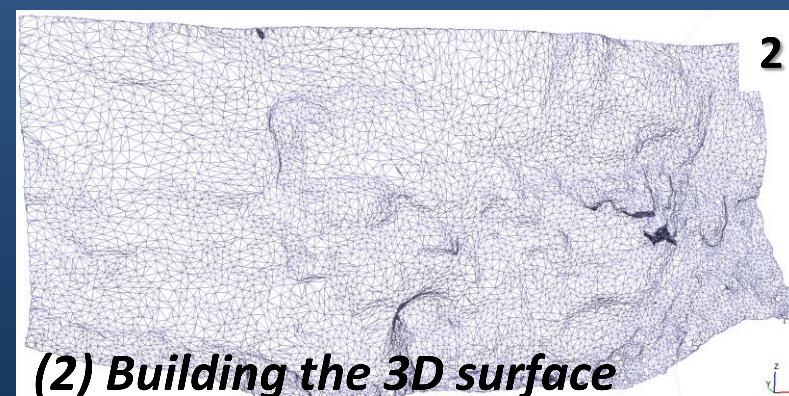


Example of micro scanline performed on acetate peel

Reservoir scale fracture analysis



(1) Building the point cloud

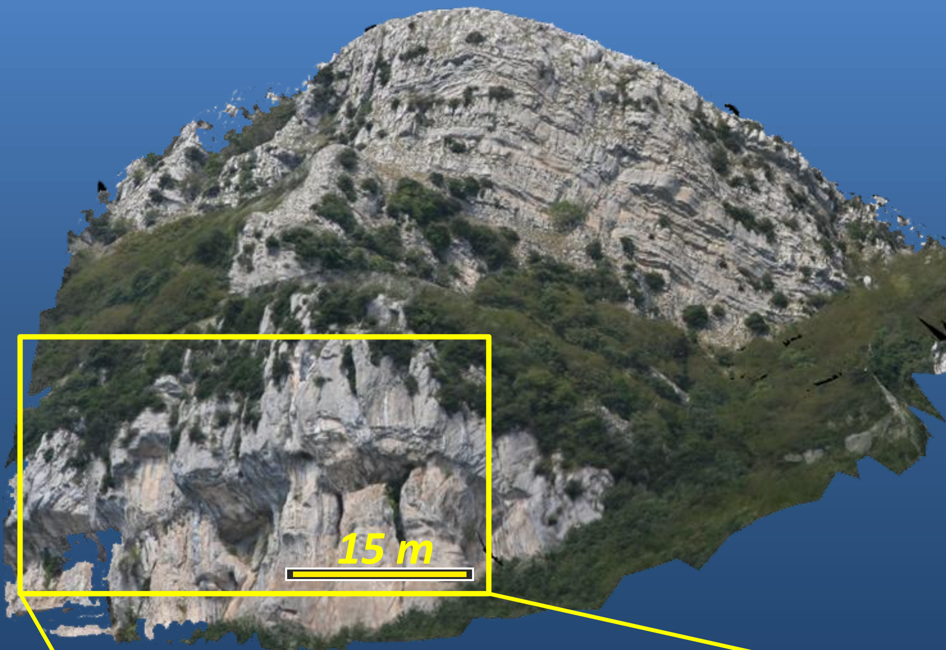


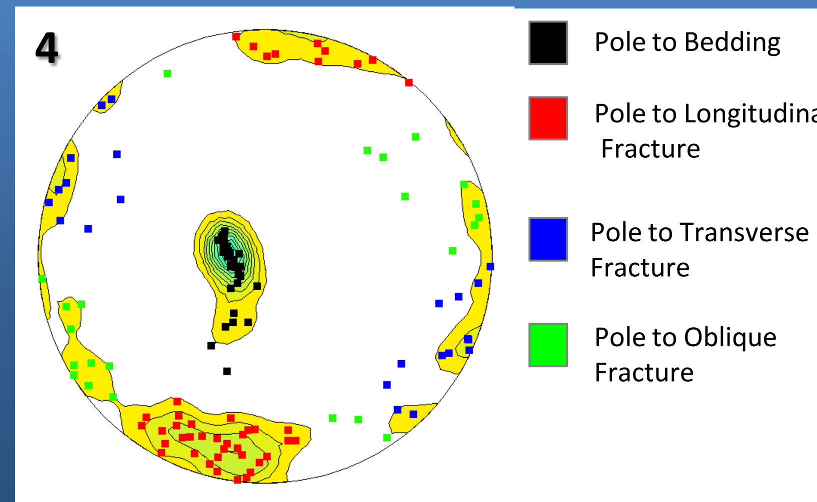
(2) Building the 3D surface

(3) Building the virtual outcrop

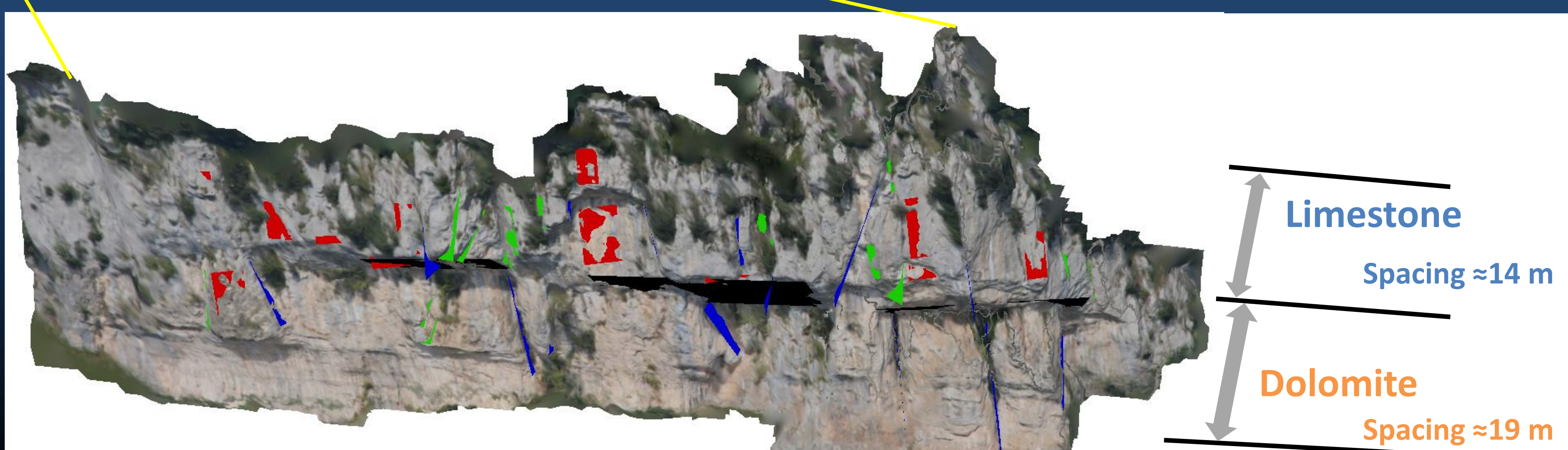
(1) Building the point cloud: photos of the entire ridge, taken from different angle

