Dolomite Outcrop Analogues as a Key to Understand the Development of Super-K Layers in a Giant Carbonate Reservoir (Upper Khuff Formation, Middle-East)*

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Abstract

The Permo-Triassic Upper Khuff Formation hosts a giant carbonate reservoir well known almost all over the Middle-East. The reservoir corresponds to a several hundred meters thick alternation of limestone, dolomite, and anhydrite bodies. Super-K layers have been identified within the reservoir by production logging tool pikes and matrix permeability over 1000 mD. These highly permeable intervals are made of several-m thick and several-km in length dolomite bodies.

Because Super-K layers represent fluid flow heterogeneities below the seismic resolution, outcrop analogues have been used to better understand the processes responsible for the development of dolomite bodies on extended area. The Upper Jurassic carbonate platform of SE France allows observing and studying at the best, different types of dolomite bodies, fault-related or associated to stratigraphic surfaces.

The objectives of this work focuses on:

- the stratigraphic architectures of carbonate outcrops and subsurface reservoirs;
- the relationships between the sedimentary processes and dolomite bodies development in the carbonate outcrops and subsurface reservoir;
- the origin, geometry, and development of Super-K layers in the subsurface reservoirs.

Results of this study show that most of the highly porous/permeable bodies are found below major emersion surfaces. Emersions and linked meteoric dissolution were responsible for secondary porosity creation (vuggy and moldic). Then, subsequent brines reflux during the deposition of inner shelf facies above emersion surfaces, has created dolomitisation front resulting in highly porous/permeable bodies.

Super-K layers are developed within the dolomite bodies during burial, due to the dissolution of residual anhydrite or calcite. Such mesogenetic dissolution was probably related to the genesis of humic acid during or just before hydrocarbon filling and is considered as the final step for the stratabound Super-K development.

Saddle dolomite is locally found within a Super-K layer located in a well close to a major basement-rooted fault. Zebras and exotic minerals associated to the saddle dolomite argue for fluid deriving from the basement. As a late burial event, saddle dolomite invaded and partly cemented the Super-K layer. To conclude, Super-K layers in the Upper Khuff Formation result from the combination of shallow burial (meteoric dissolution and reflux dolomitisation) and deep burial (sulfate/calcite dissolution) diagenesis.

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DOLOMITE OUTCROP ANALOGUES AS A KEY TO UNDERSTAND THE DEVELOPMENT OF SUPER-K LAYERS IN A GIANT CARBONATE RESERVOIR (UPPER KHUFF FORMATION, MIDDLE-EAST)

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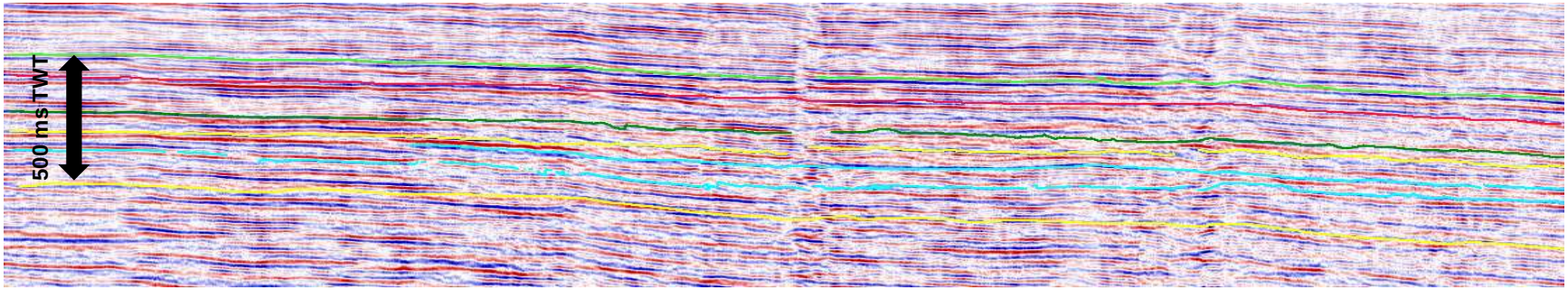
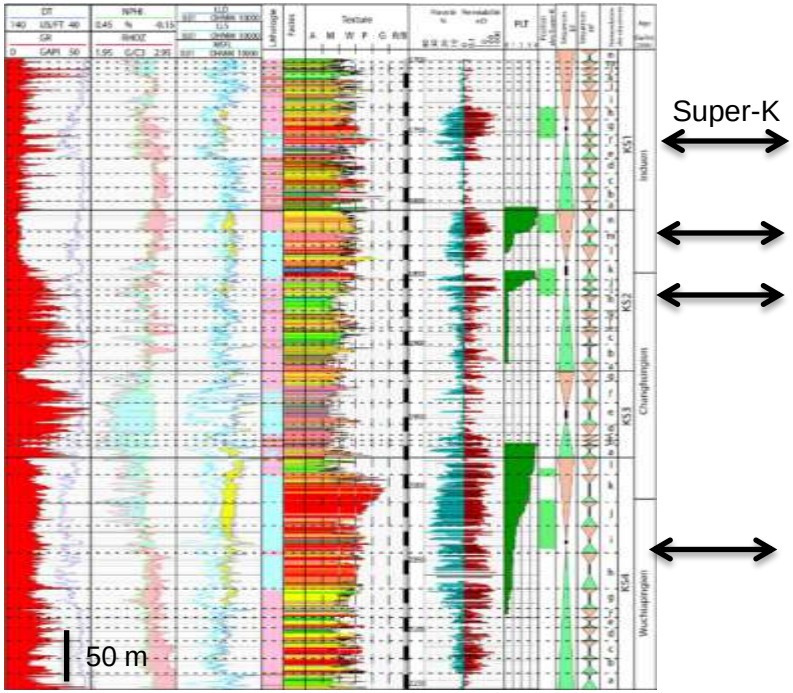
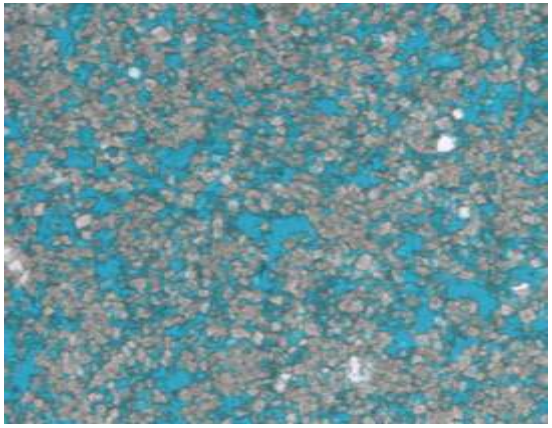
PROBLEM STATEMENT

- **CAN WE PREDICT SUPER-K LAYERS IN THE UPPER KHUFF FM. ?**





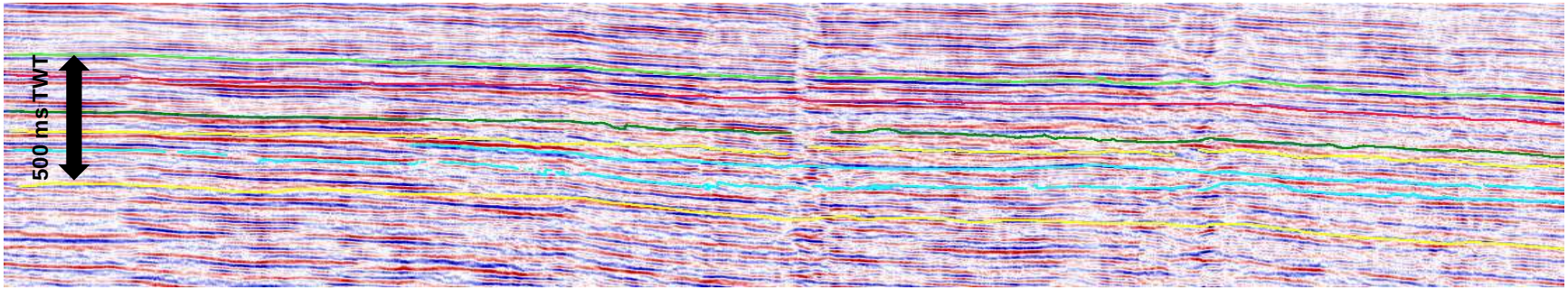
- **Given low seismic resolution?**
- **Without dynamic data ?**

