PS Diagenesis Impact on Permeability of a Large Carbonate Reservoir*

Irene Cantarero[1], Anna Travé[1], Xiomara Márquez[2] and Noureddine Bounoua[3]

Search and Discovery Article #20279 (2014)**
Posted November 17, 2014

*Adapted from poster presentation given at AAPG International Conference & Exhibition, Istanbul, Turkey, September 14-17, 2014

[1]Petrologia i Geoquímica, Barcelona University, Barcelona, Spain (i_cantarero@ub.edu, atrave@ub.edu)
[2]Maersk Oil Research and Technology, Doha, Qatar
[3]Qatar Petroleum, Doha, Qatar

Abstract

Preliminary results of a diagenetic study of an Aptian carbonate reservoir in the Middle East indicate that both porosity and permeability started to be modified soon after deposition. However, present day permeability is mainly controlled by late, randomly distributed calcite cements. Diagenesis started with the development of micritic envelops that occurred in restricted marine conditions, commonly associated with precipitation of small cubic pyrite crystals. Soon after, these still loose sediments became influenced by meteoric waters because of a sea level drop producing chalkification of mollusk fragments. Neomorphism from aragonite to calcite of rudist and corals and development of millimeter-thick irregular fractures probably occurred at this time. Subsequent dissolution generated centimeter-size vugs, mouldic porosity and enlargement of previous fractures, which were partially filled with sediment and totally occluded by calcite cement. Pedogenic features, such as microcodium-like calcite, also developed. Later, calcite cement rims around bioclasts precipitated under phreatic conditions. A second dissolution episode generated most of the present day mouldic porosity. The last calcite cementation event was characterized by isolated large crystals in interparticle and in the previously formed mouldic porosity. At least two events of pyrite precipitation have been recognized: pyrite replacing bioclasts and pyrite filling vugs. Some of the observed key points are: 1) Intraparticle porosity in *Orbitolinas* has remained uncemented since deposition; 2) Vuggy porosity shows a different distribution pattern than mouldic porosity within the studied rocks pointing to different dissolution events; and, 3) The late isolated large calcite crystals occluded porosity very locally but their spatial distribution within the pore throats are a key control in permeability modification. This work indicates that the fundamental understanding of the diagenetic modifications of the pore system is essential to reservoir modelling and prediction at well, inter-well and reservoir scale.

DIAGENESIS IMPACT ON PERMEABILITY OF A LARGE CARBONATE RESERVOIR

Irene Cantarero[1], Anna Travé[1], Xiomara Márquez[2], Noureddine Bounoua[3]

1 Departament de Geoquímica, Petrologia i Prospecció Geològica. Universitat de Barcelona, Spain (i_cantarero@ub.edu, atrave@ub.edu)
2 Maersk Oil Research and Technology Centre
3 Qatar Petroleum

1. INTRODUCTION

Carbonate reservoirs are often characterised by a great heterogeneity on their petrophysical properties (porosity and permeability), playing an important role on the rate of hydrocarbon production and recovery. These variations are due to the depositional setting and subsequent diagenetic changes produced by processes such as cementation, dissolution and replacement. In turn, the distribution of these processes is controlled by the origin of fluids, the diagenetic environment and the thermal evolution of the basin (Neilson et al., 1998; Brigaud et al., 2009; Nader et al., 2013). Also, the presence of faults with their behaviour as barriers or conduits can modify these petrophysical properties (Caine et al., 1996; Swennen et al., 2003). Thus, in order to predict the distribution of these properties, the comprehension of all the aforementioned controls is required.

This work is focused on the diagenetic study of one reservoir unit of the Al Shaheen field, which is located in offshore Qatar, at 180 Km from Doha (Fig. 1). This field produces since 1996 from a stack of cretaceous reservoir units (Fig. 2). The reservoir unit is represented by a progradational system with a clear division in platform, barrier and basin (Fig. 3).