Reservoir scale fracture analysis





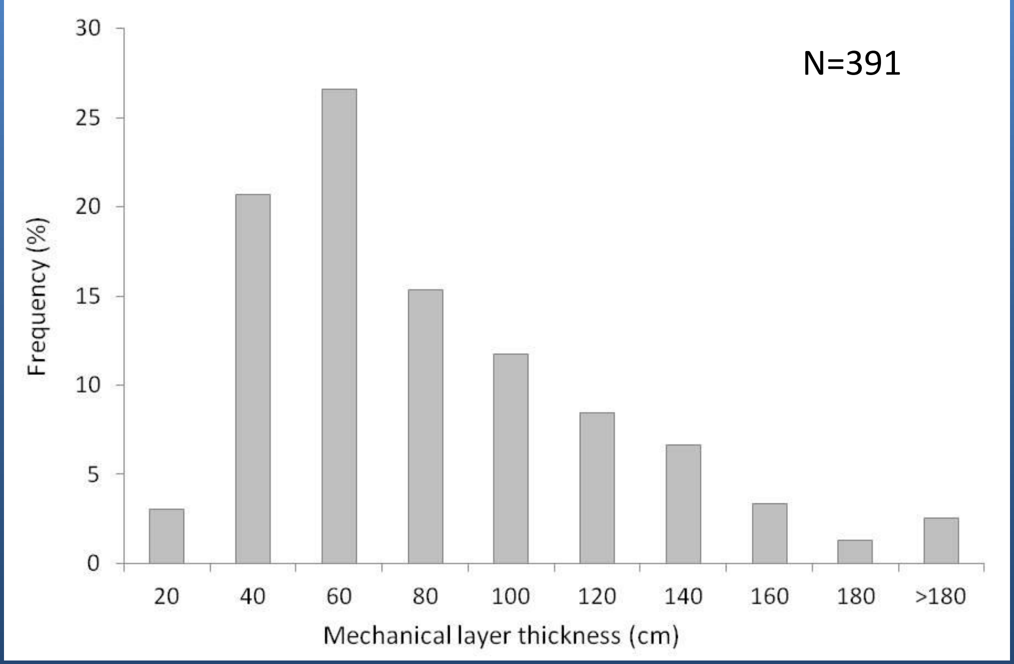
(4) Acquiring structural data using 3D virtual outcrop