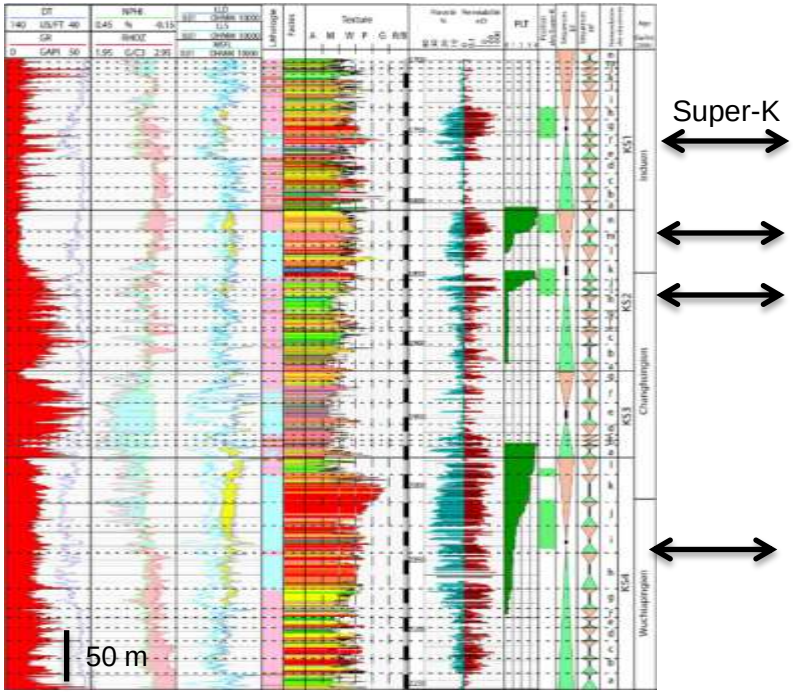


φ= 25 %
K= 2396mD
d=2.85 g/cm^3

PROBLEM STATEMENT

- **CAN WE PREDICT SUPER-K LAYERS IN THE UPPER KHUFF FM. ?**



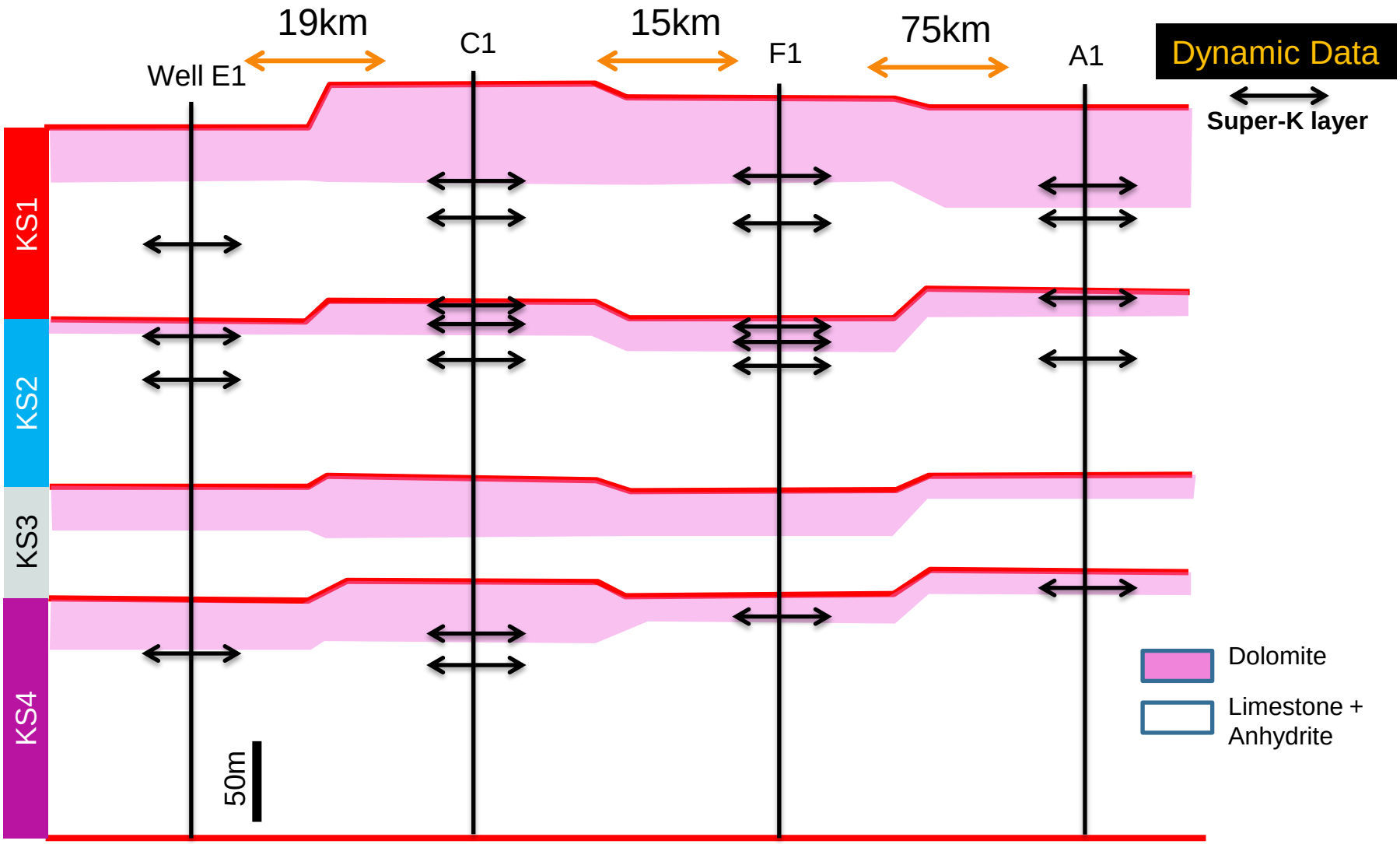


- **Given low seismic resolution?**
- **Without dynamic data ?**

- **Super-K layers:**
  - **Origin** (sedimentary and diagenetic) **?**
  - **Geometry ?**
  - **Stratigraphic architecture ?**
  - **Properties ?**

STRATIGRAPHIC CORRELATION OF SUPER-K LAYERS

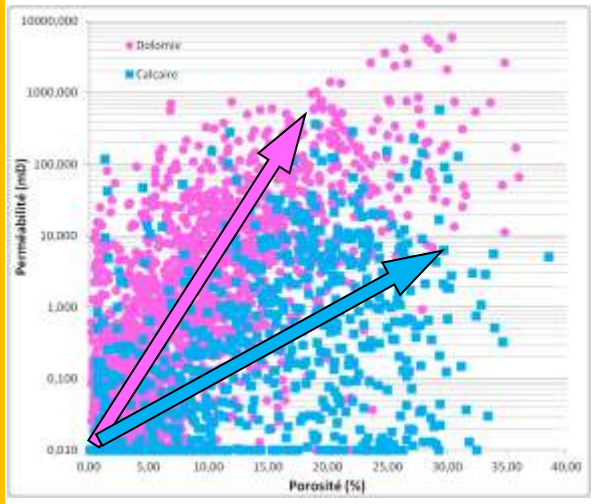
- **Relation to diagenetic dolomite bodies?**



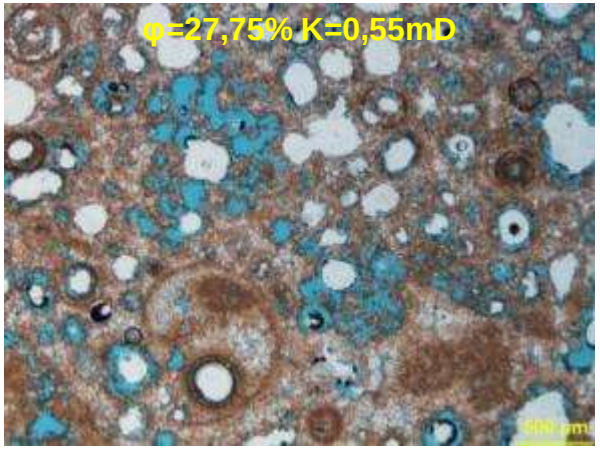
SUPER-K PERMEABILITY LAYERS
ROCK FABRICS AND PETROPHYSICS

Well data

Super-K are frequently **dolomite-supported** in subsurface reservoirs:

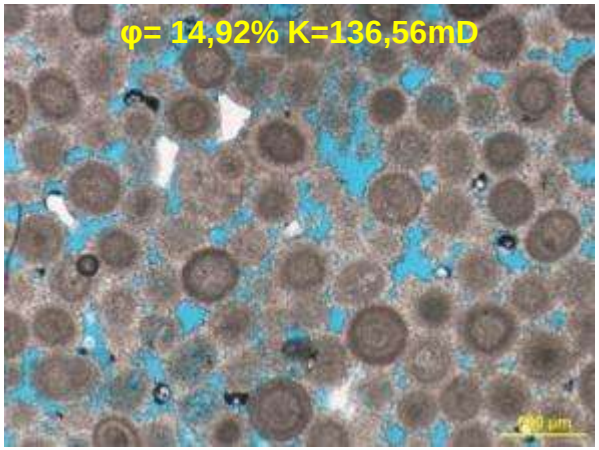


Moldic



LIMESTONE

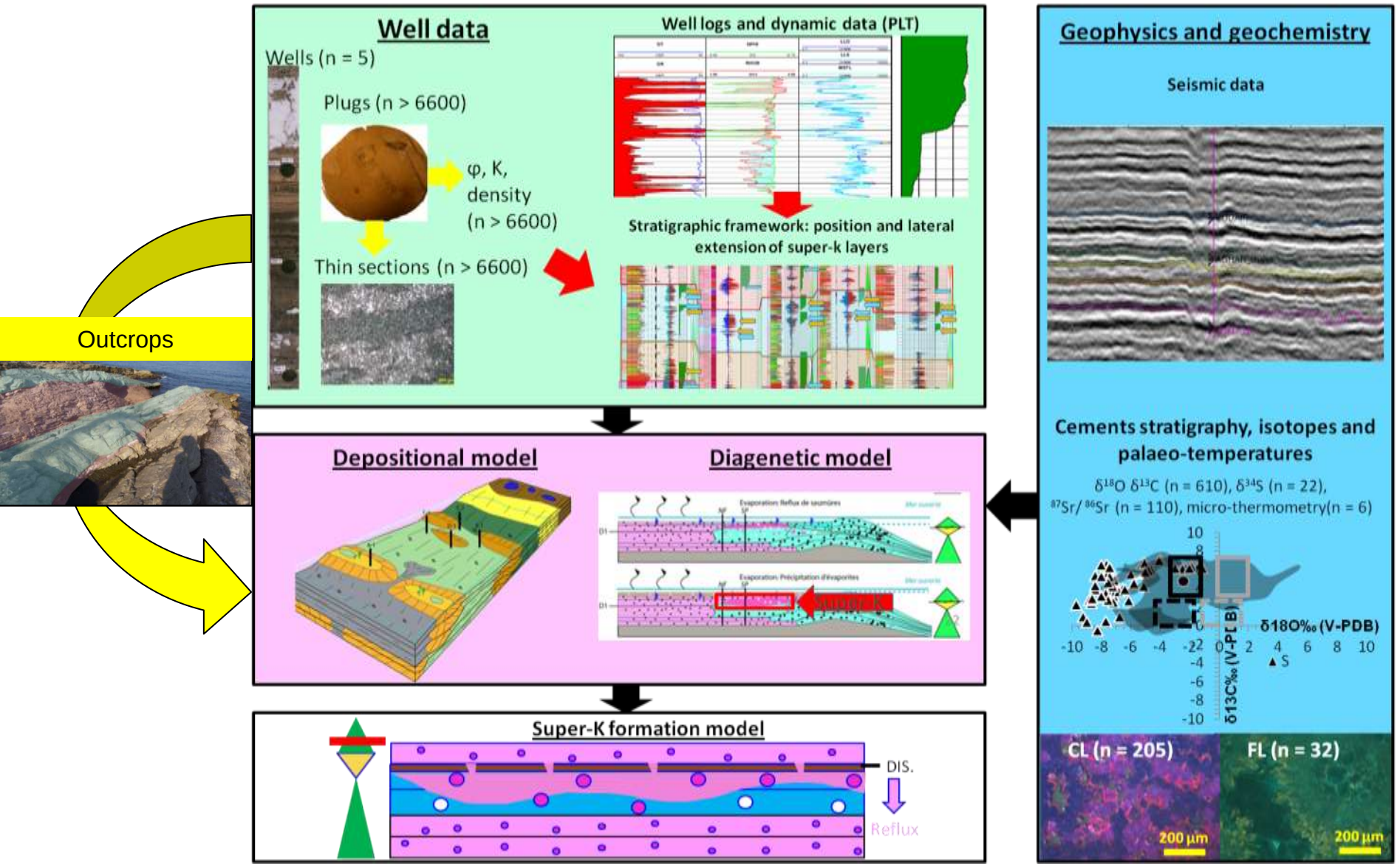
Intergranular/Intercristalline



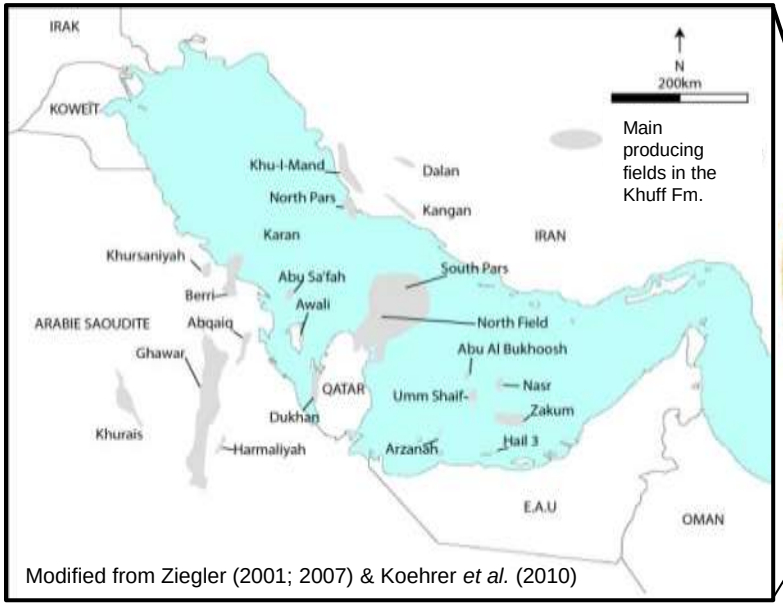
DOLOMITE

Importance of the prediction of dolomite bodies ?