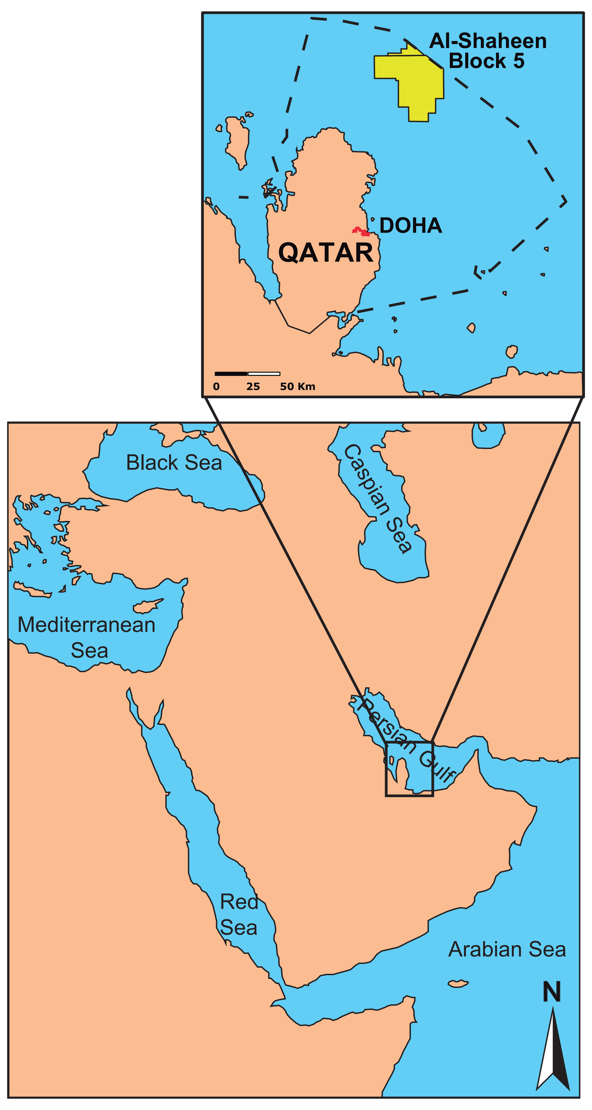

Figure 1. Location of Al-Shaheen field

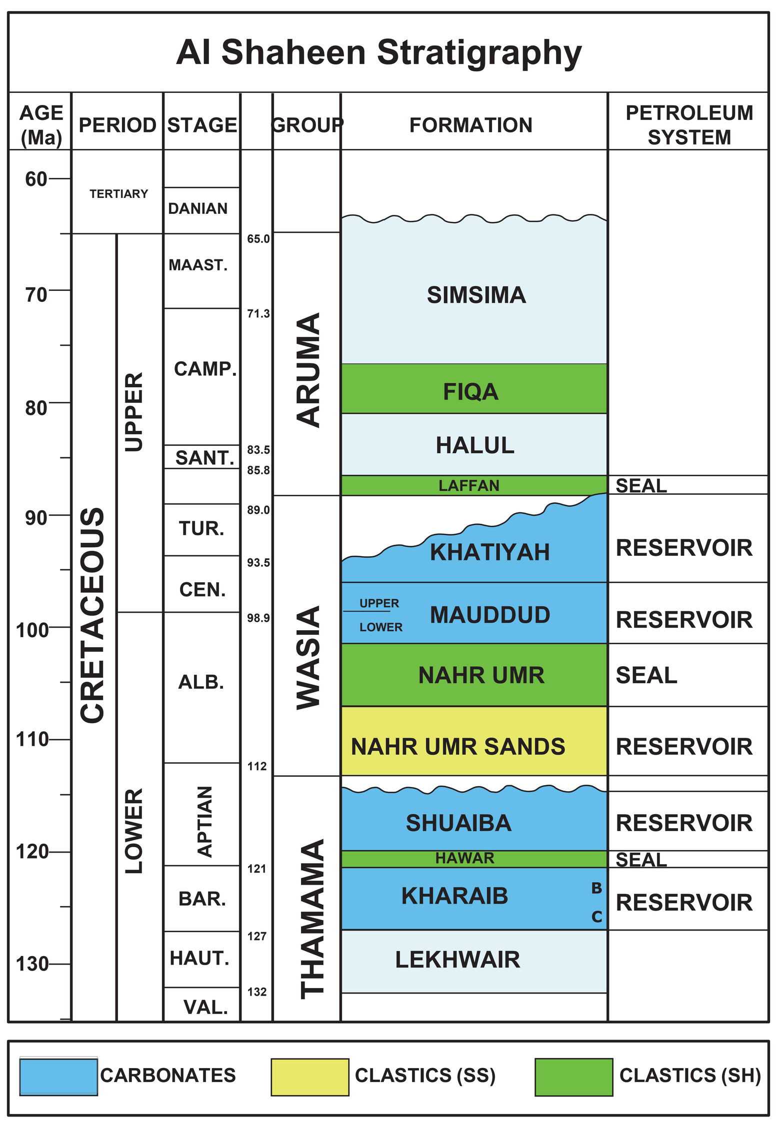

Figure 2. Stratigraphy of the Al-Shaheen field, showing the different Cretaceous reservoir and seal units.

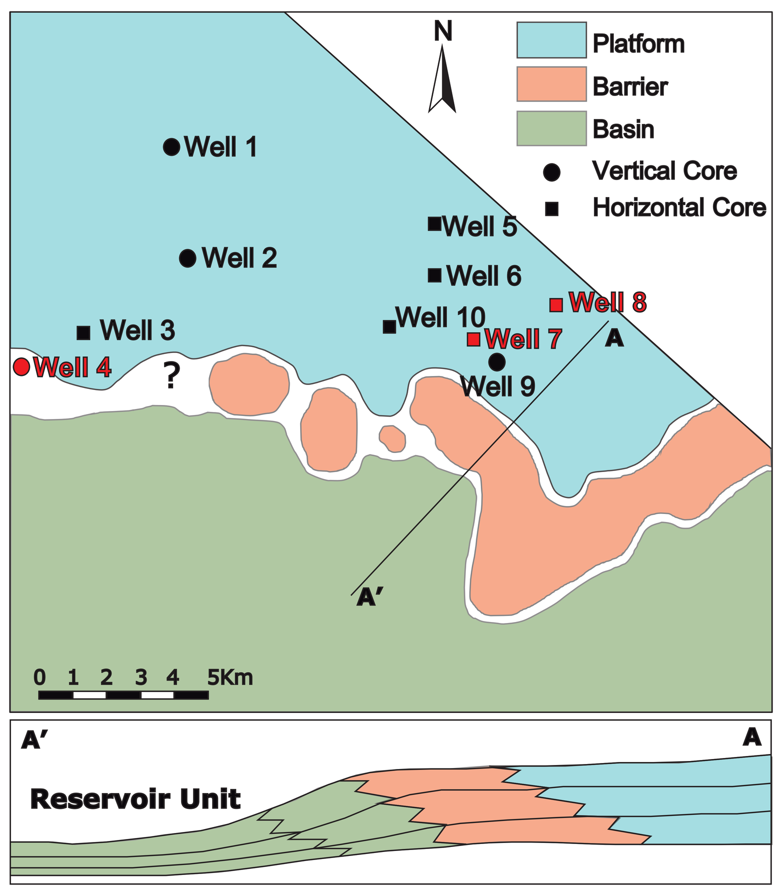

Figure 3. Schematic map and cross-section of the geometries and distribution of the different depositional settings (platform, barrier and basin) of the studied reservoir unit. Also, the location of the wells is shown (in red, the ones shown in this poster).

2. OBJECTIVES

The reservoir unit, object of this study, is characterised by a very heterogeneous distribution of porosity and permeability ,as shown in figure 4.

Athough it seems that the barrier and the platform show the best permeability conditions, they also show a high poro-perm variability, indicating that **another process different than a facies control is also controlling or modifying these properties.**

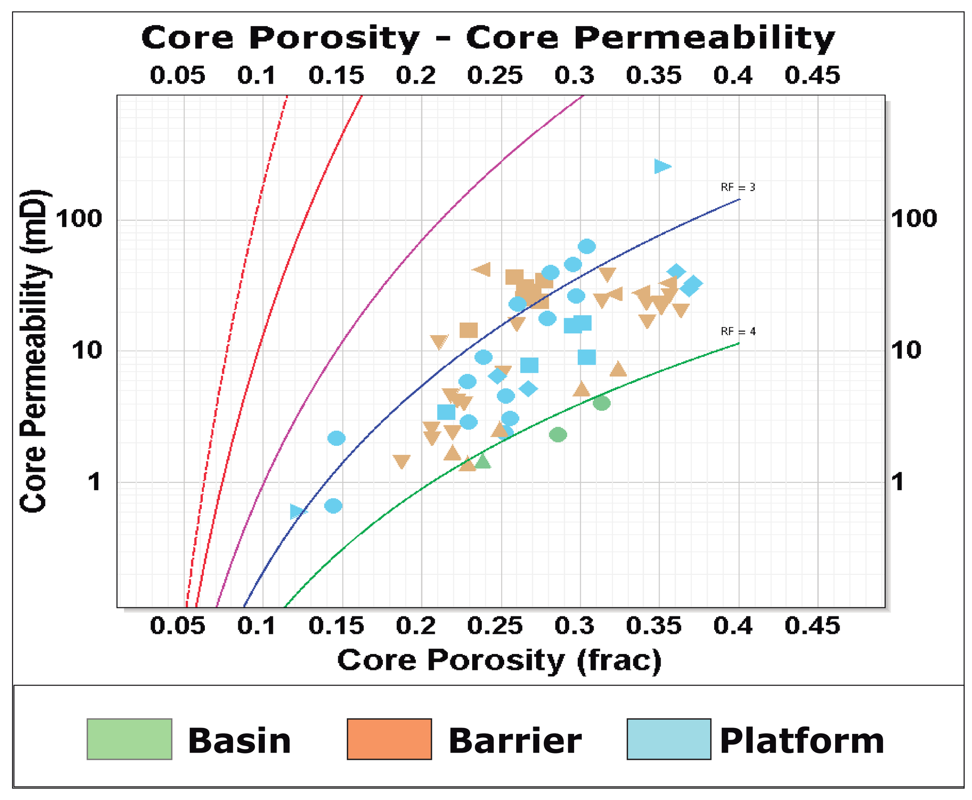

Figure 4. Porosity and permeability crossplot of the basin, barrier and platform areas of the Shuaiba reservoir unit (Finlay et al., 2014).

Thus, in order to address this problem, it is compulsory to establish **which might be the impact of the origin and distribution of the calcite cement in the hetereogenity of this reservoir unit.**

This issue has triggered the onset of this ongoing study, which is focused on the origin and spatial distribution of cements in the platform area.

3. RESULTS

Well 7

The main processes affecting Well 7 are: 1) development of bioturbation by both animals and roots; and, 2) fractures and stylolites (fig. 5 & 6).