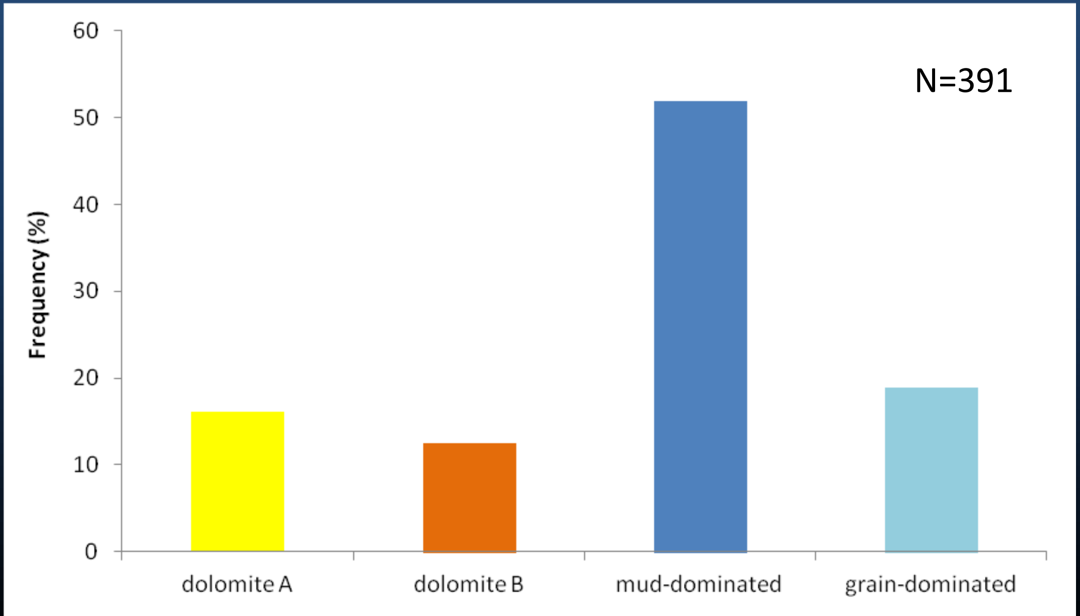
Outcrop scale: mechanical layer log

'BACKGROUND' FRACTURE SETS

Outcrop scale: mechanical layer distribution

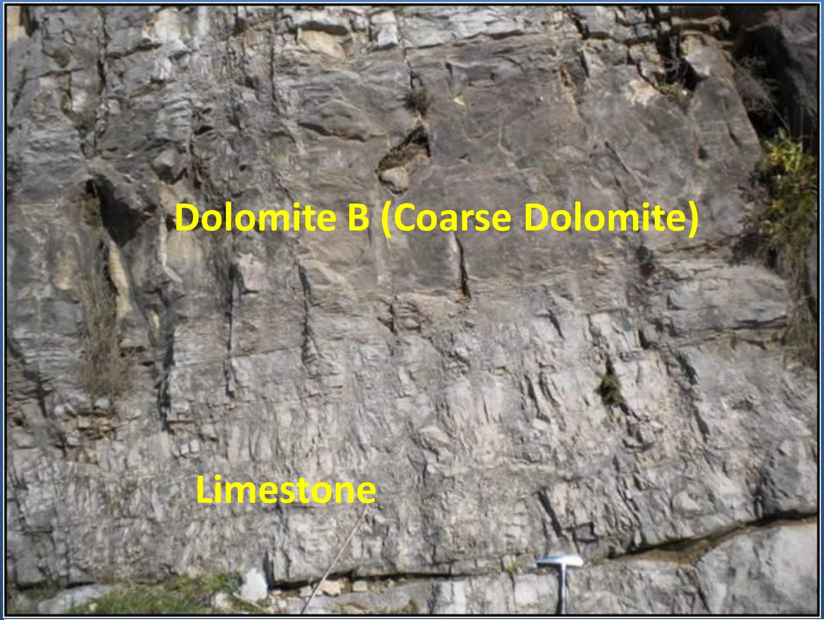


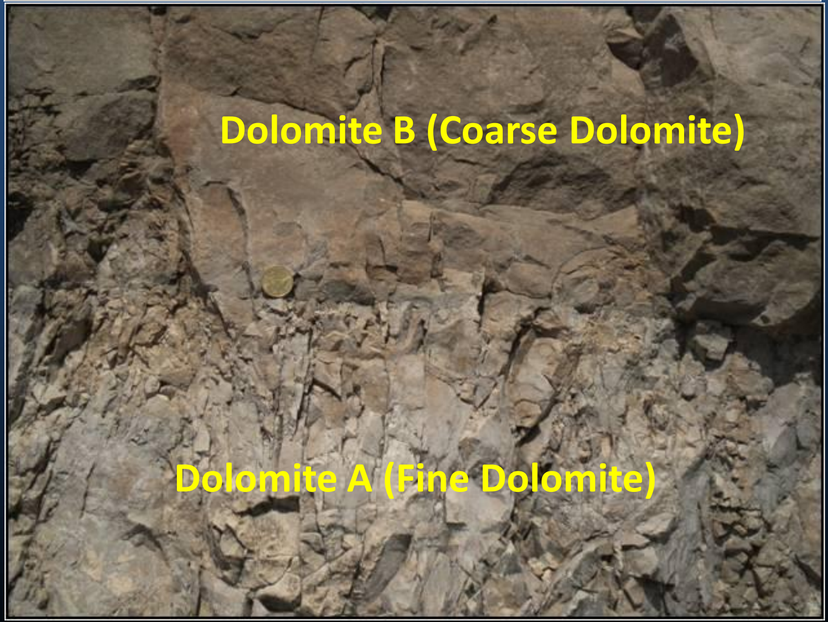
Frequency distribution of mechanical layer thickness (%) in the logged carbonate succession.

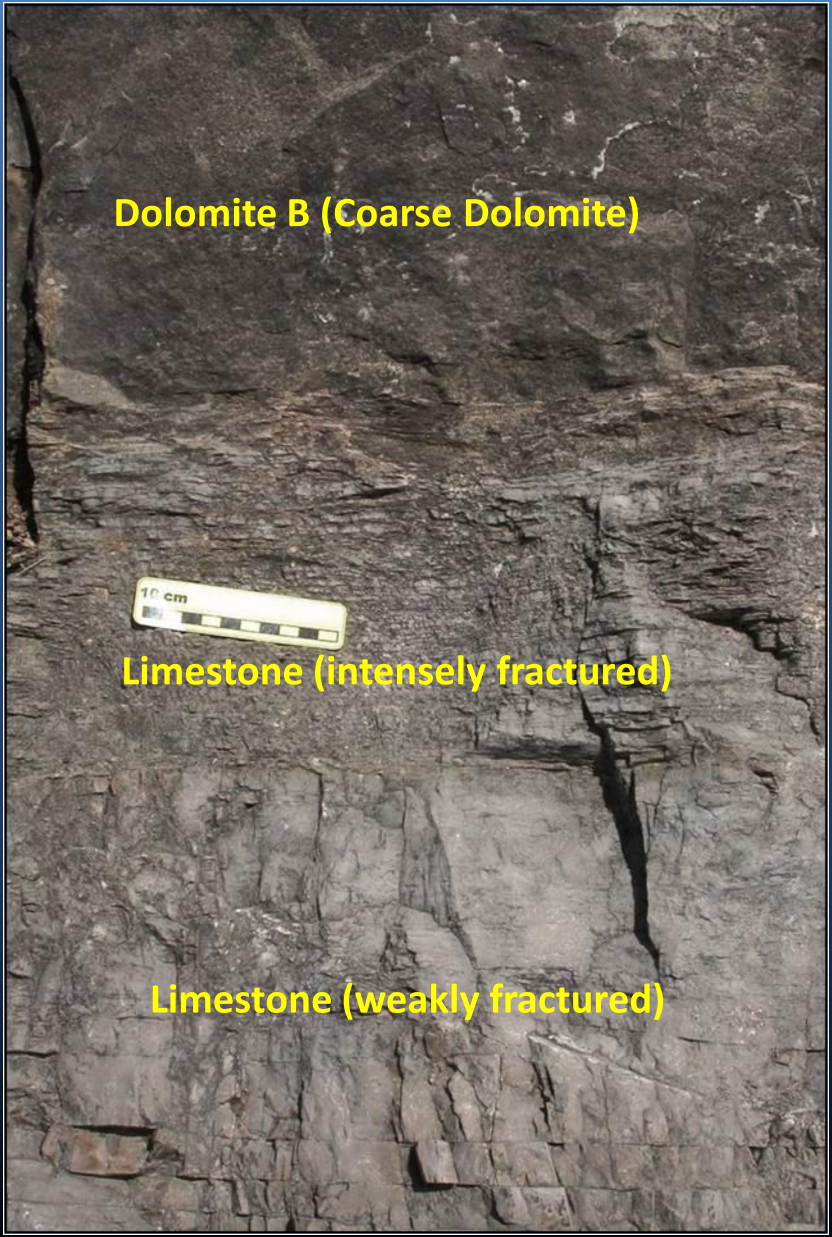


Frequency distribution of different petrofacies (%) in the logged succession.