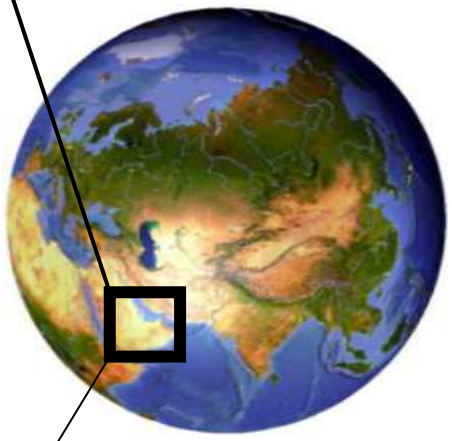
STUDY WORKFLOW



CASE STUDY: THE KHUFF FORMATION

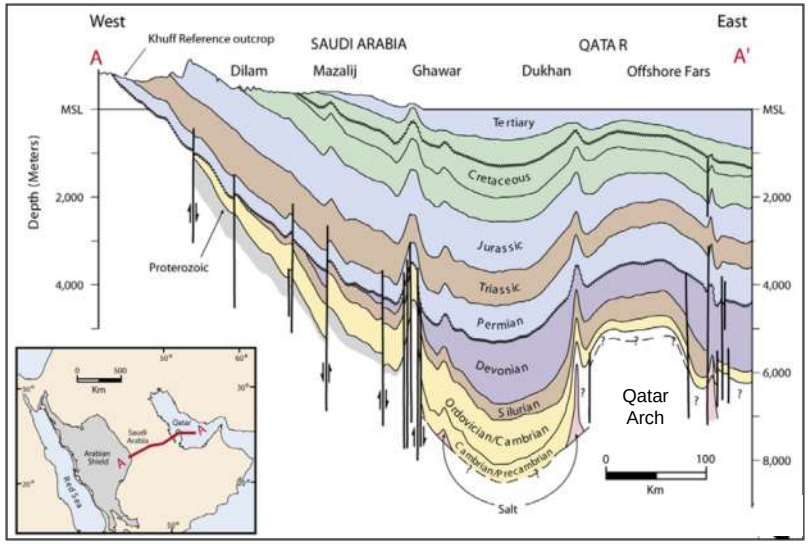


Modified from Ziegler (2001; 2007) & Koehrer *et al.* (2010)



The biggest gas field in the world

- 13 % of proven gas reserves (1250 tcf) (IEA, 2010)
- Discovered in 1971 with planned exploitation till ~2120



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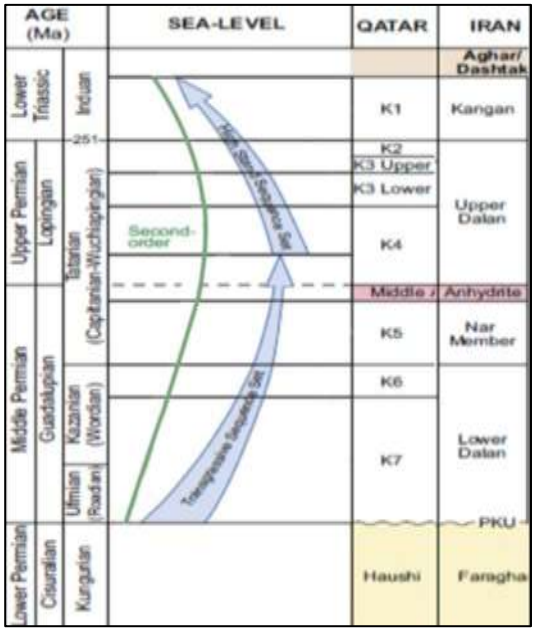


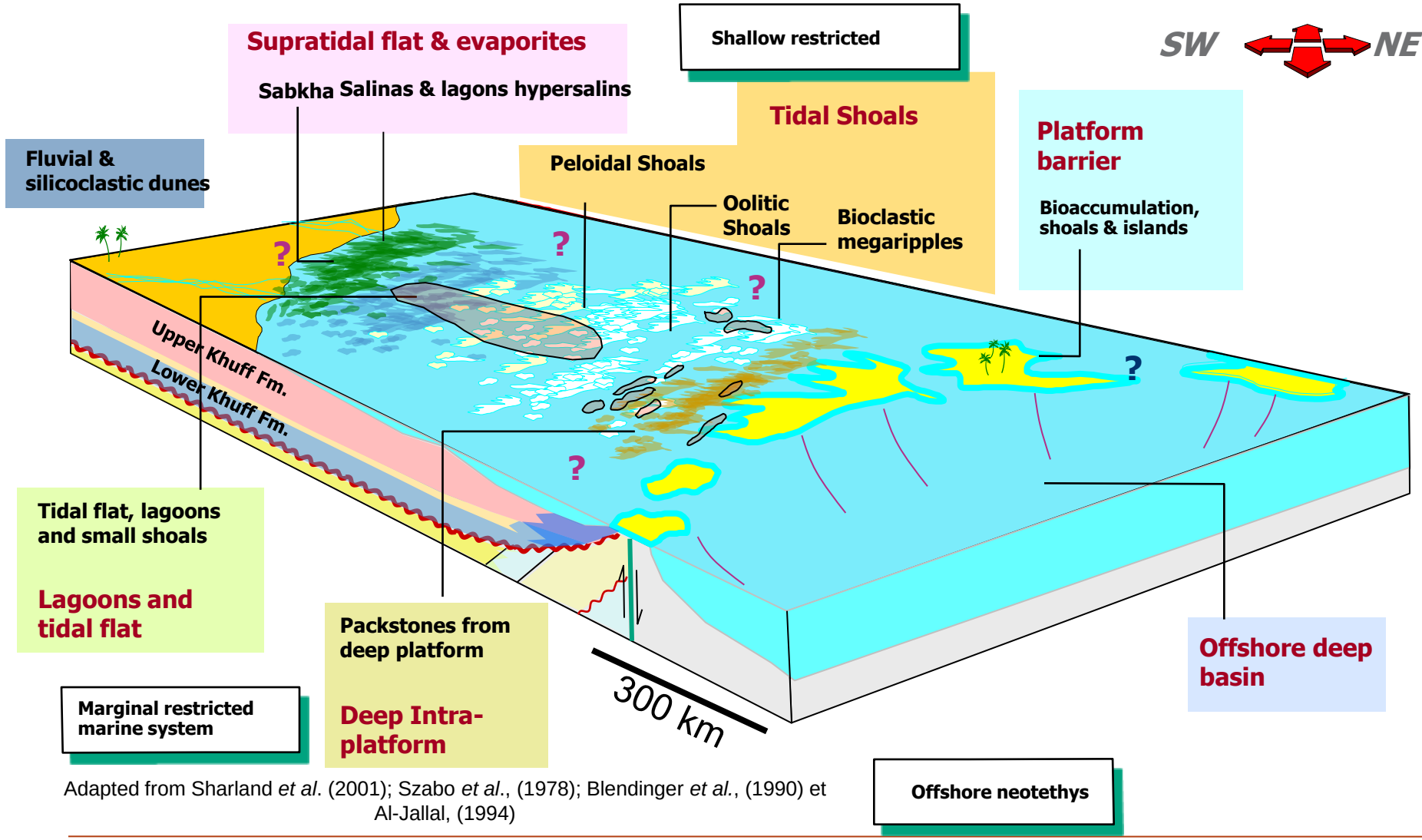
Modified from Alsharhan (2006)

Upper part of the Khuff Fm. : 4 reservoir units (K1 to K4)

Regressive hemicycle of the 2nd order sequence

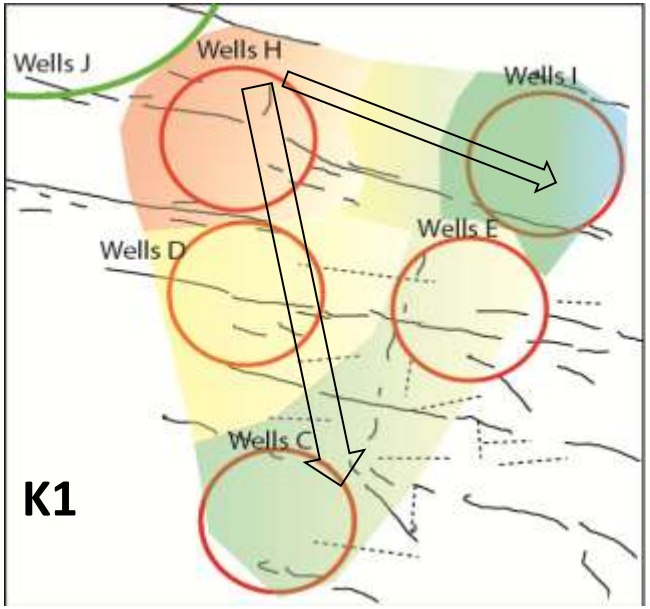
This study

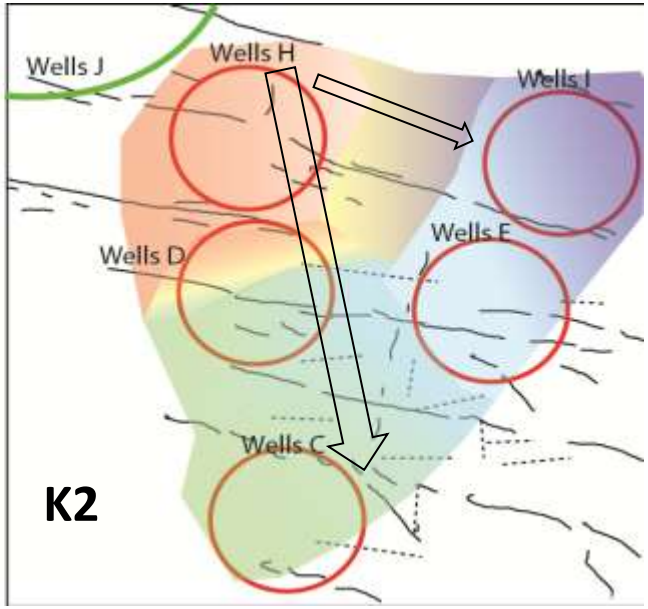
PALAEOENVIRONMENTS: WIDE PLATFORM WITH A MOSAIC OF CARBONATE FACIES

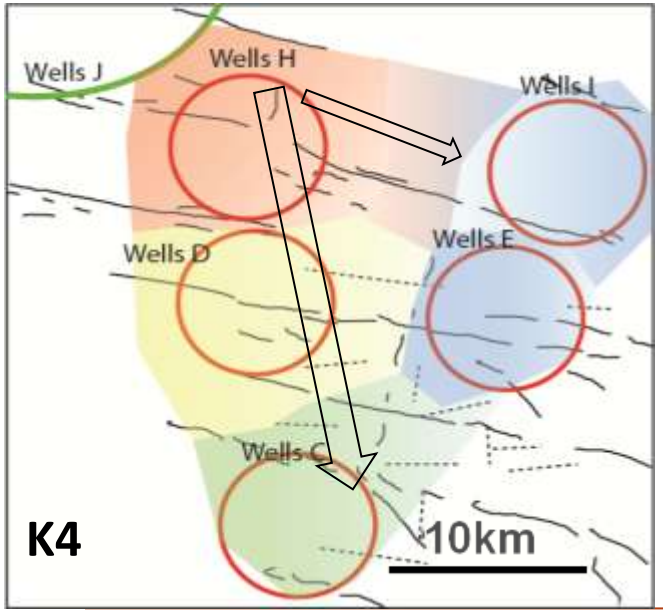


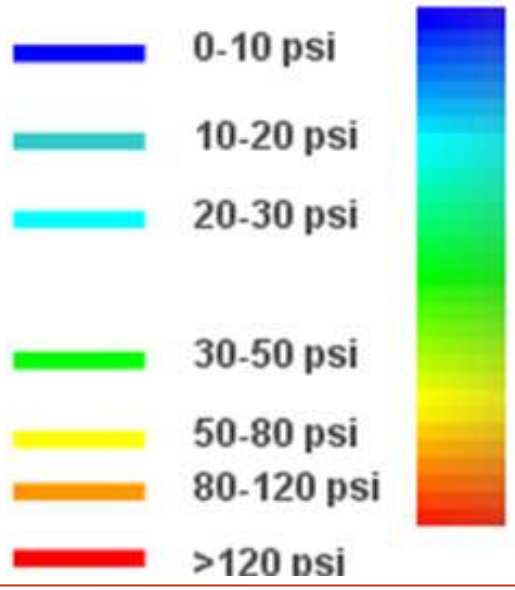
Adapted from Sharland *et al*. (2001); Szabo *et al*., (1978); Blendinger *et al.*, (1990) et Al-Jallal, (1994)