Rhizocretions are cemented by pyrite and two generations of calcite (Cc0 and Cc1) (fig. 8).

Fractures and stylolites are consistent with strike-slip tectonics (fig. 7). They have been enlarged and filled by sediment, which has been dolomitized and dedolomitized, and by later calcite cement (Cc2) (fig. 8). OIl is emplaced within the intercrystalline porosity of calcite Cc2. Later dissolution along small fractures occurred.

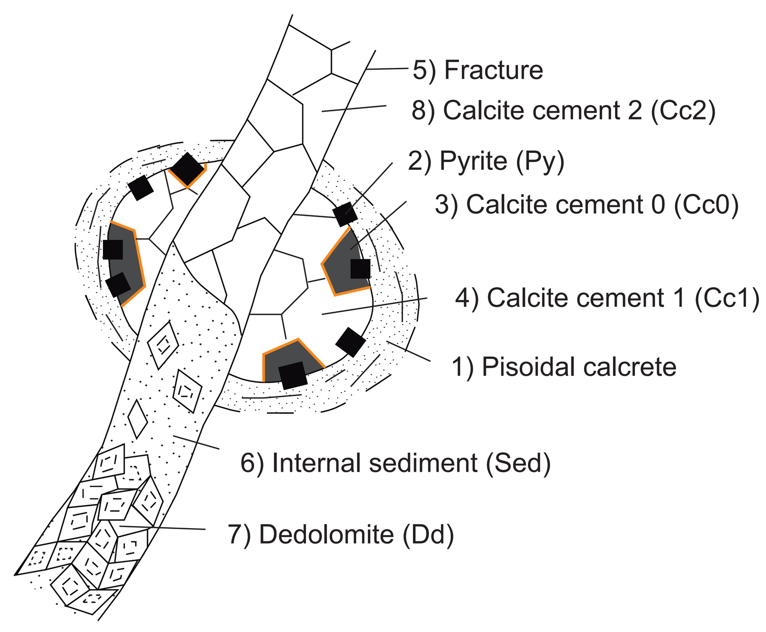

Figure 6. Summary sketch of diagenetic and tectonic features, showing their crosscutting relationships and their related cements.

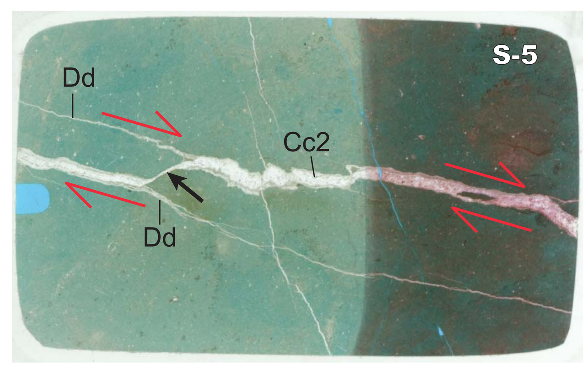

Figure 7. Thin section showing the linkage (black arrow) between the two fault segments formed during fault reactivation after precipitation of dolomite. The linkage is only filled by calcite cement Cc2.

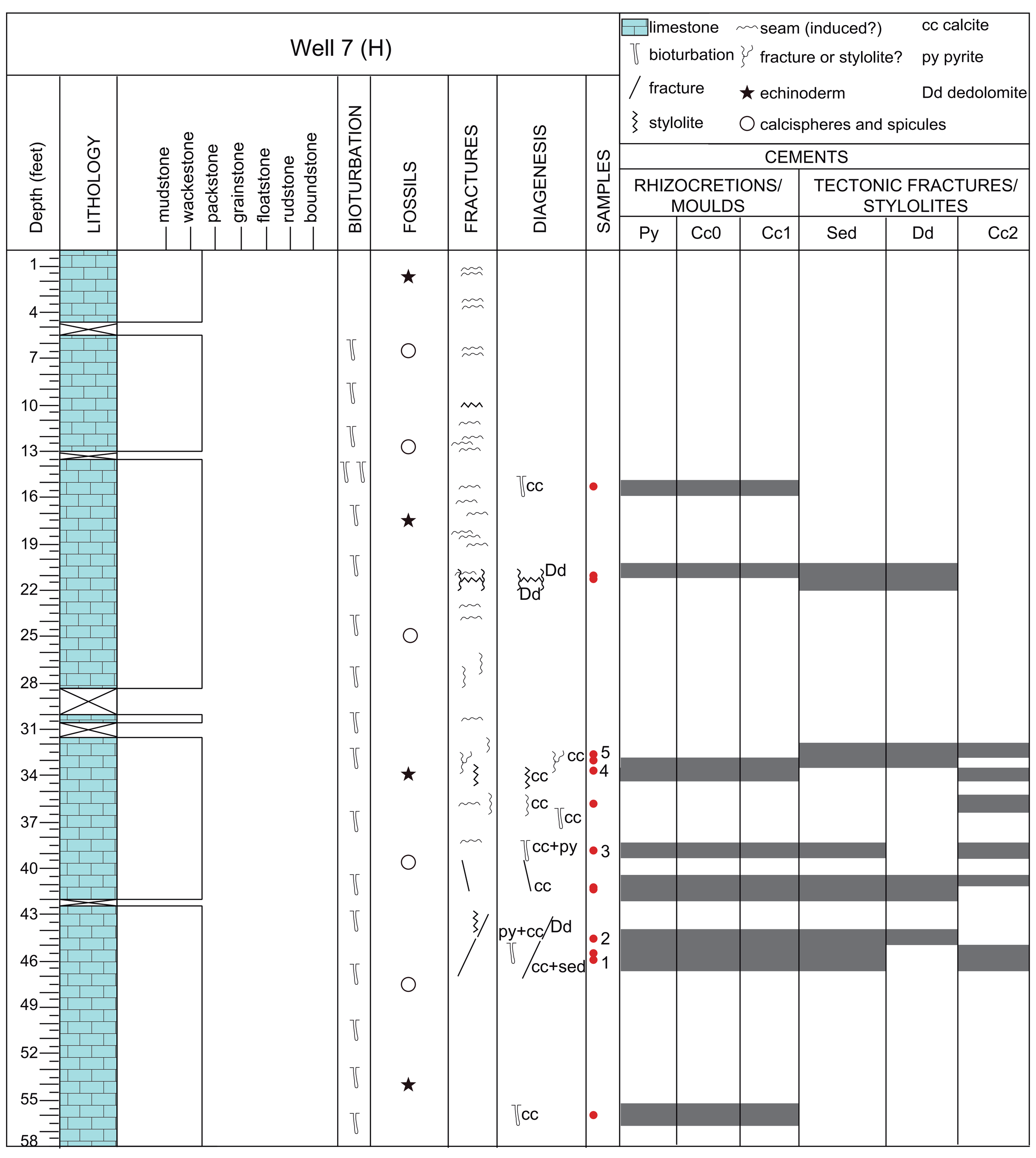

Figure 5. Stratigraphic column of well 7, indicating the distribution of cements.