Fractured carbonates - outcrop scale

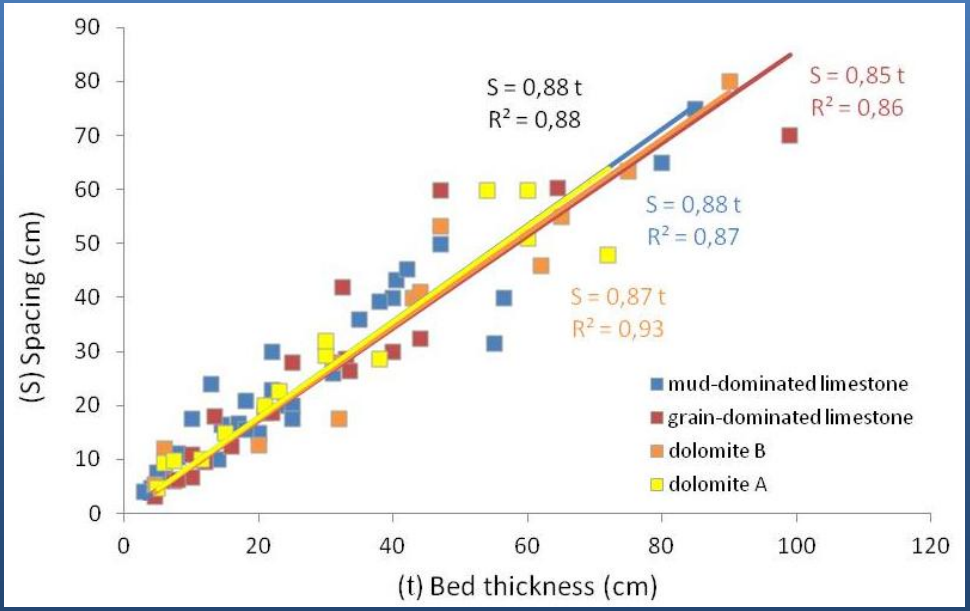




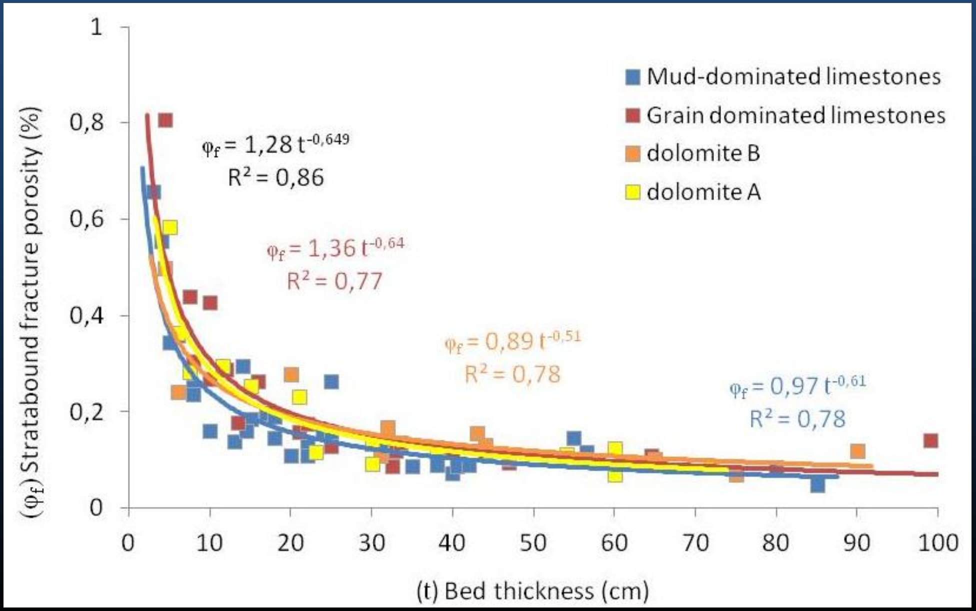


Outcrop-scale fracture analysis

Stratabound fracture network



Fracture spacing vs. Mechanical bed thickness



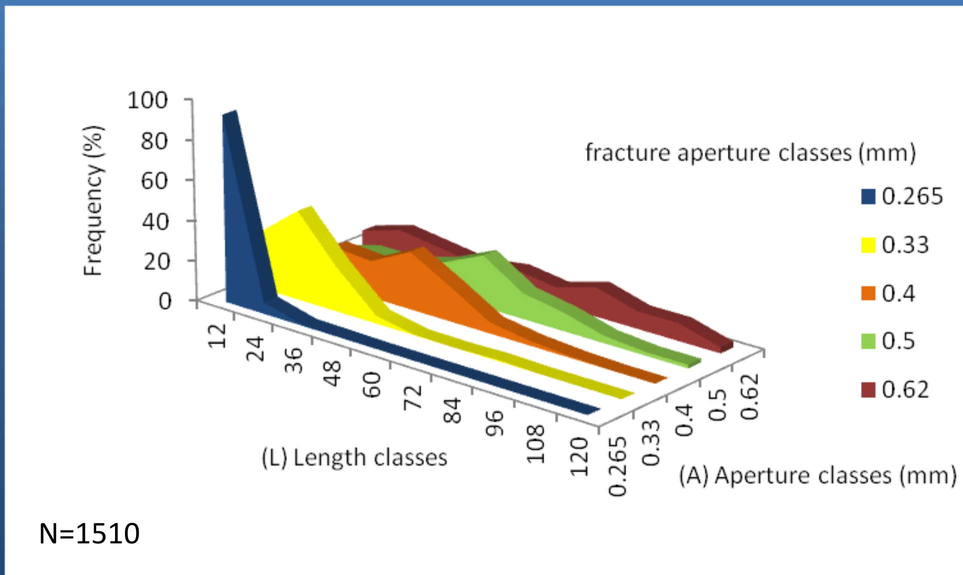
$$\varphi_f = \frac{\Sigma e}{D + \Sigma e} * 100$$

φ_f = fracture porosity (%)
e = fractures aperture
D = sum of spacing between the fractures

(from Nelson, 1985)

Outcrop-scale fracture analysis

Non-stratabound fracture network

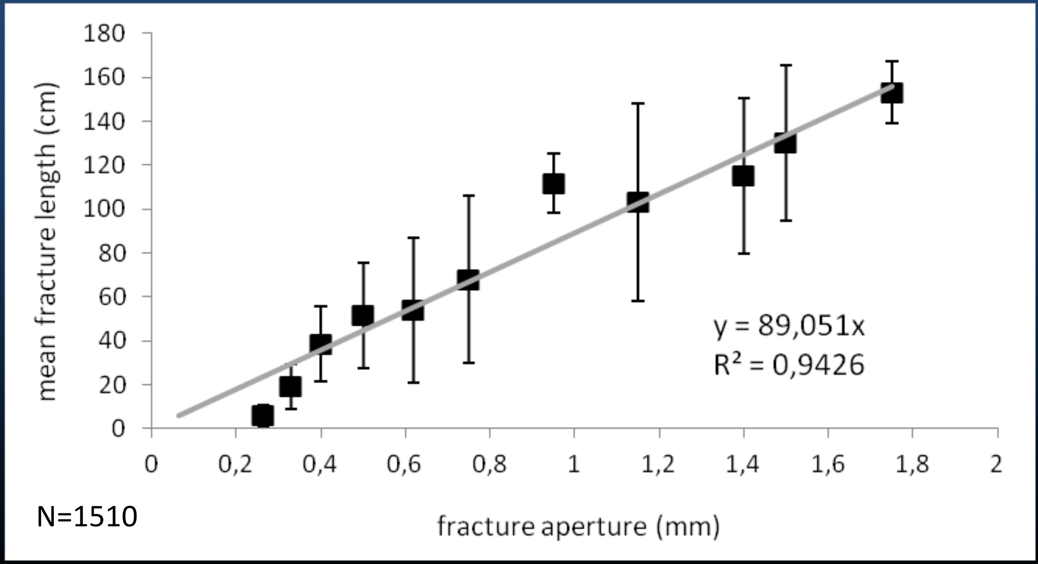


Histogram of fracture length frequency (percent) vs. fracture aperture classes (1510 data).