SUPER-K DRAINS IDENTIFICATION: PRESSURE TESTS









Wells J are producers

Wells H, D, C, E, I are observers

+ Depletion trend -

Identified fault

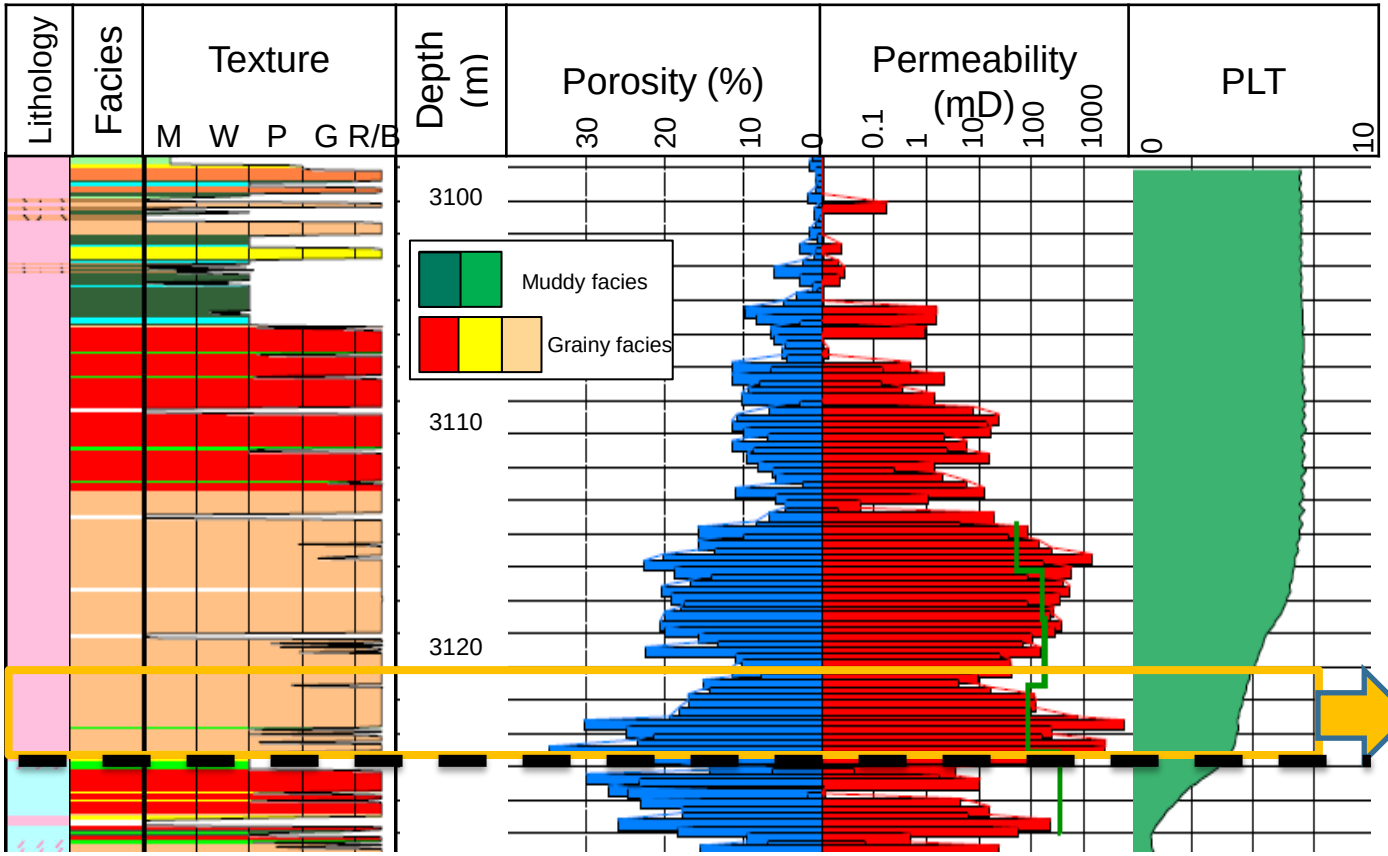
Supposed fault

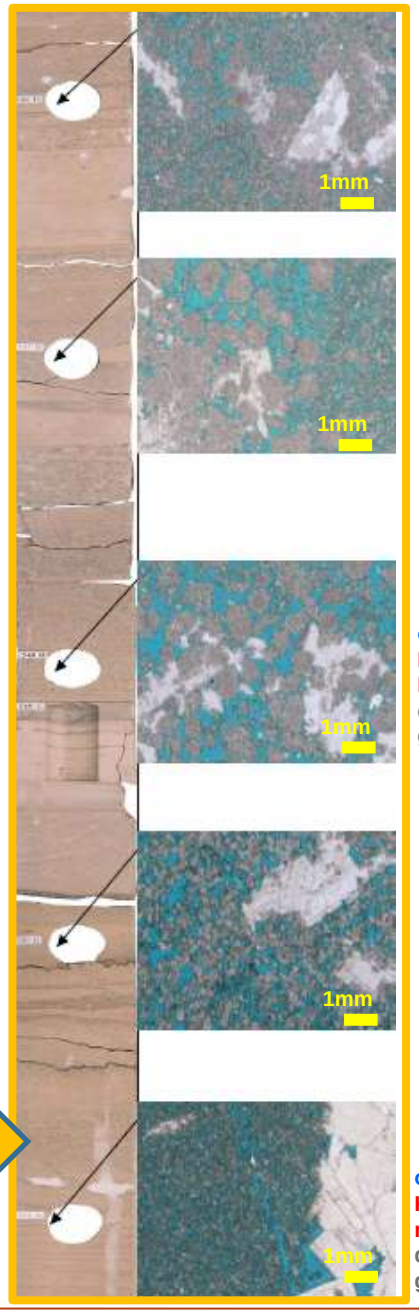
Connection over dozen of kilometers and not fully related to faults orientation: sedimentary-diagenetic control ?

SUPER-K DRAINS IDENTIFICATION: SEDIMENTARY FACIES AND PETROPHYSICAL PROPERTIES

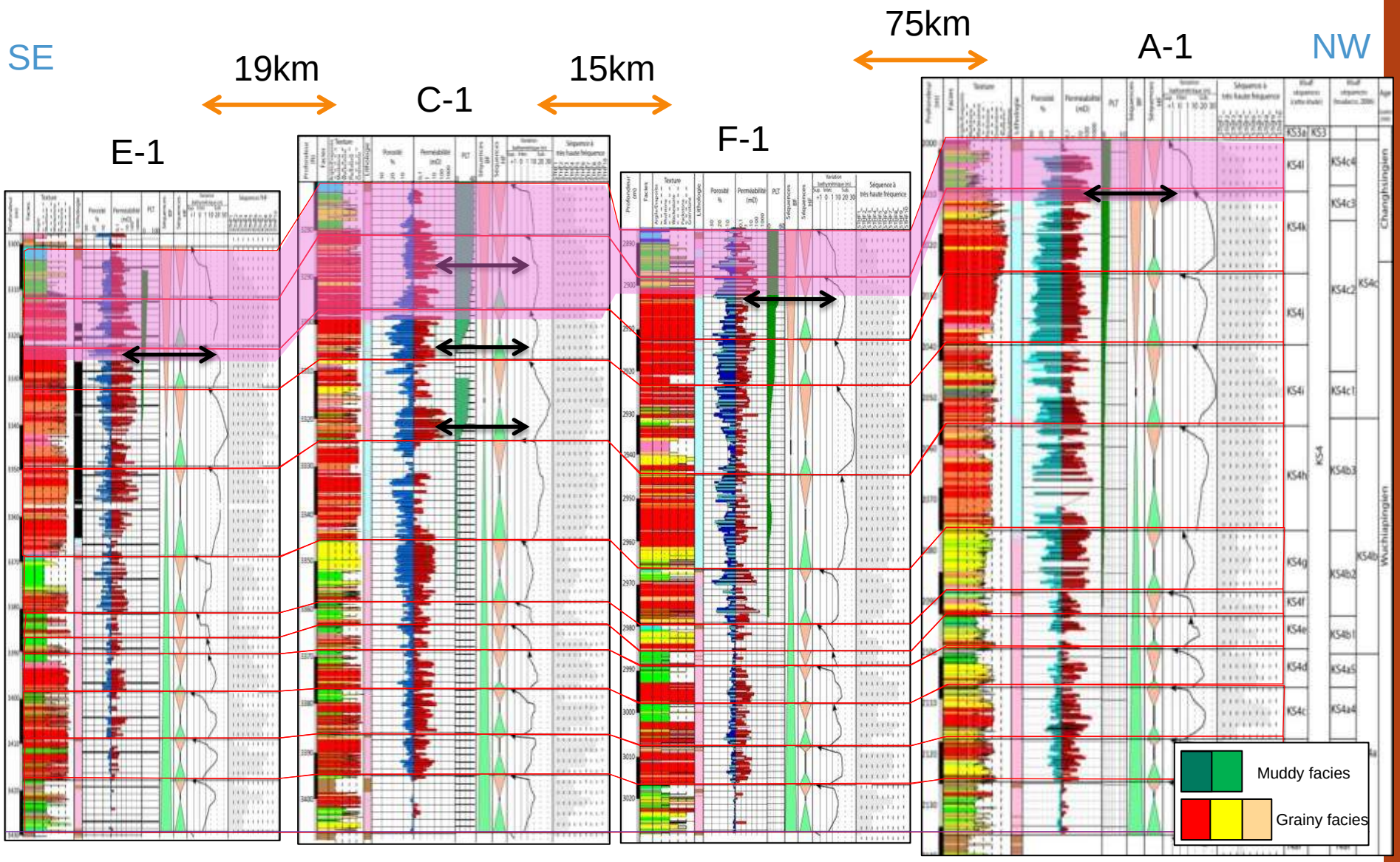
- Grain-supported and dolomitic
- Limestone-dolomite transition

- Stratigraphic correlation ? Diagenesis ?