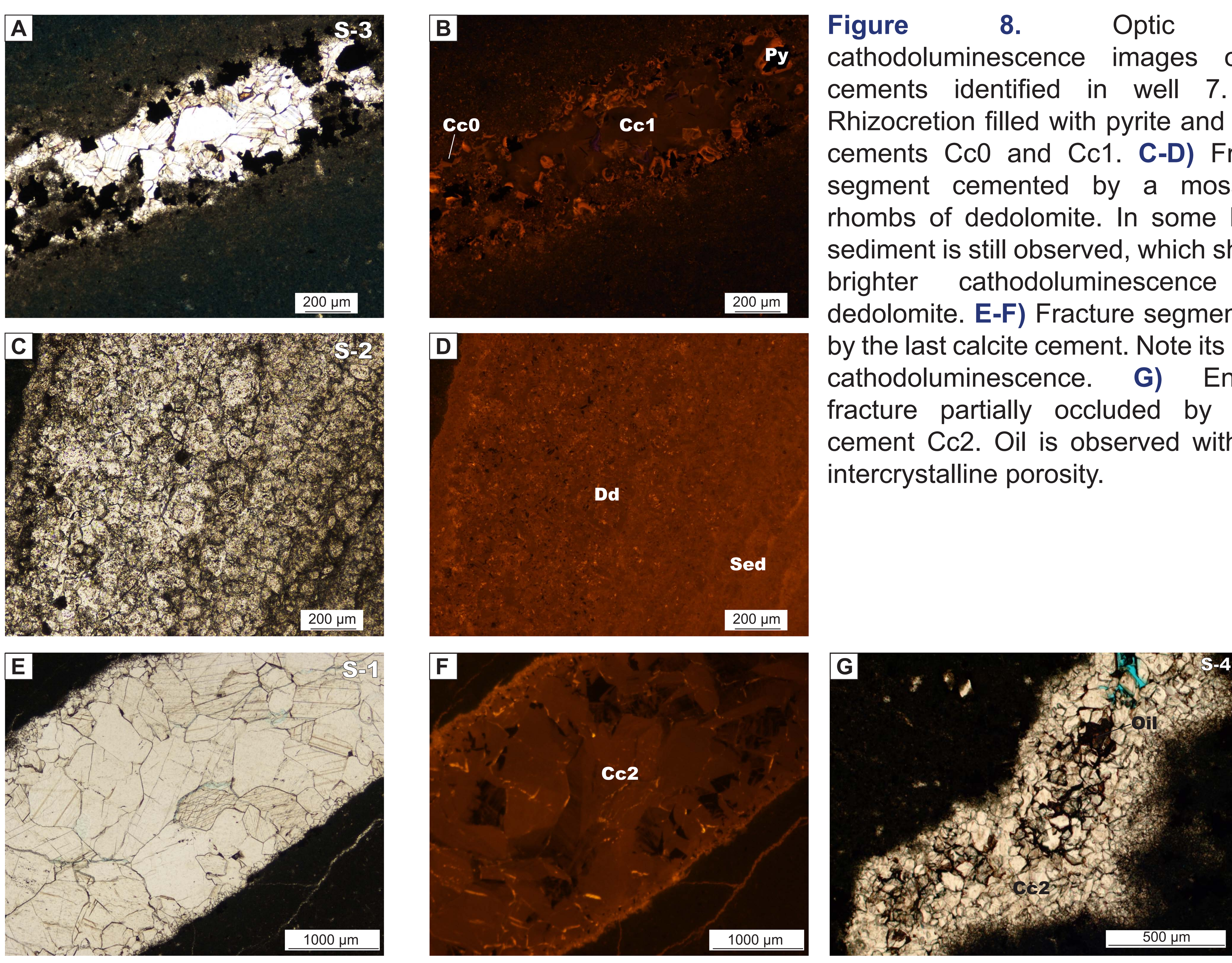

Figure 8. Optic and cathodoluminescence images of the cements identified in well 7. **A-B)** Rhizocretion filled with pyrite and calcite cements Cc0 and Cc1. **C-D)** Fracture segment cemented by a mosaic of rhombs of dedolomite. In some bands, sediment is still observed, which shows a brighter cathodoluminescence than dedolomite. **E-F)** Fracture segment filled by the last calcite cement. Note its patchy cathodoluminescence. **G)** Enlarged fracture partially occluded by calcite cement Cc2. Oil is observed within the intercrystalline porosity.

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Well 4

Well 4 is a 87-feet vertical core characterised by (Fig. 9 & 10):

1) Dolomitization/dedolomitization of the host rock (Dd) (fig. 11)
2) The presence of different **soil features** along the 87 feet:
   - Gibbsite precipitation (Gibb), occluding the porosity of the dedolomitized host rock, giving a patchy texture (fig. 11)
   - Pyrite nodules replacing the host rock matrix and bioclasts (Py)
   - Rhizocretions, root traces, pisoidal calcretes and fractures filled by calcite cement Cc0 to Cc2 (fig. 12)
3) Locally, in remaining pores inside the pyrite nodules, calcite cements Cc3 (highly ferroan) to Cc6 (non-ferroan) have been observed (fig. 12).

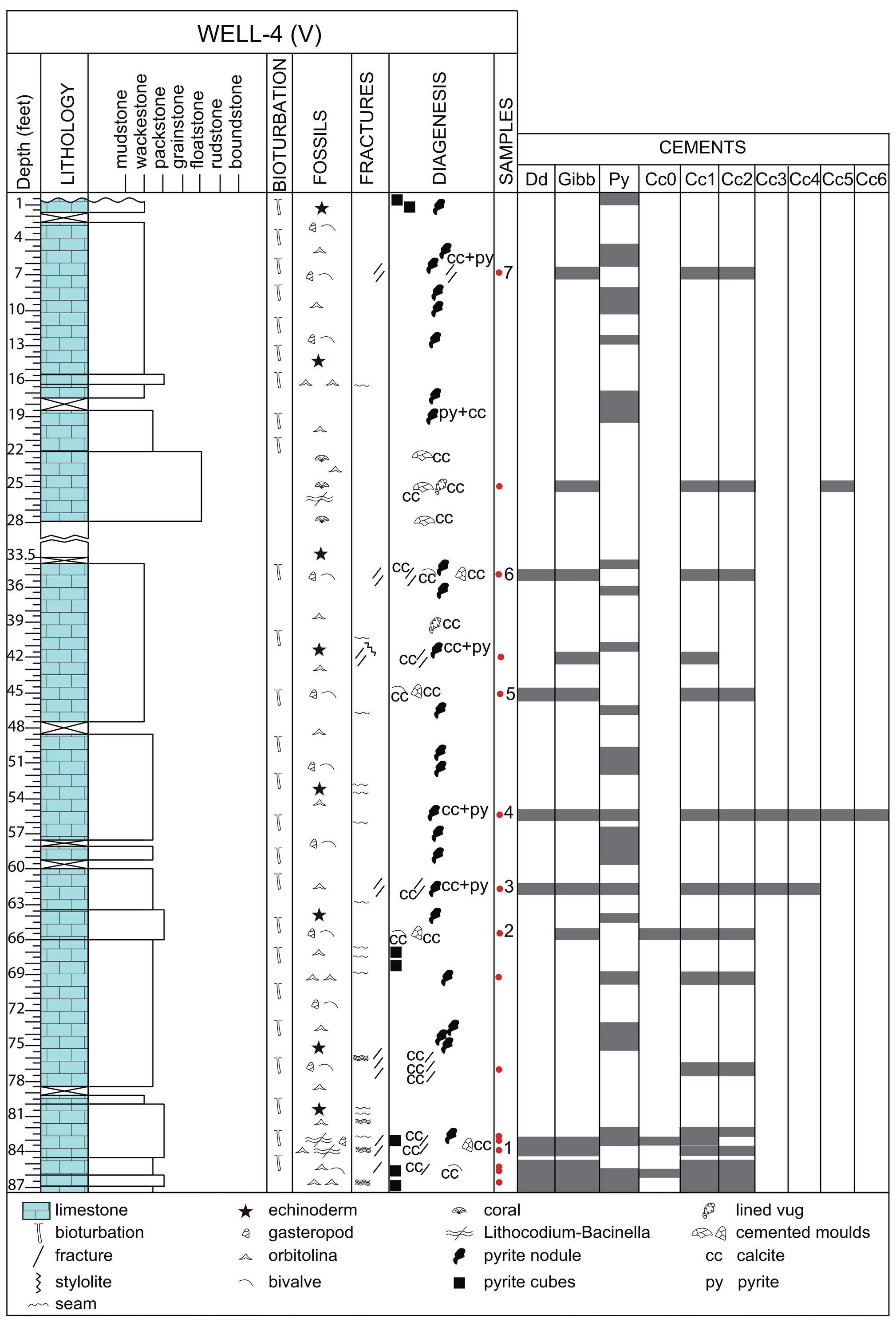


Figure 9. Stratigraphic column of well 4, indicating the distribution of cements.