A linear relationship exists between mean fracture length and fracture aperture.
The linear best-fit that intercepts the origin is:

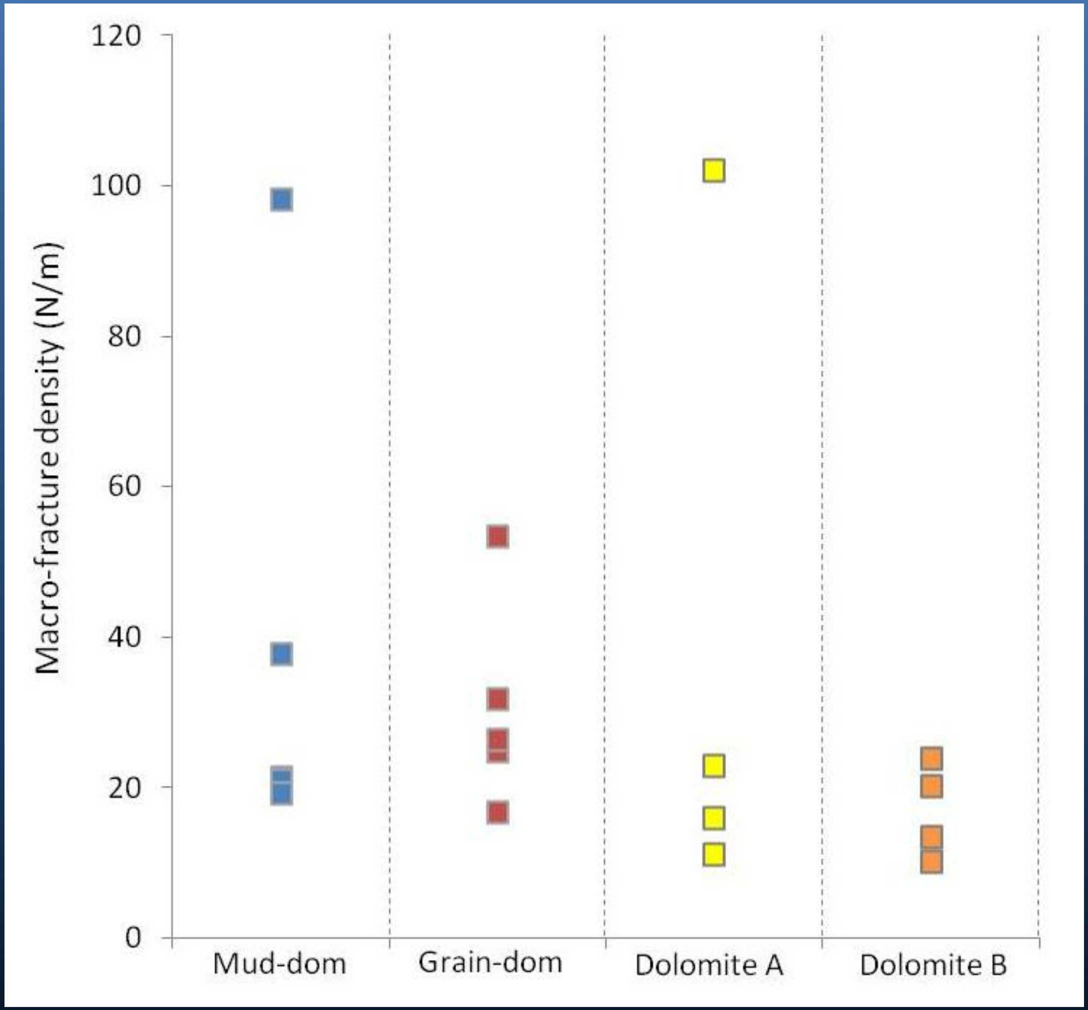
L ≈ 1000A

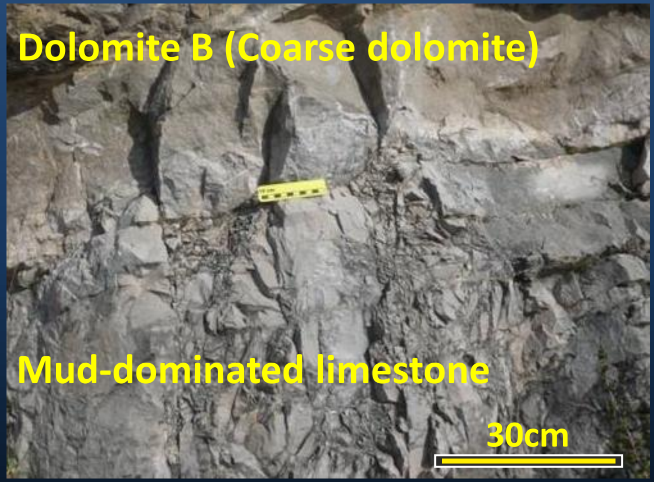
i.e. the aspect ratio is 10^{-3}



Outcrop-scale fracture analysis

Non-stratabound fracture network

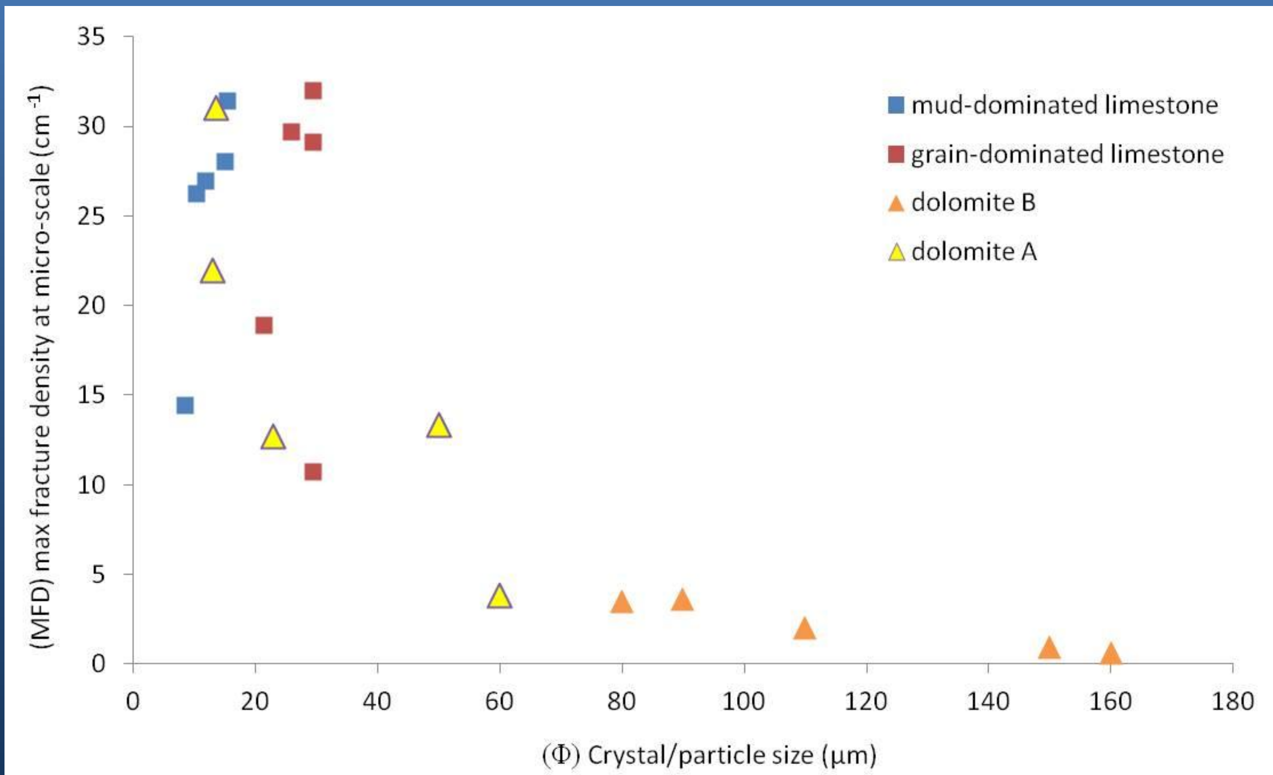




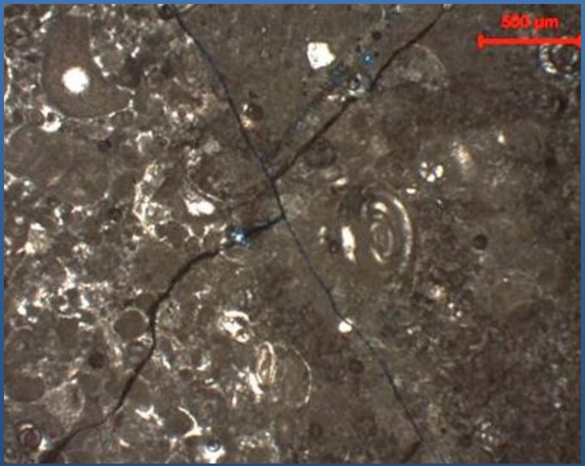
Macrofracture Density vs Texture and Lithology

Micro-scale fracture analysis

Non-stratabound fracture network



Microfracture Density vs Crystal Size (Φ)
(data collected in thin section)