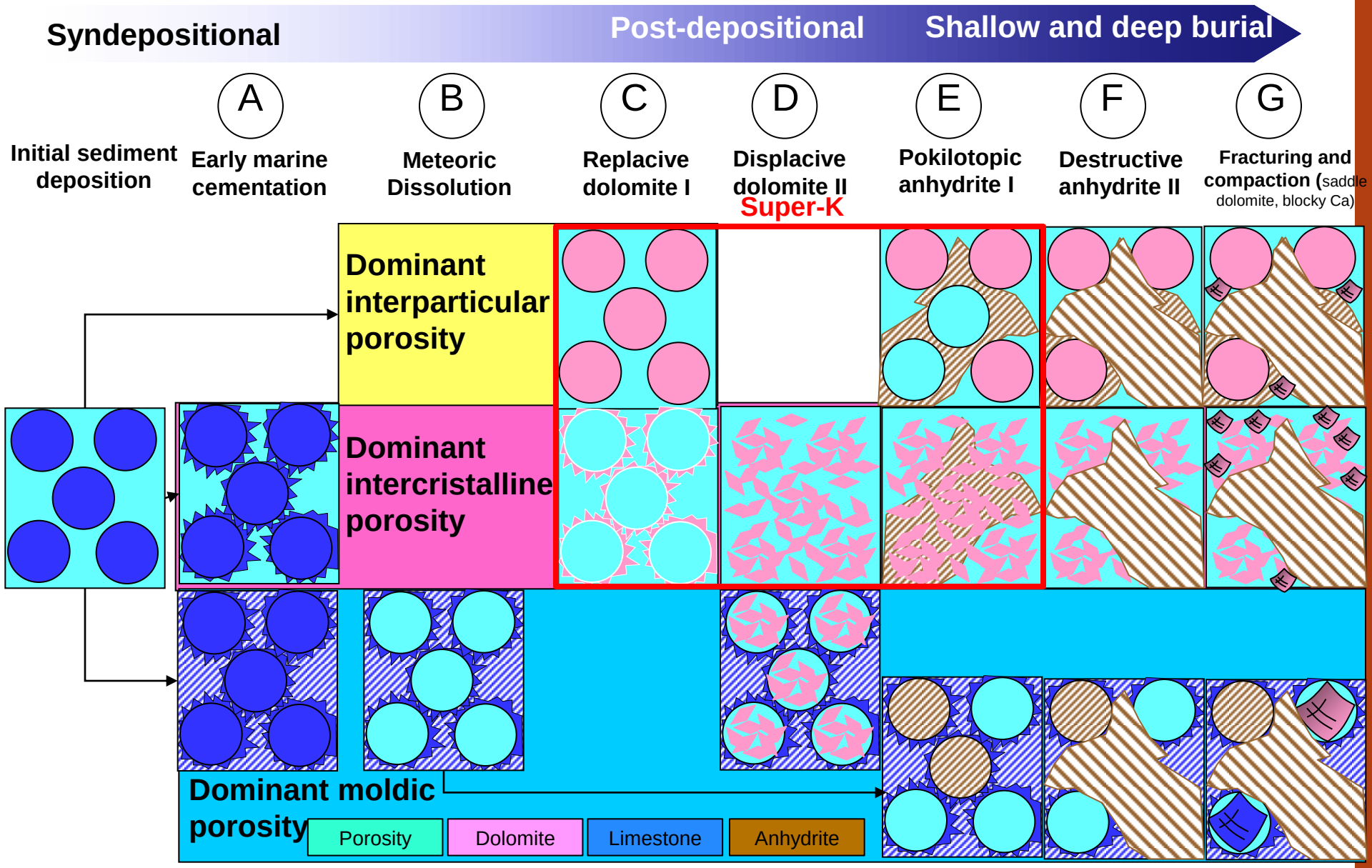




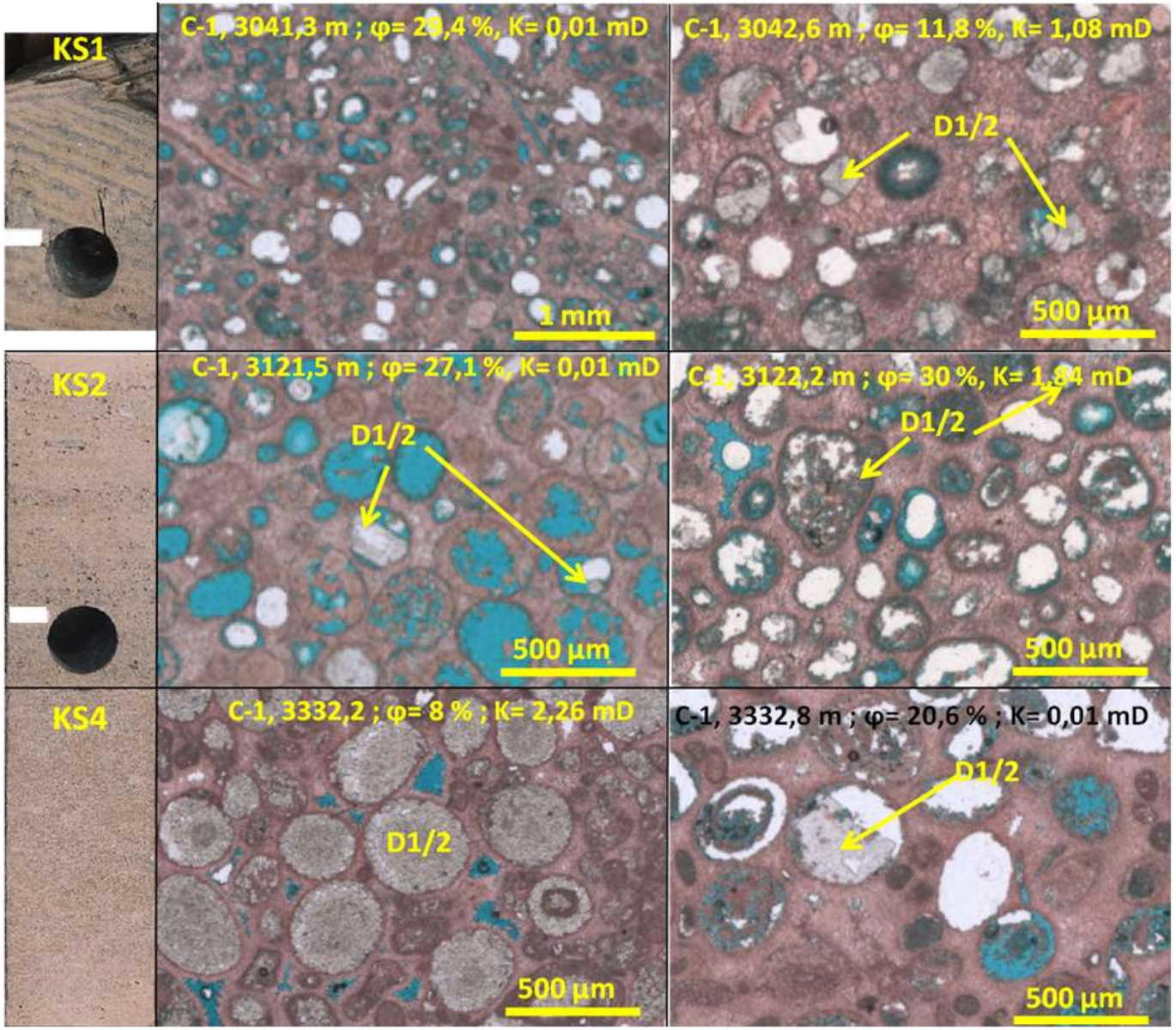
CORRELATION : SUPER-K LOCATION IN KS4



1 FACIES FOR 3 DIAGENETIC PATHWAYS



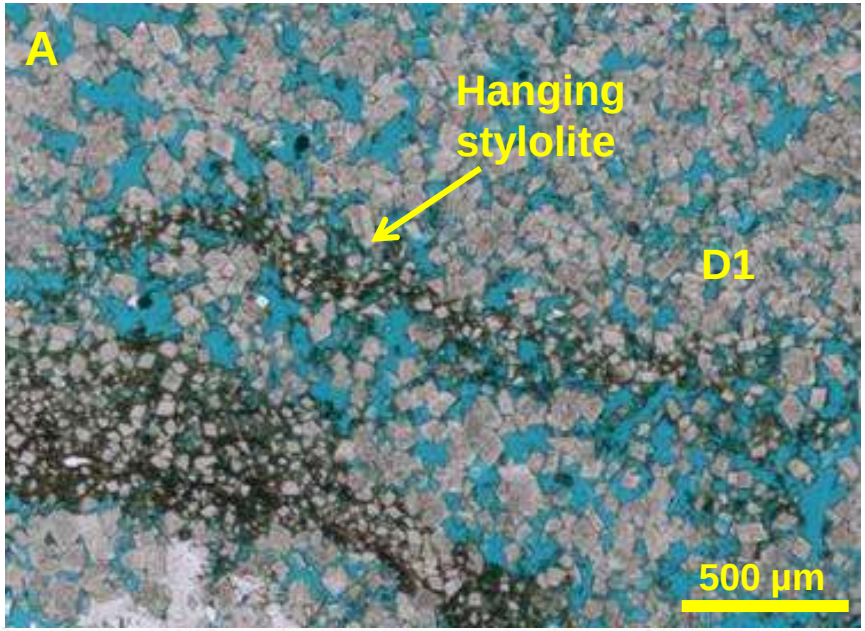
EOGENETIC POROSITY: ARAGONITE/CALCITE DISSOLUTION

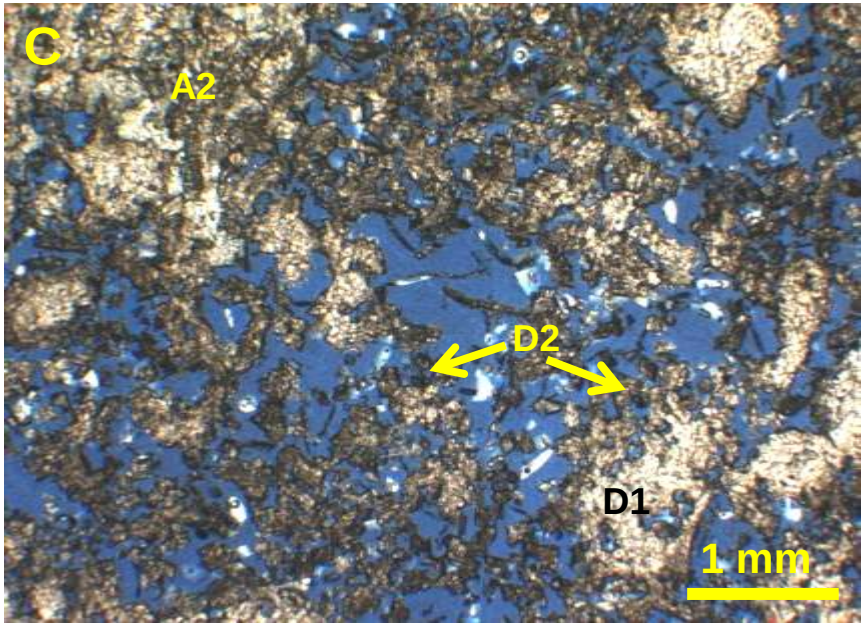


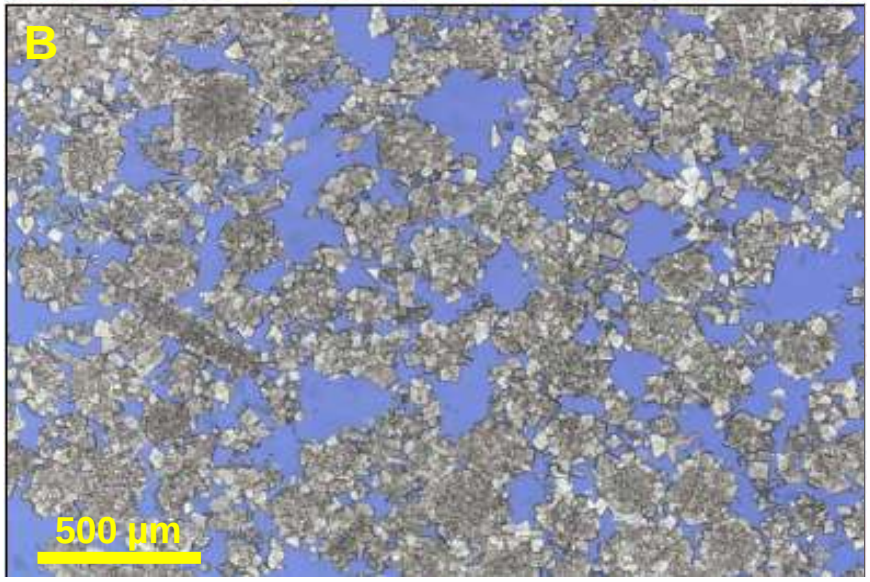
1
Meteoric dissolution of grains = moldic porosity

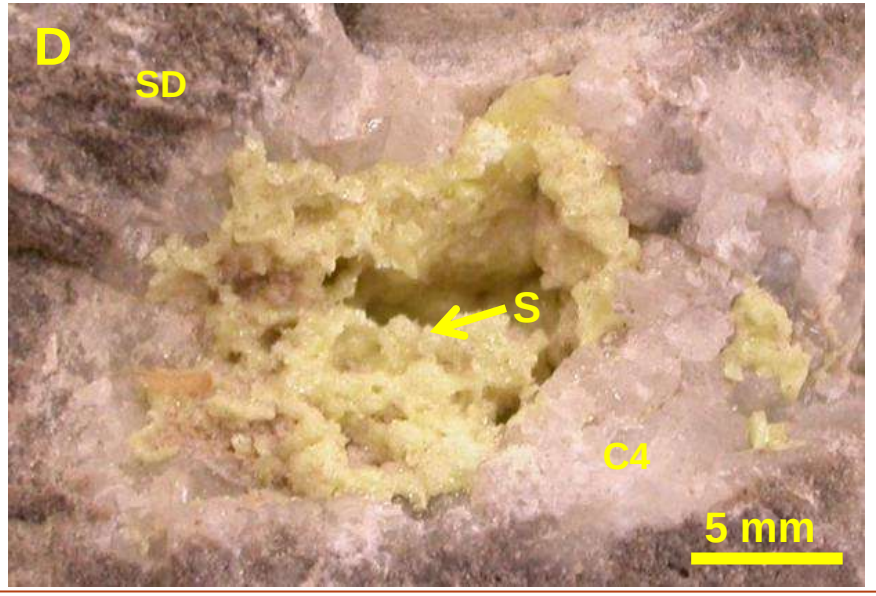
2
Dolomitisation (D1&D2) prior and/or after dissolution

MESOGENETIC POROSITY: CALCITE AND/OR SULPHATE DISSOLUTION (TSR?)