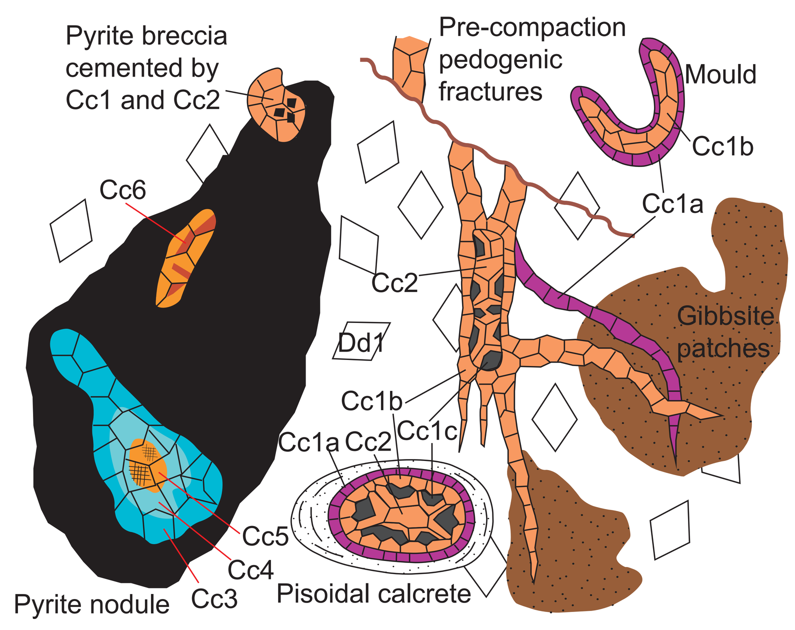
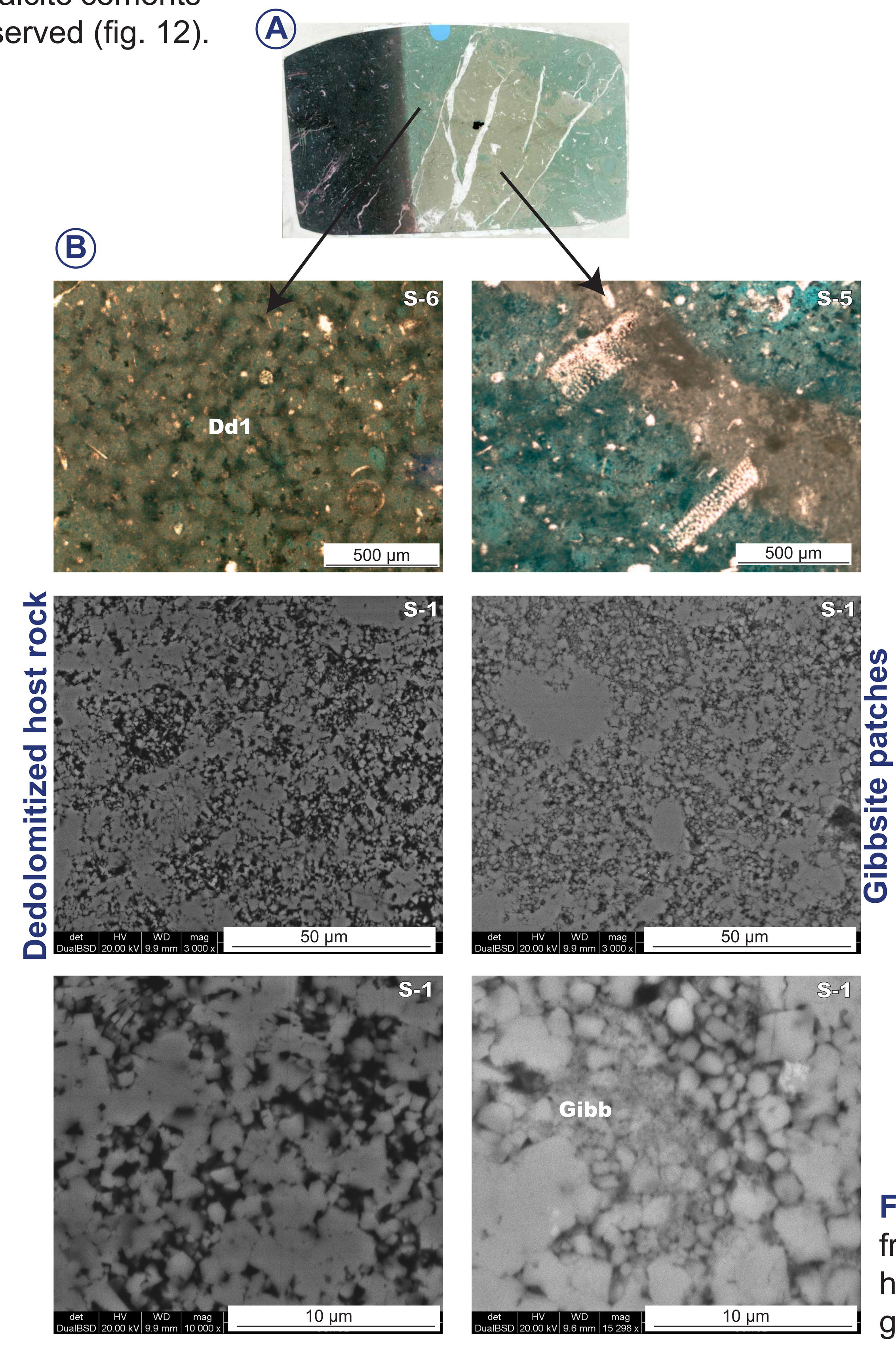


Figure 10. Sketch of the different diagenetic features and their related cements.