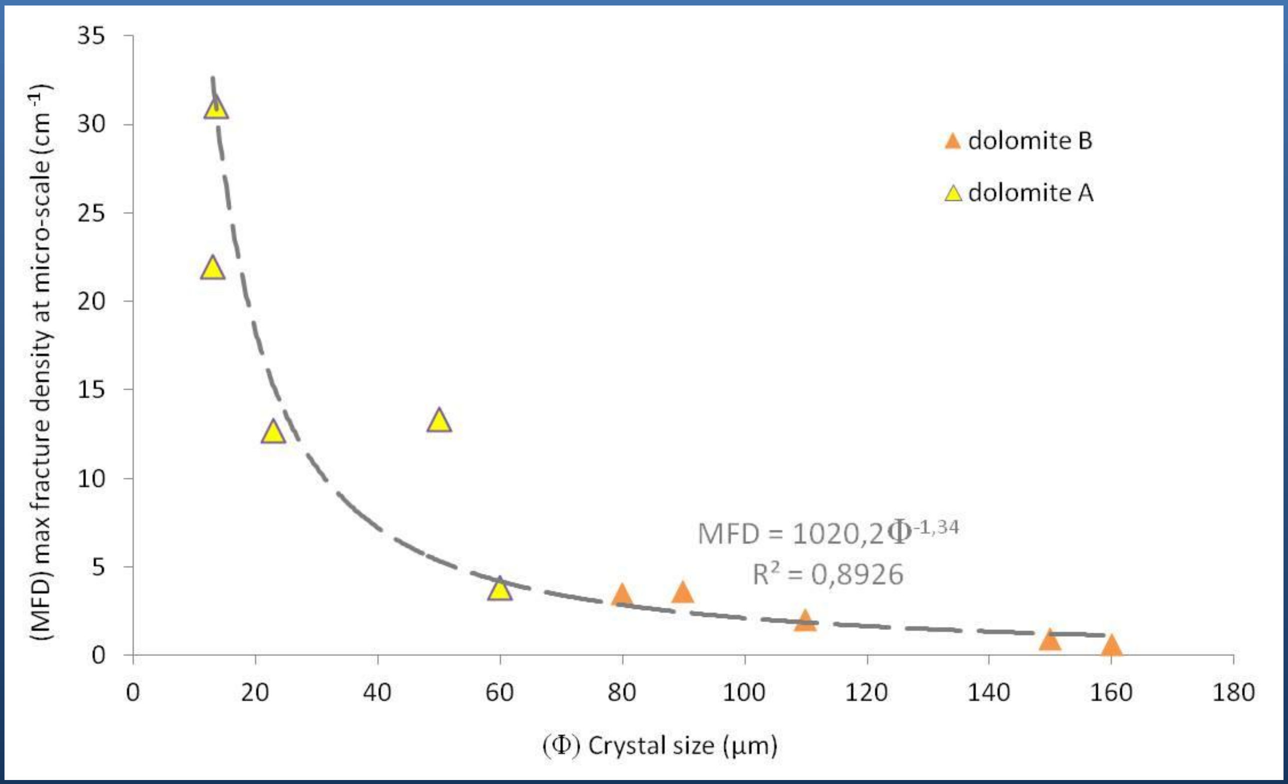


Grain-dominated limestone

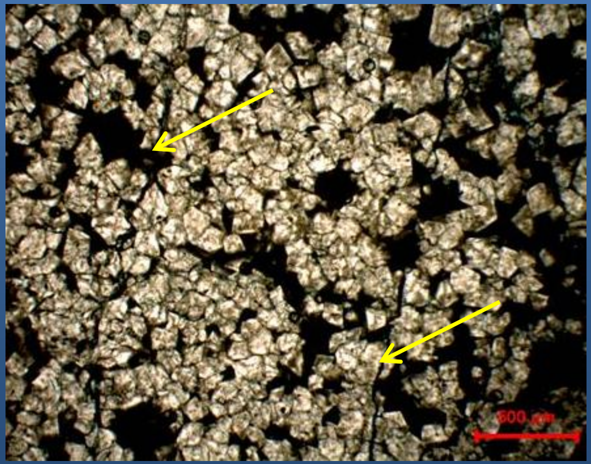
Mud-dominated limestone

Micro-scale fracture analysis

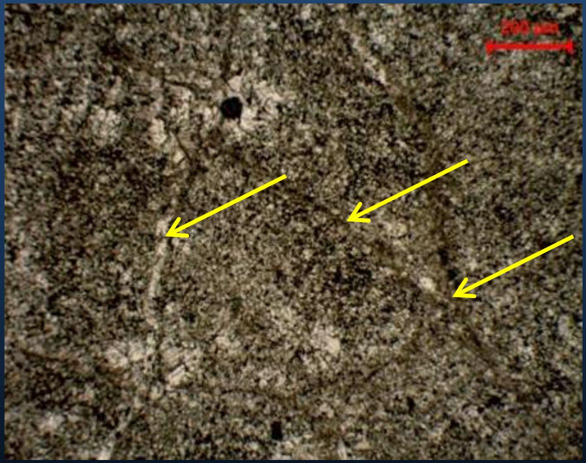
Non-stratabound fracture network in dolomites



Micro-fracture Density vs. Crystal Size (Φ)
(data collected in thin section)