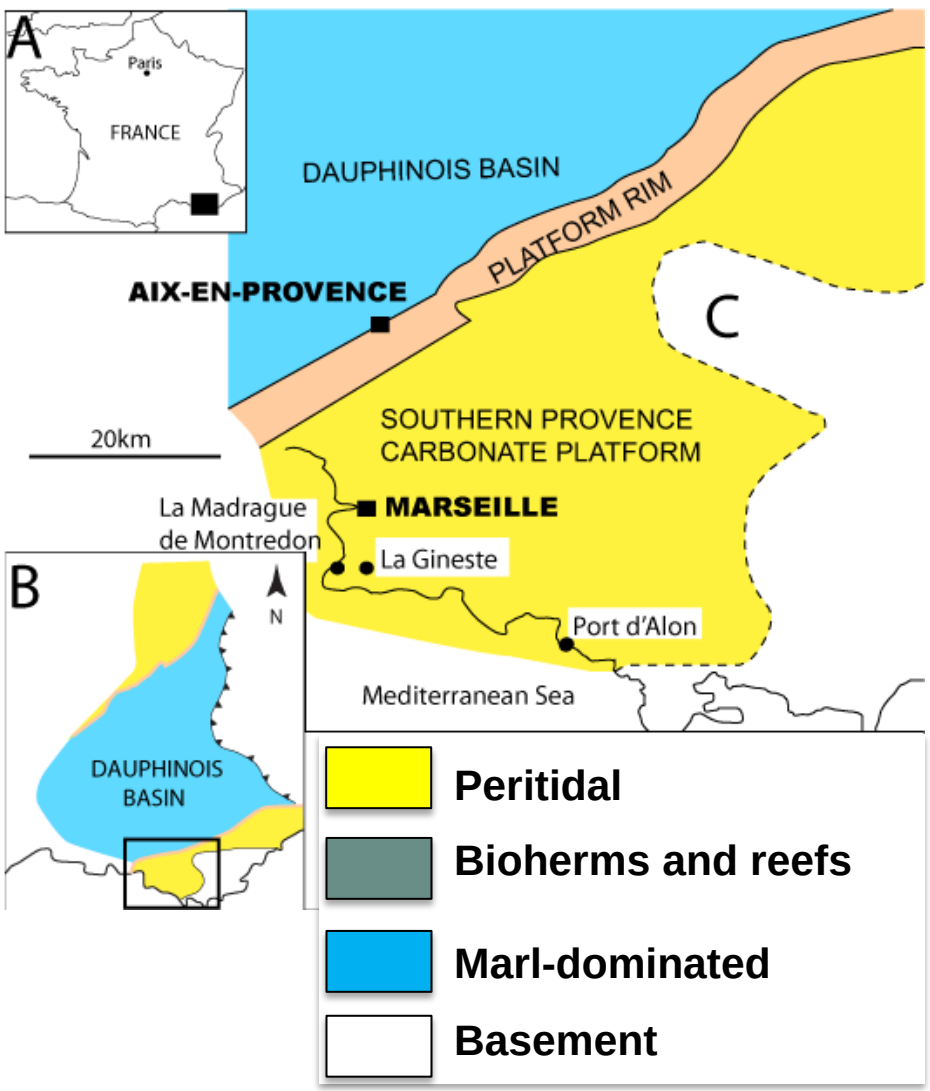


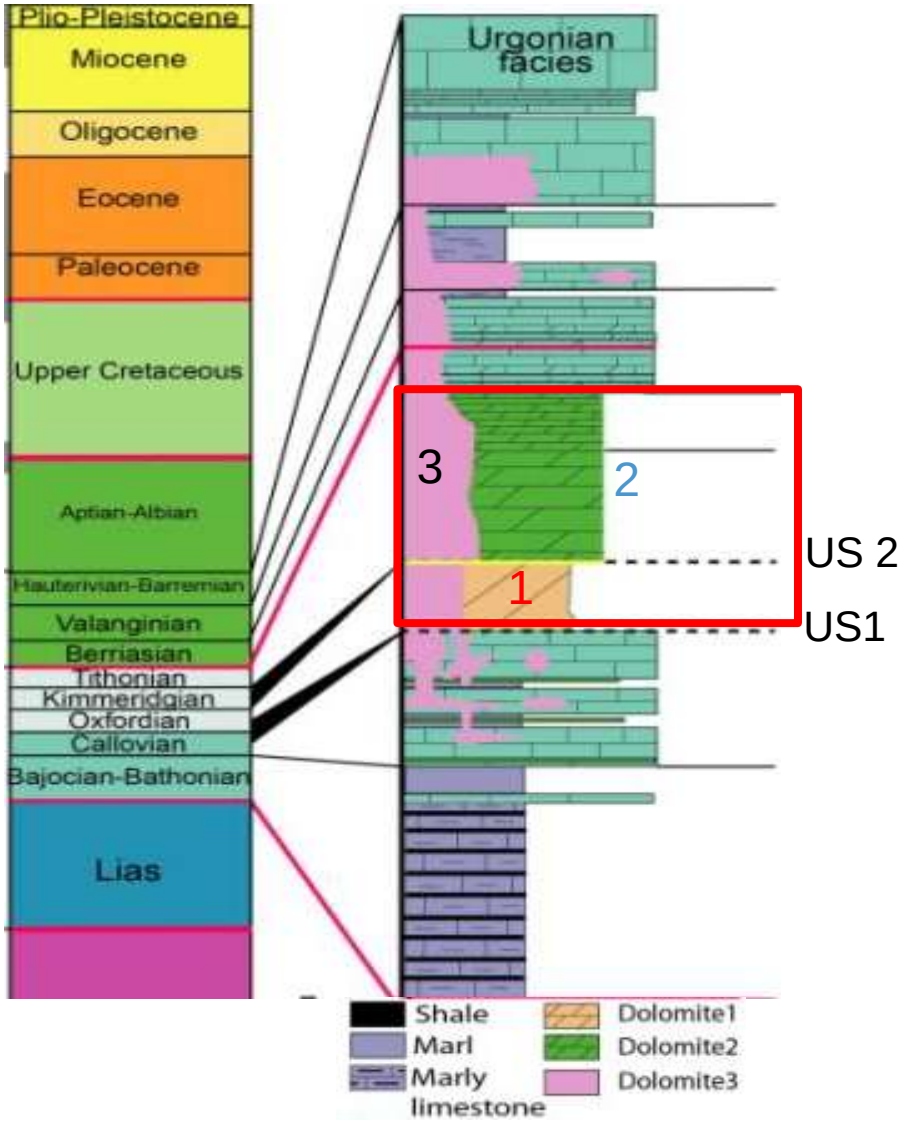






PALEOGEOGRAPHY AND LITHOLOGY

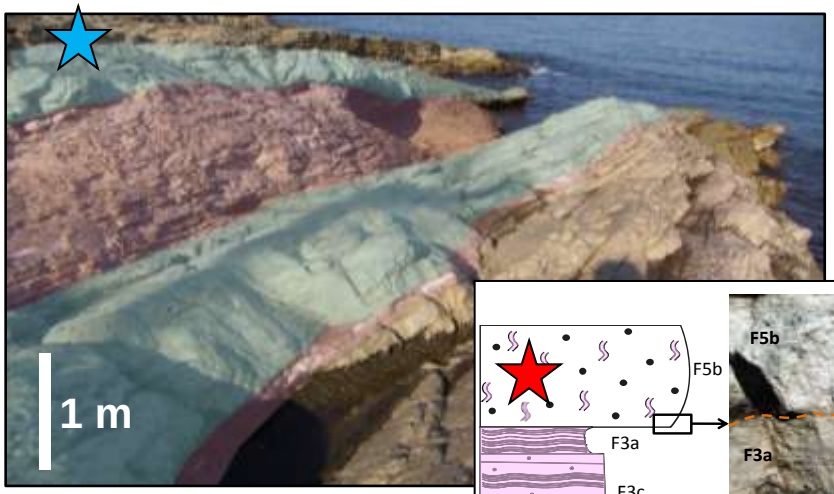


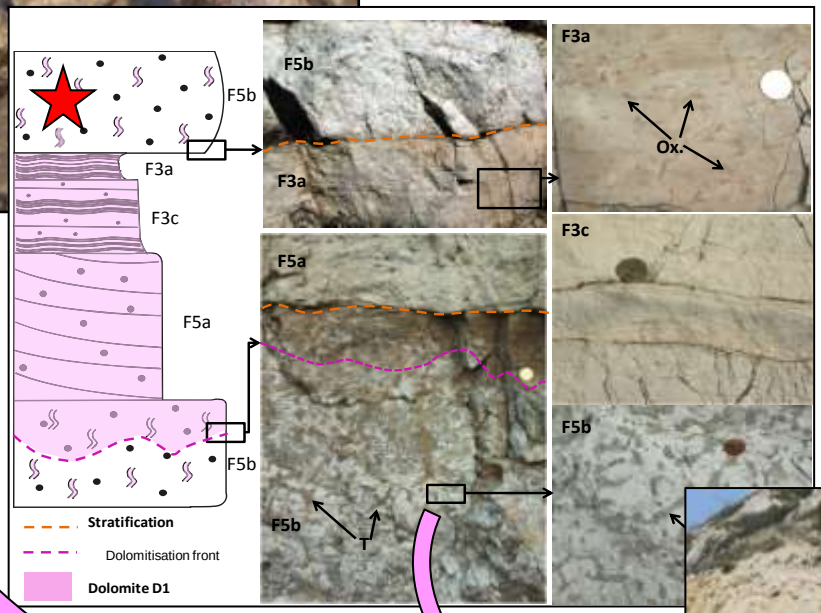


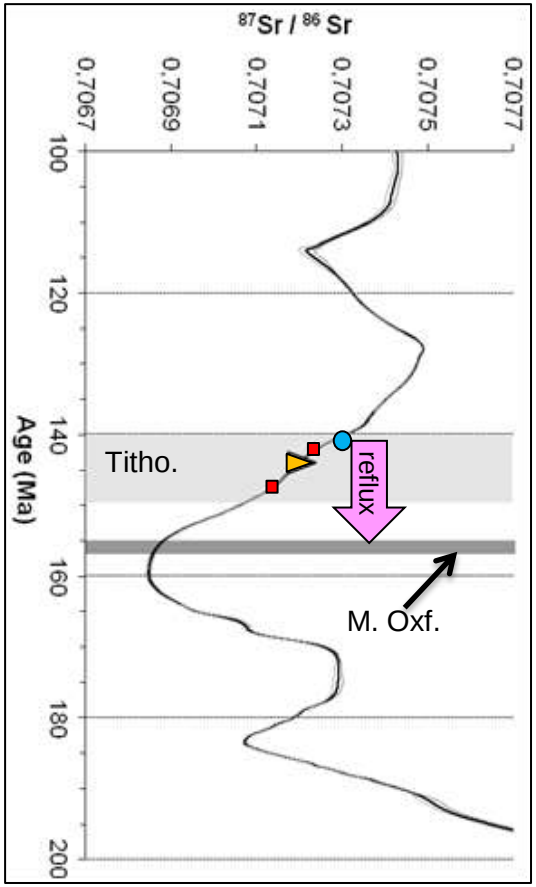
3 types of dolomite: 1 : Massive (VT) 2: Stratabound (DEF, GIN, MAD) 3: Fault-related