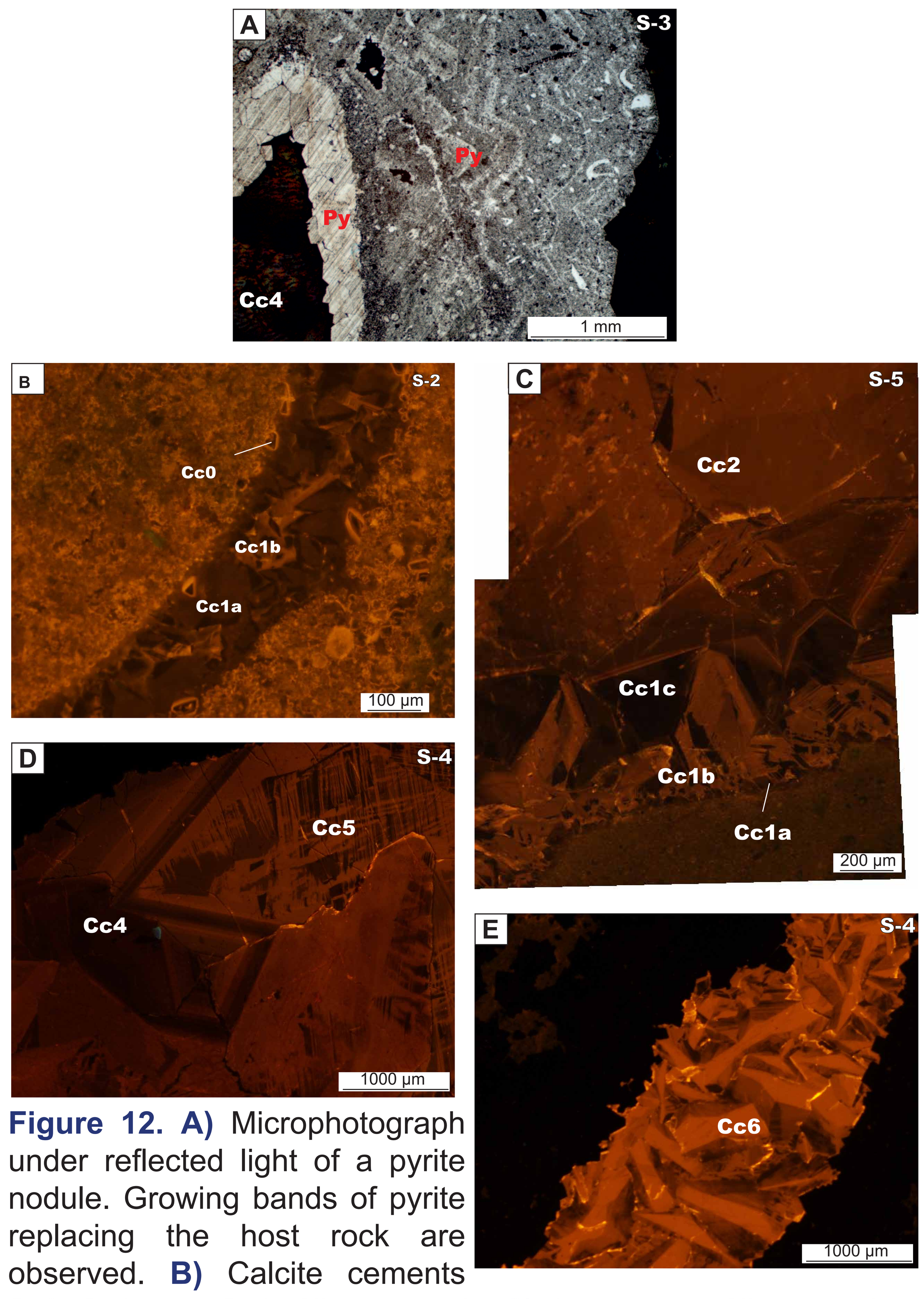


Figure 12. A) Microphotograph under reflected light of a pyrite nodule. Growing bands of pyrite replacing the host rock are observed. **B)** Calcite cements Cc0, Cc1a and Cc1b filling a mould. **C)** Rhizocretion filled by calcite cement Cc1 (a,b and c) and Cc2. **D-E)** Later calcite cements in the porosity inside the pyrite nodules.

Figure 11. A) Thin section showing the spatial relationship between fractures and brown patches. **B)** Comparison between the dedolomitized host rock, with high microporosity, and the brown patches of low porosity generated by the precipitation of gibbsite.

Well 8

In Well 8, rudist-dominated fabrics have been studied revealing the following diagenetic sequence (Fig. 13, 14 & 15):

1) Perforation of rudist shells and development of micritic envelopes
2) Internal peloidal sediment
3) Mouldic and vug dissolution and neomorphism of aragonitic part of rudist shells, patchy ferroan (Cc1±py)
4) Non-luminescent bladed calcite with an outer thin bright orange line in mouldic and vug porosity (Cc2)
5) Post-compaction dissolution of calcitic shells
6) Rim of ferroan and non-ferroan bladed calcite and pyrite in last mouldic dissolution (Cc3)
7) Highly ferroan blocky calcite (Cc4)
8) Big sparry calcite crystals with a dull and bright orange with a striped black pattern luminescence (Cc5)
9) Zoned bright to dull orange calcite cement (Cc6)
10) Dissolution

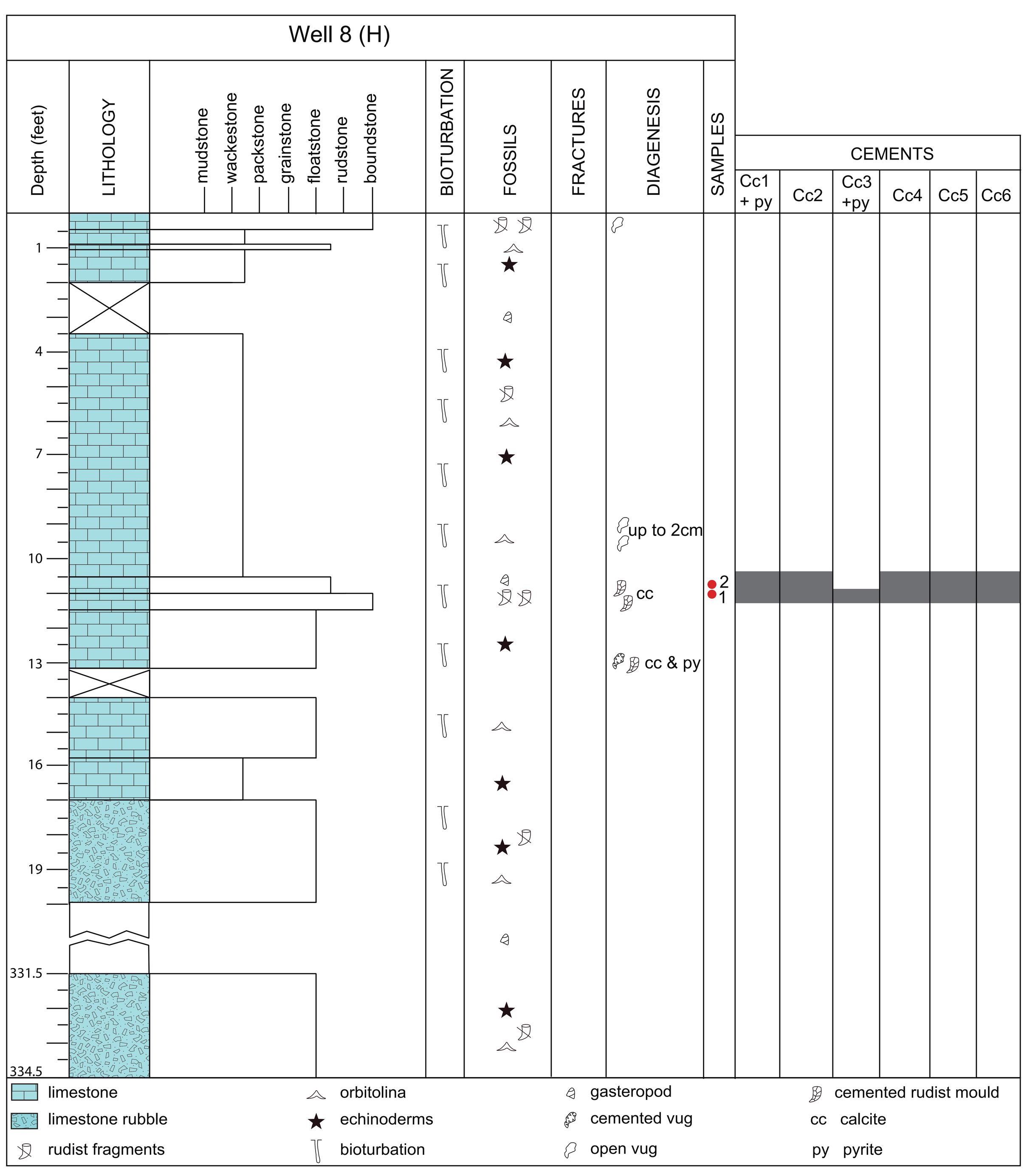


Figure 13. Stratigraphic column of well 8, indicating the distribution of cements.