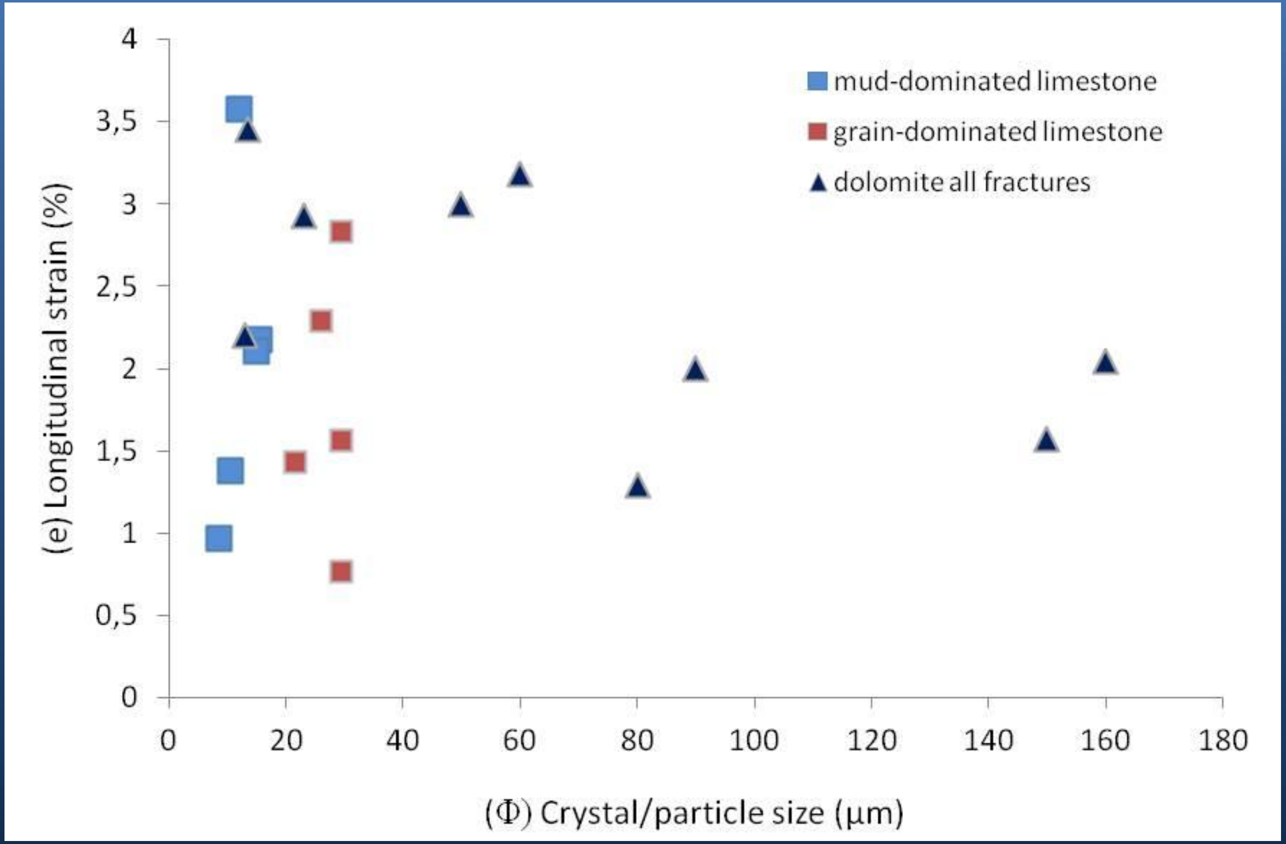
Dolomite B Φ = 110 µm

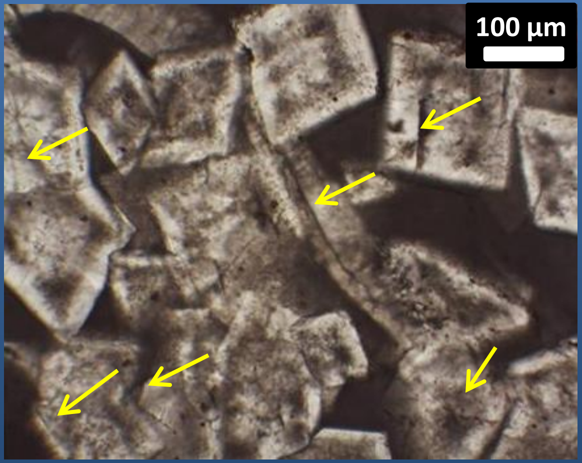


Dolomite A Φ = 13 µm

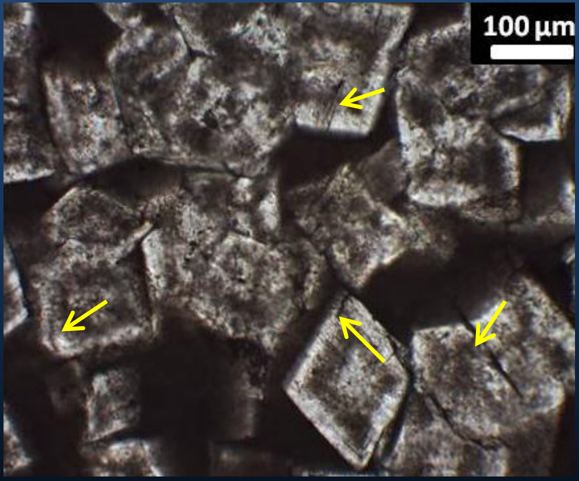
Micro-scale fracture analysis

Non-stratabound fracture network





Dolomite B Φ= 150 µm



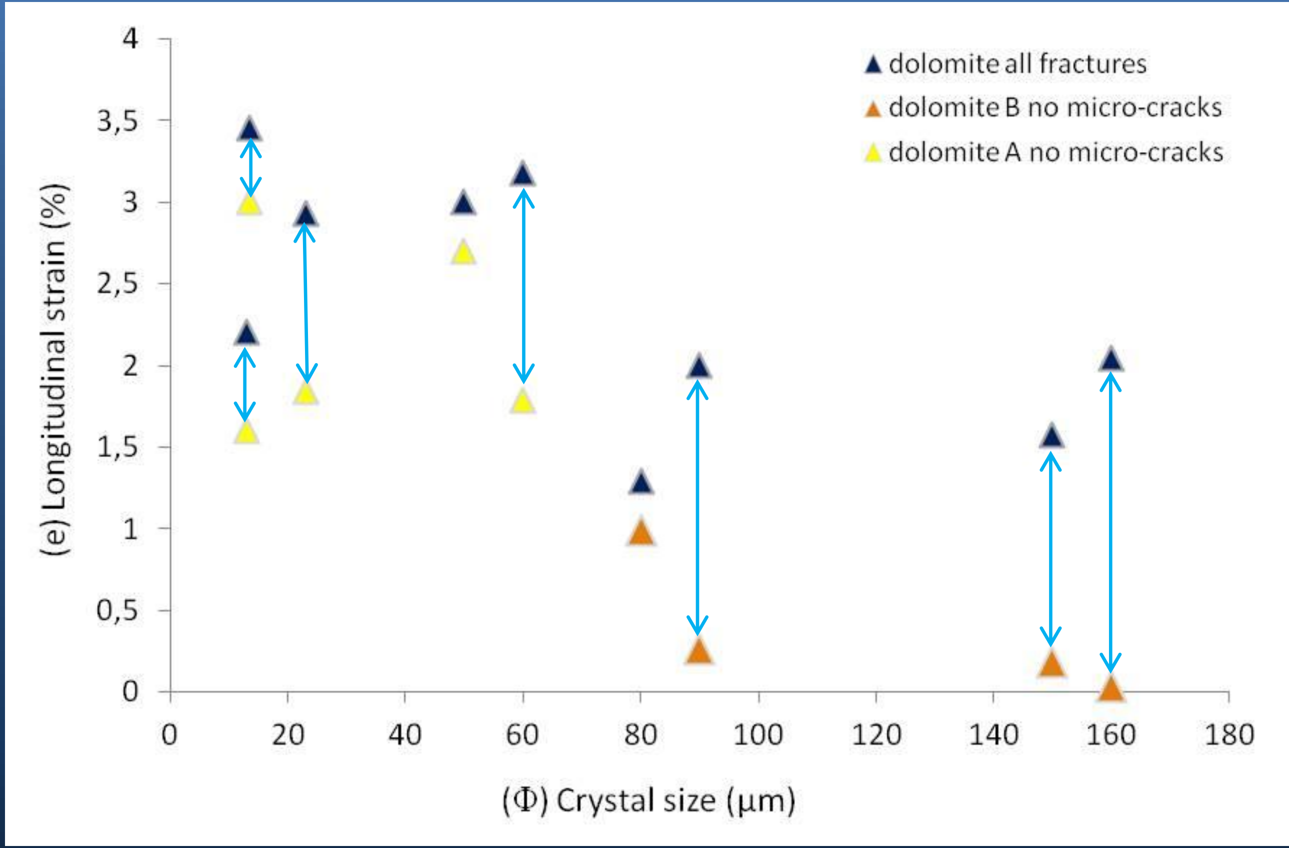
Dolomite B Φ= 160 µm

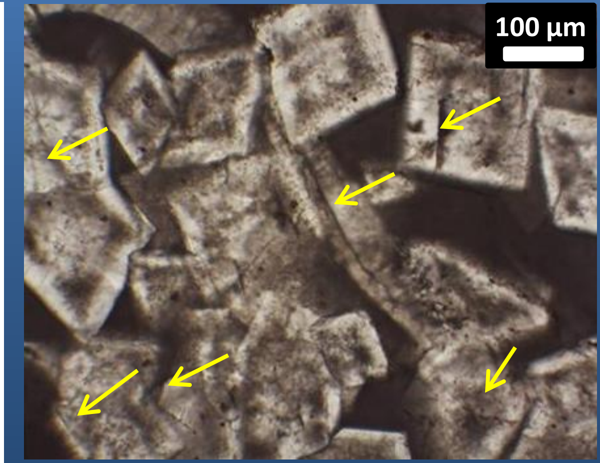
Longitudinal strain (%)= $\frac{\Sigma e}{D} * 100$

e= fractures aperture
D= sum of spacing between the fractures

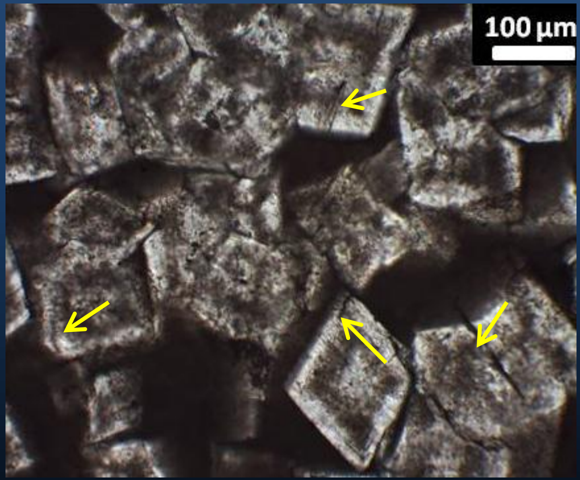
Micro-scale fracture analysis

Non-stratabound fracture network





Dolomite B Φ= 150 μm



Dolomite B Φ= 160 μm

Longitudinal strain (%)= $\frac{\Sigma e}{D} * 100$

e= fractures aperture
D= sum of spacing between the fractures

Conclusions

1. Stratabound fracture distribution and associated porosity are strongly dependent on mechanical bed thickness (outcrop-scale analysis).

2. At the reservoir- and outcrop-scale, textural and lithological properties do not play a significant role on non-stratabound fracture distribution.

3. At the micro-scale, non-stratabound fracture density is mainly controlled by crystal size. This dependency, described by a power law, was verified also for the dolomites representing the most productive interval of Tempa Rossa reservoir.

4. In dolomites, the role of crystal size largely overcomes that of lithology in controlling micro-scale rock strain.

5. Crystal size can be considered as the main parameter controlling fracture distribution at the micro-scale and therefore influencing significantly the hydraulic behavior of non-stratabound fracture systems.

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