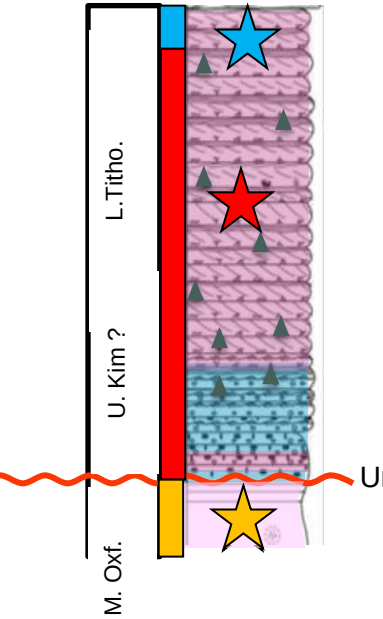
STRATIGRAPHY AND FACIES

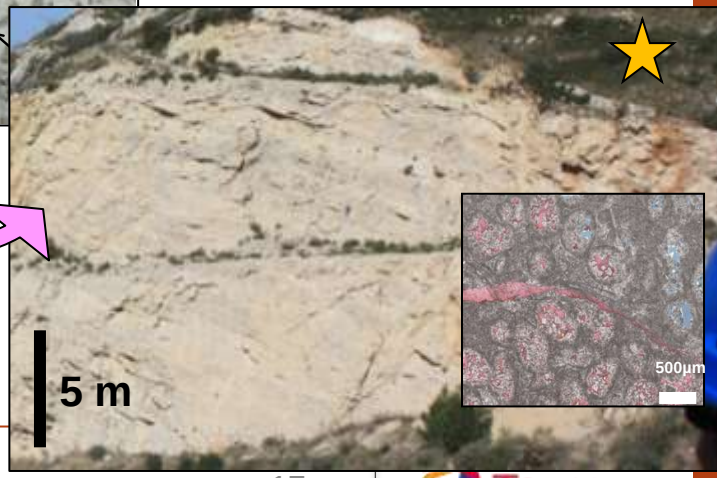
DOLOMITISATION MODEL





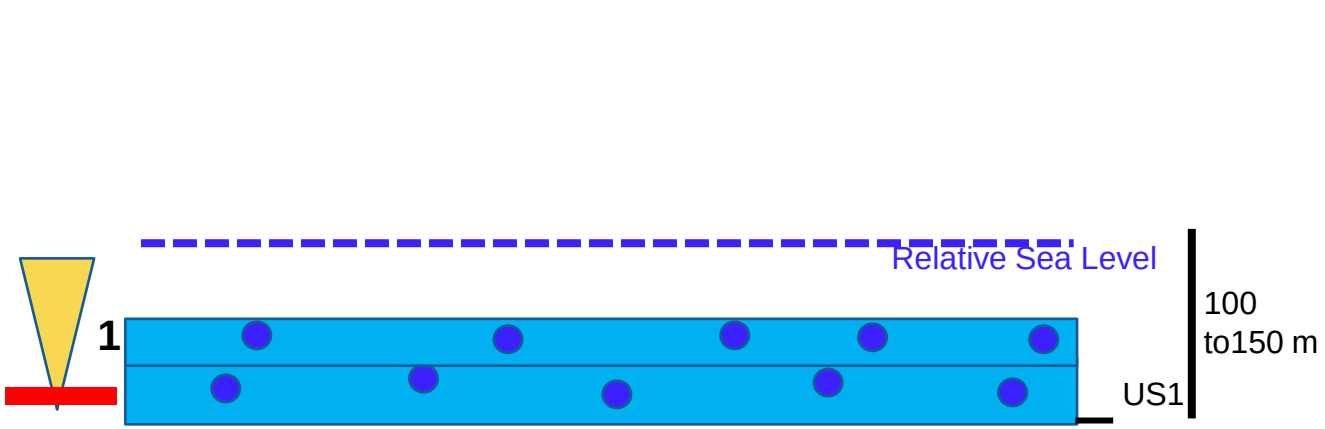






Brines reflux from peritidal environments to meteorically dissolved oolitic shoals