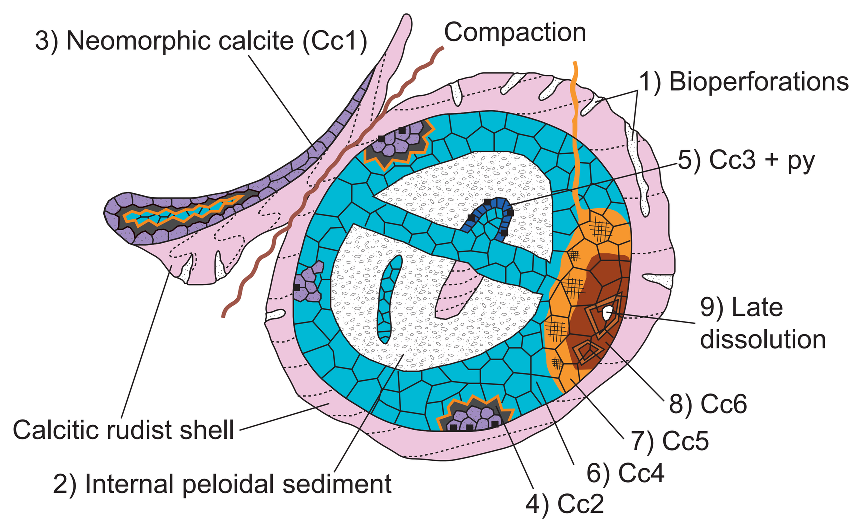


Figure 14. Sketch of the sequence of cements established in well 8.

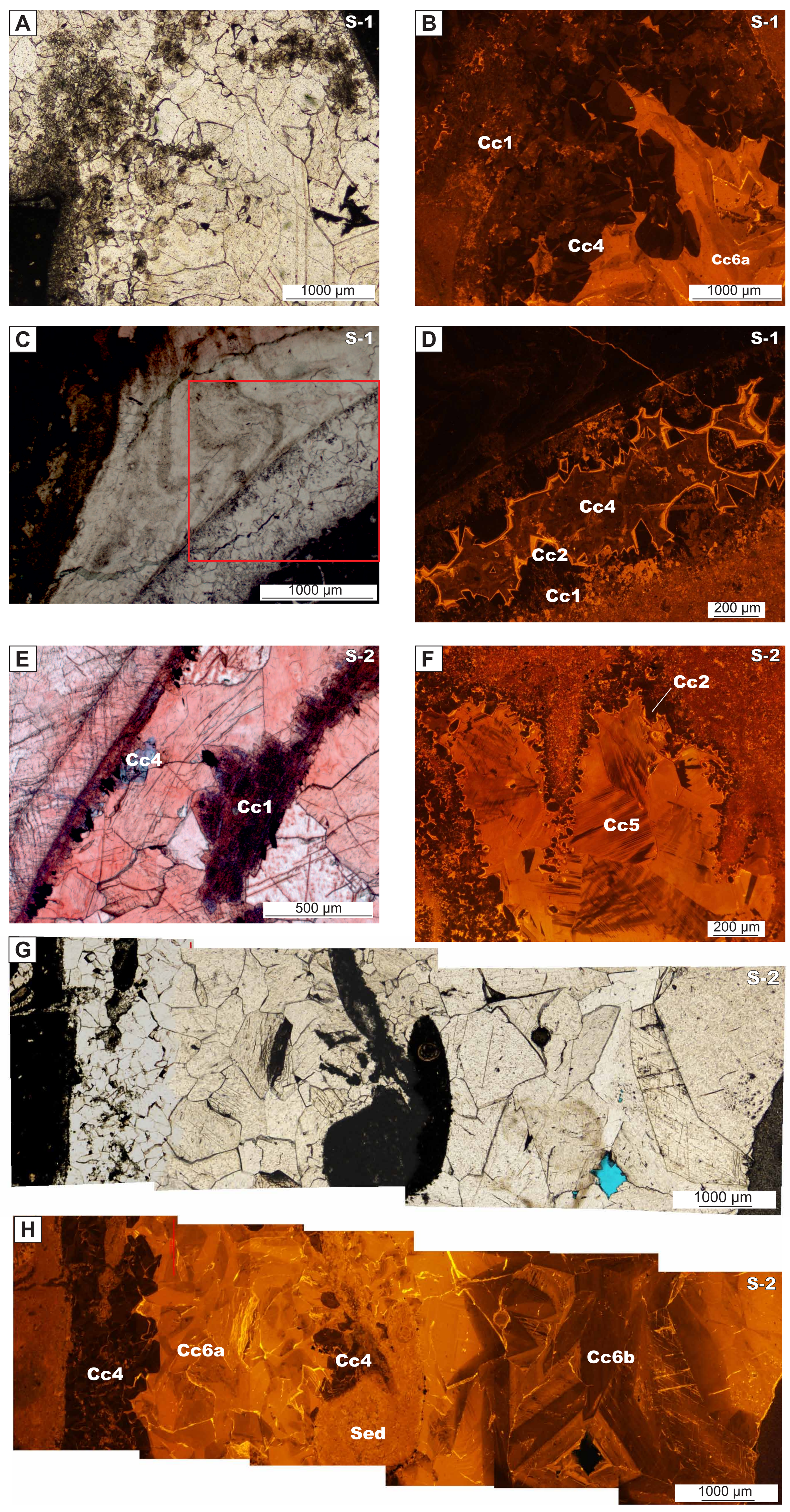


Figure 15. Microphotographs under plane light and cathodoluminescence of the main cements in well 8. **A-B)** Aragonitic rudist shell partially neomorphised and partially dissolved. Within the mouldic porosity cements Cc4 and Cc6 precipitate. **C-D)** Rudist fragment. The calcitic shell mantains the structure whereas the aragonitic one has been neomorphised and dissolved, precipitating later Cc2 and Cc4 cements. **E)** Note the patchy ferroan character of neomorphic calcite. **F)** Mouldic porosity filled with calcite cements Cc2 and Cc5. **G-H)** Sequence of later calcite cements from Cc4 to Cc6. A later dissolution is observed.