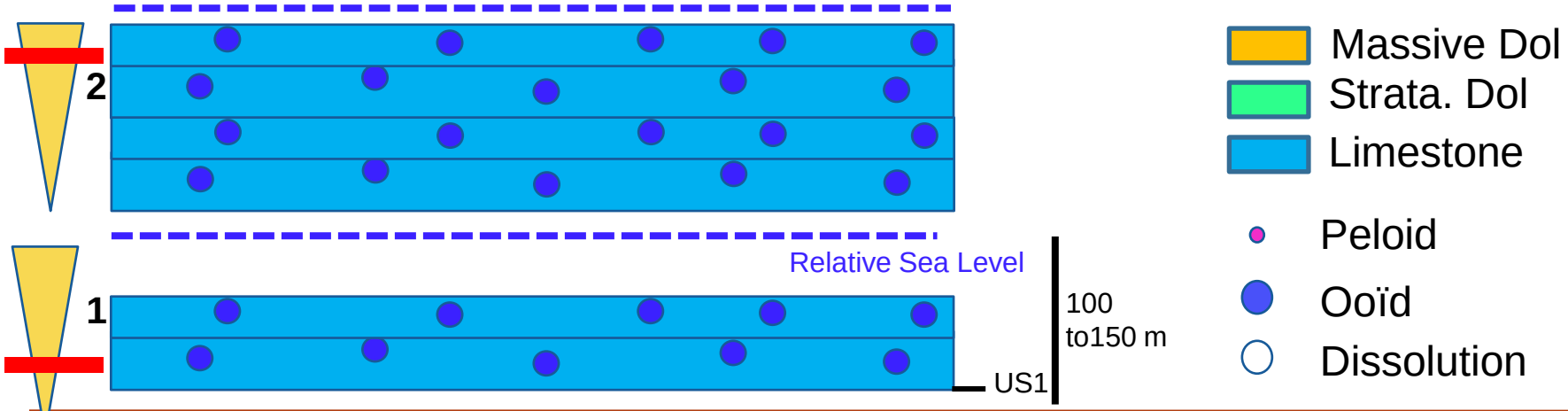
GENETIC MODEL FOR MASSIVE AND STRATABOUND DOLOMITE BODIES



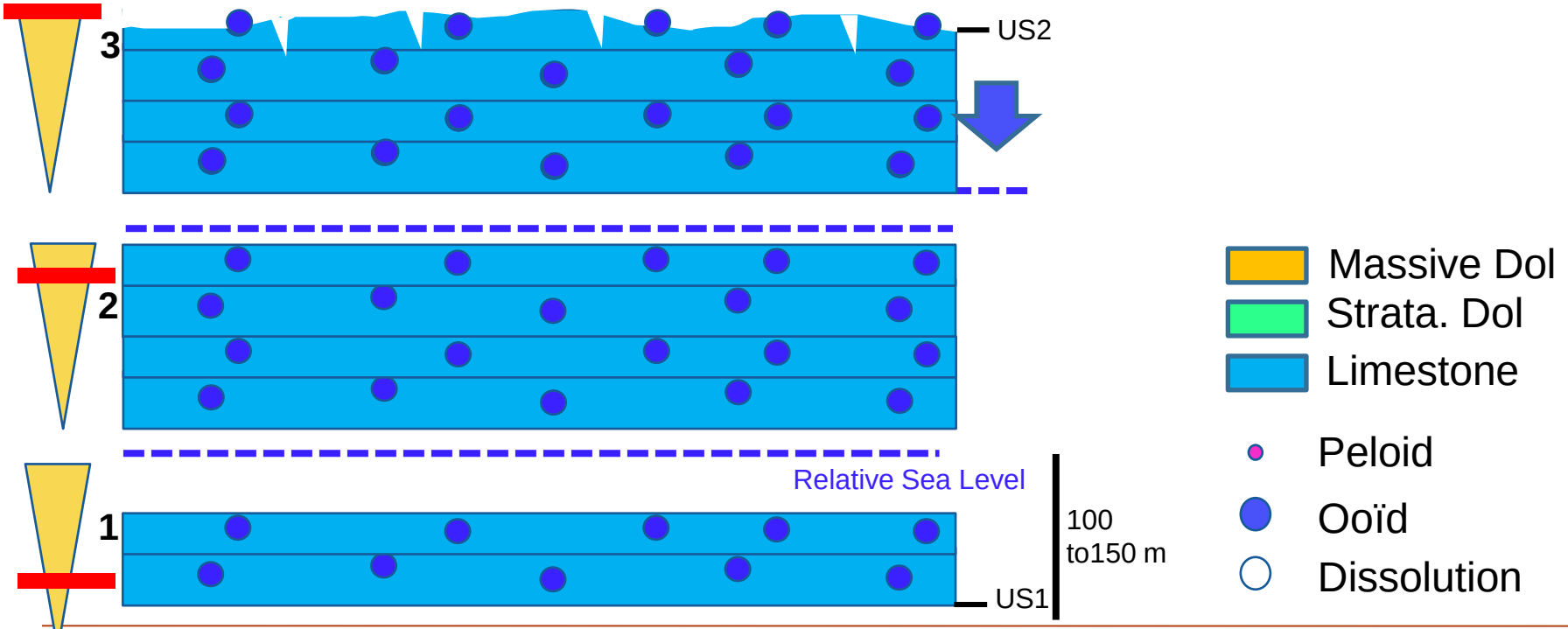
Massive Dol
Strata. Dol
Limestone

Peloid
Ooïd
Dissolution

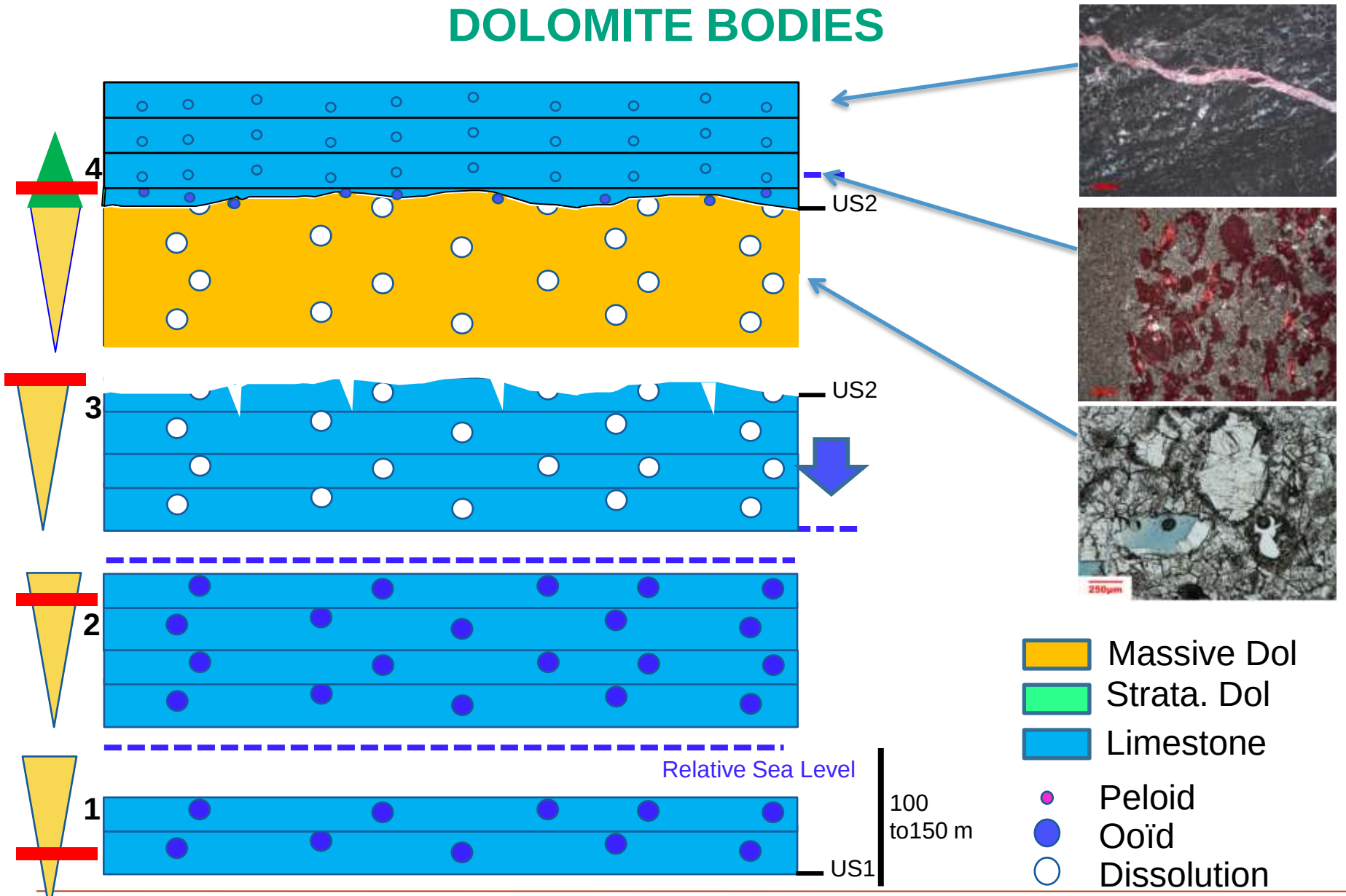
GENETIC MODEL FOR MASSIVE AND STRATABOUND DOLOMITE BODIES



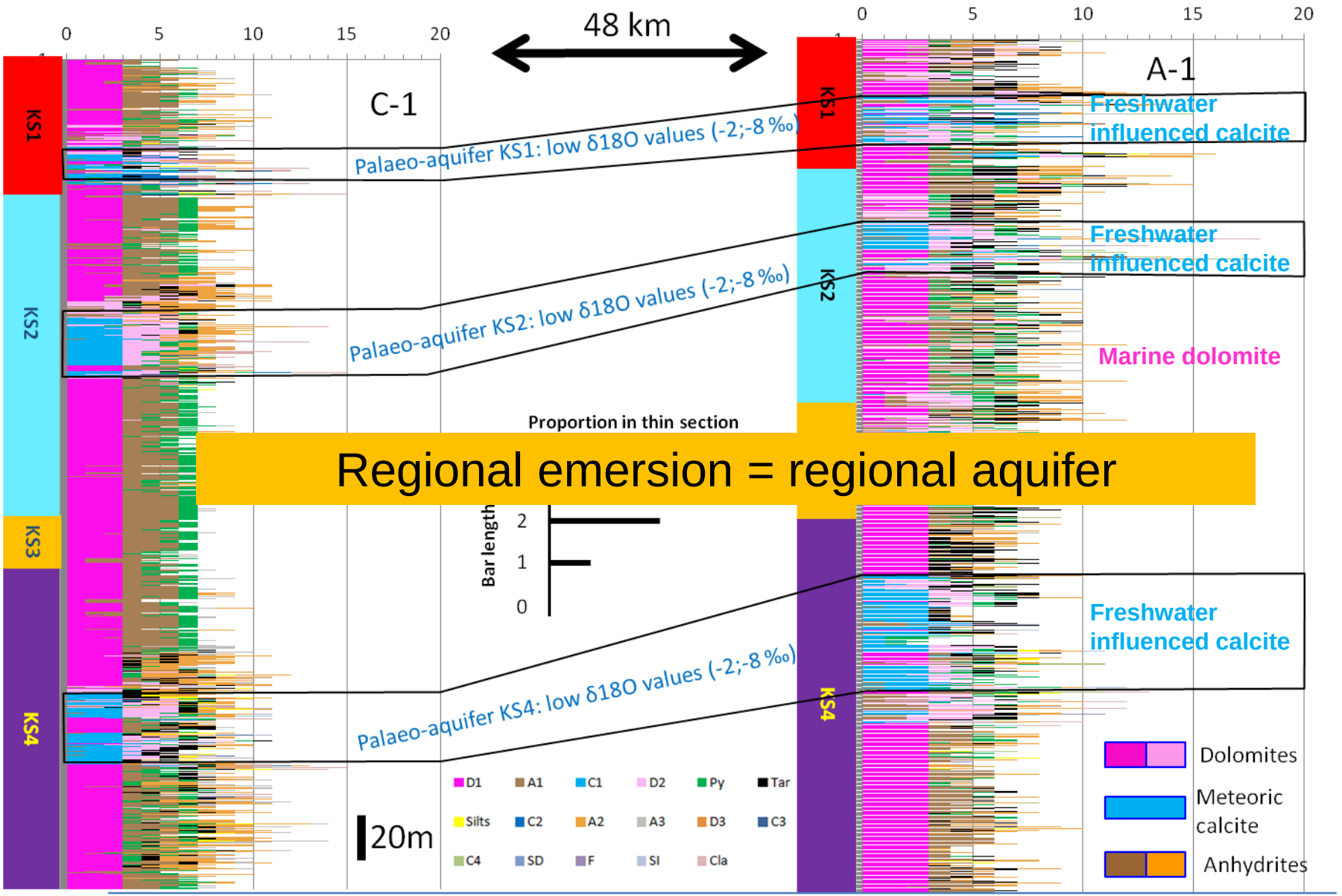
GENETIC MODEL FOR MASSIVE AND STRATABOUND DOLOMITE BODIES



GENETIC MODEL FOR MASSIVE AND STRATABOUND DOLOMITE BODIES

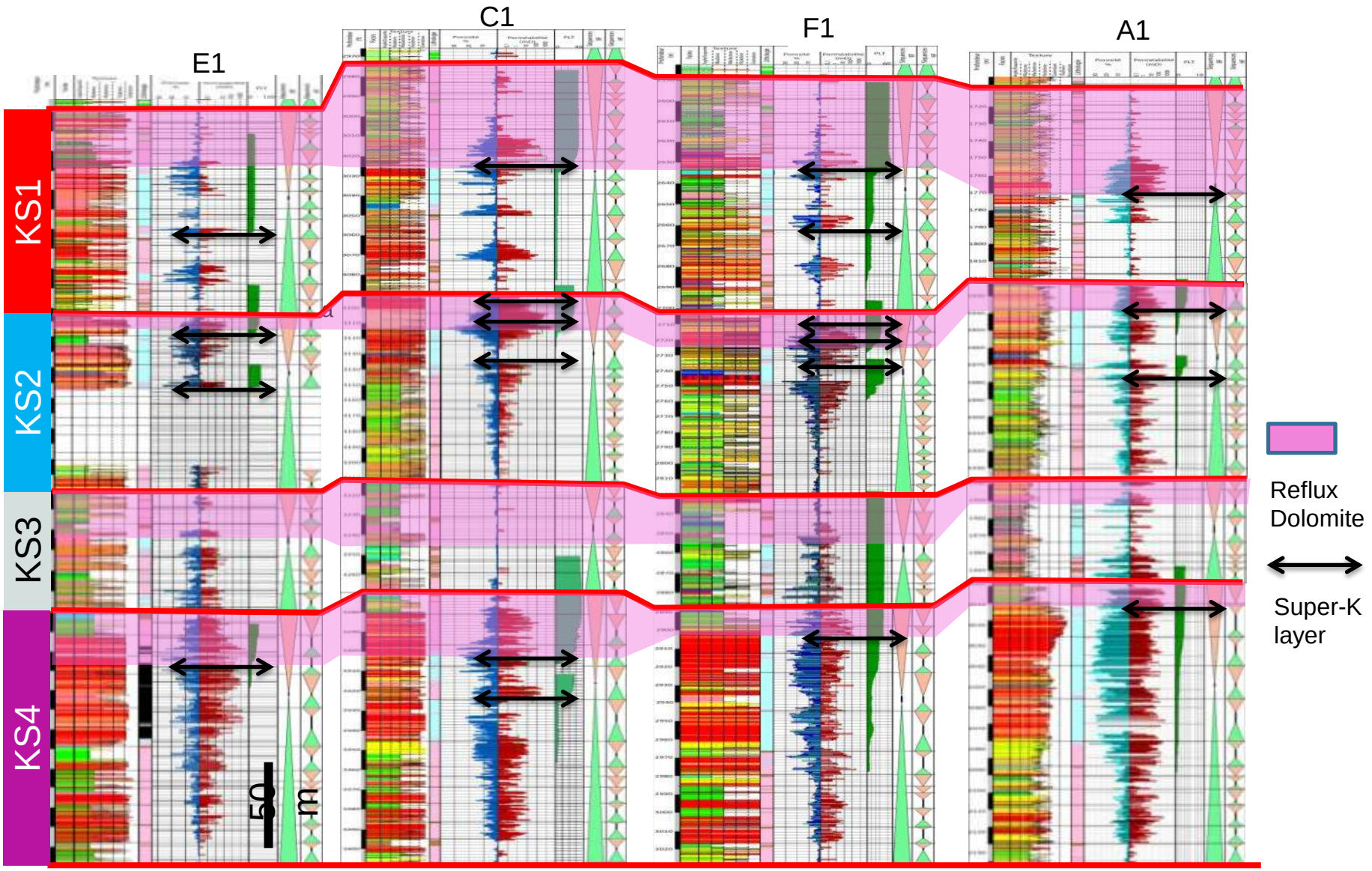


GEOCHEMISTRY: SPATIAL DISTRIBUTION OF DIAGENETIC BODIES

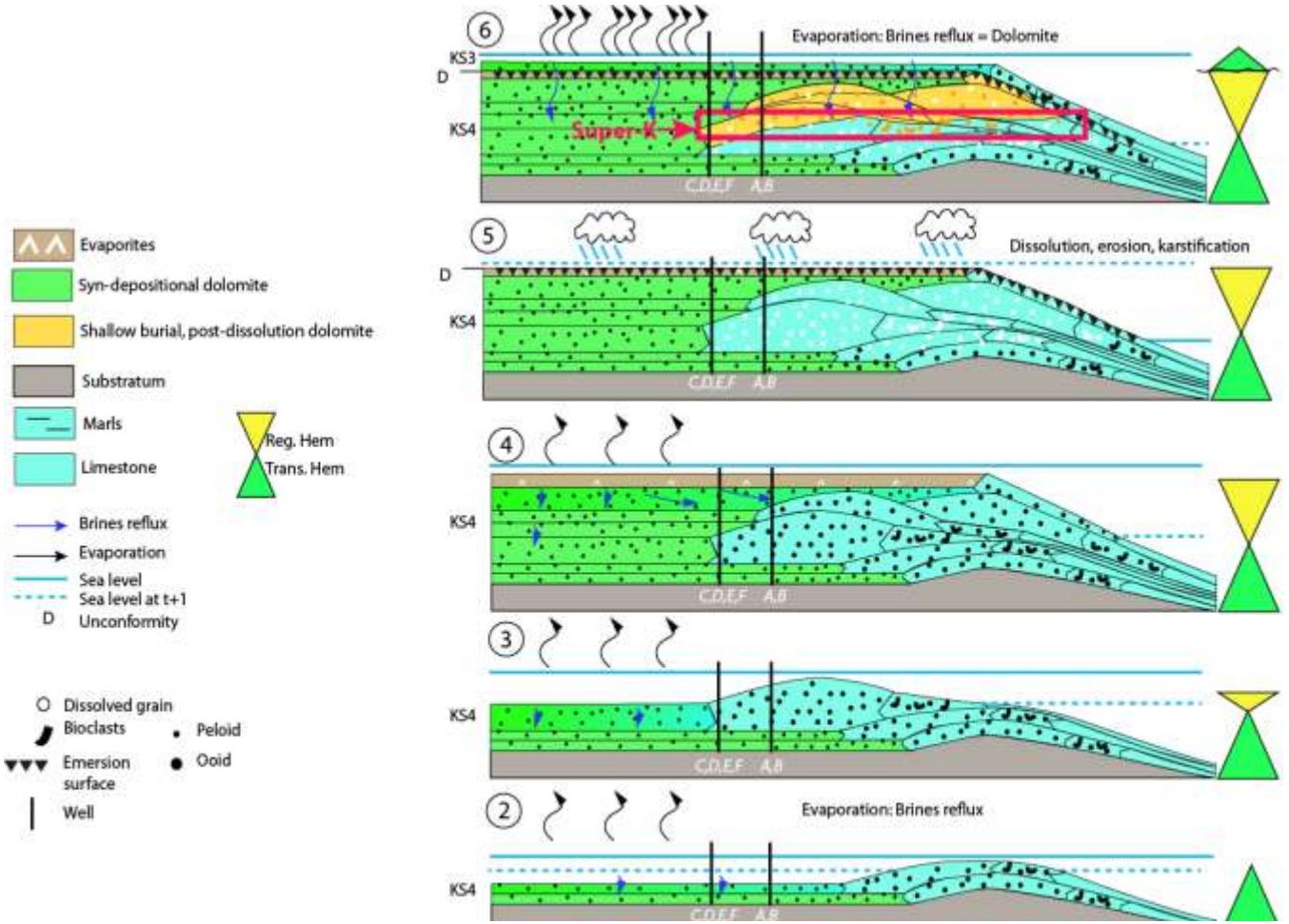


Regional emersion = regional aquifer

SUPER-K : GRAIN-SUPPORTED FACIES + DOLOMITE + BURIAL DISSOLUTION



SUPER-K FORMATION MODEL: EXAMPLE OF KS4



CONCLUSIONS

• CAN WE PREDICT SUPER-K LAYERS IN THE UPPER KHUFF FM. ?

- **Partially conformable to stratigraphy**
- **Tracking shallow-burial dolomitic diagenetic front**
- **Below major exposure surfaces** (regional sequence boundary)

- **Controlling factors**
  - Grain-supported facies (beach, shoal)
  - Meteoric dissolution linked to major exposure
  - Subsequent reflux dolomitisation of dissolved facies
  - Burial dissolution of calcite/anhydrite (oil charge ?, TSR ?,…)

- **Recommandations**
  - High-resolution stratigraphy, sedimentary and diagenesis approach
  - Use of analogues to validate processes

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