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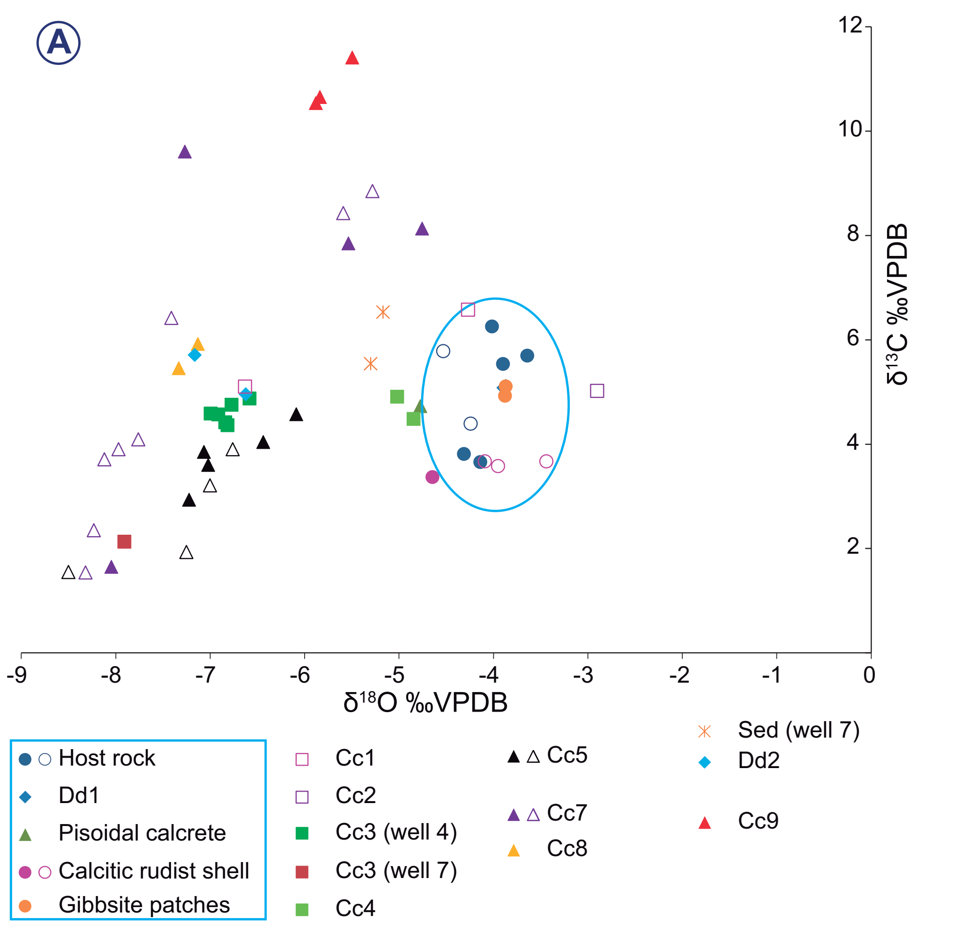
Petrographic summary

According the petrographic characteristics and the crosscutting relationships of the cements identified in the three wells, a global sequence is proposed (Table 1).

Table 1. Global sequence of cements

Well 7	Well 4	Well 8	Global sequence of cements
	Dd		Dd1
	Gibbsite		Gibbsite
Py	Py	Cc1+py	Cc1 +Py
Cc0	Cc0	Cc2	Cc2
Cc1	Cc1 (a,b,c)		Cc3
	Cc2		Cc4
	Cc3	Cc3+py Cc4	Cc5
	Cc4		Cc6
	Cc5	Cc5	Cc7
	Cc6	Cc6	Cc8
Dd			Dd2
Cc2			Cc9

Geochemistry



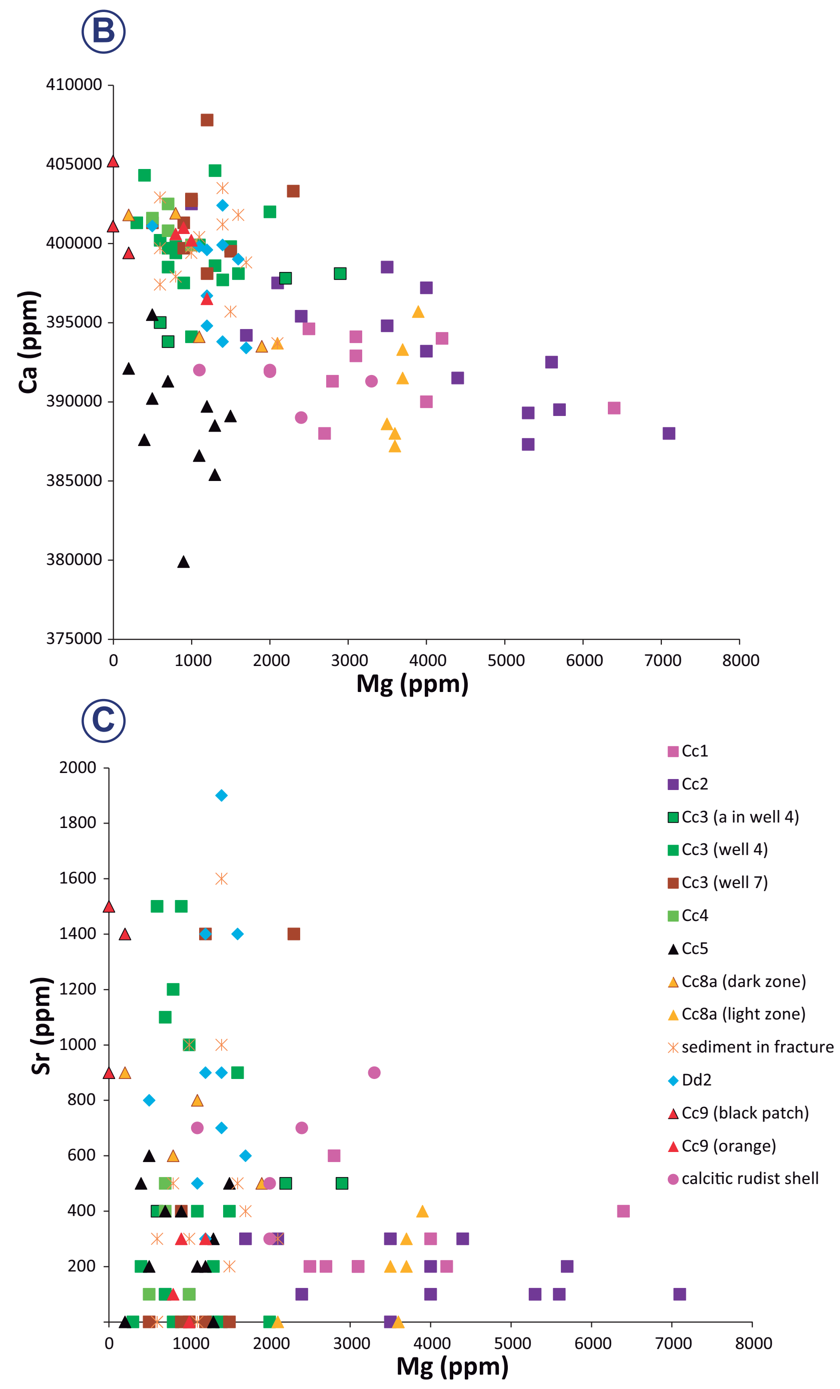


Figure 16. A) δ18O-δ13C crossplot of the different calcite cements in the studied wells. Note the data alignement of ferroan (Cc5) and post-ferroan (Cc7-Cc8). Close symbols are new data obtained in this study whereas open symbols are data from Raven & Dickson (2007). B) Ca vs Mg crossplot. C) Sr vs Mg crossplot.

4. CONCLUSIONS

From petrographical observations and geochemical analyses, the following diagenetic sequence with its relative diagenetic environments is proposed (fig. 17):

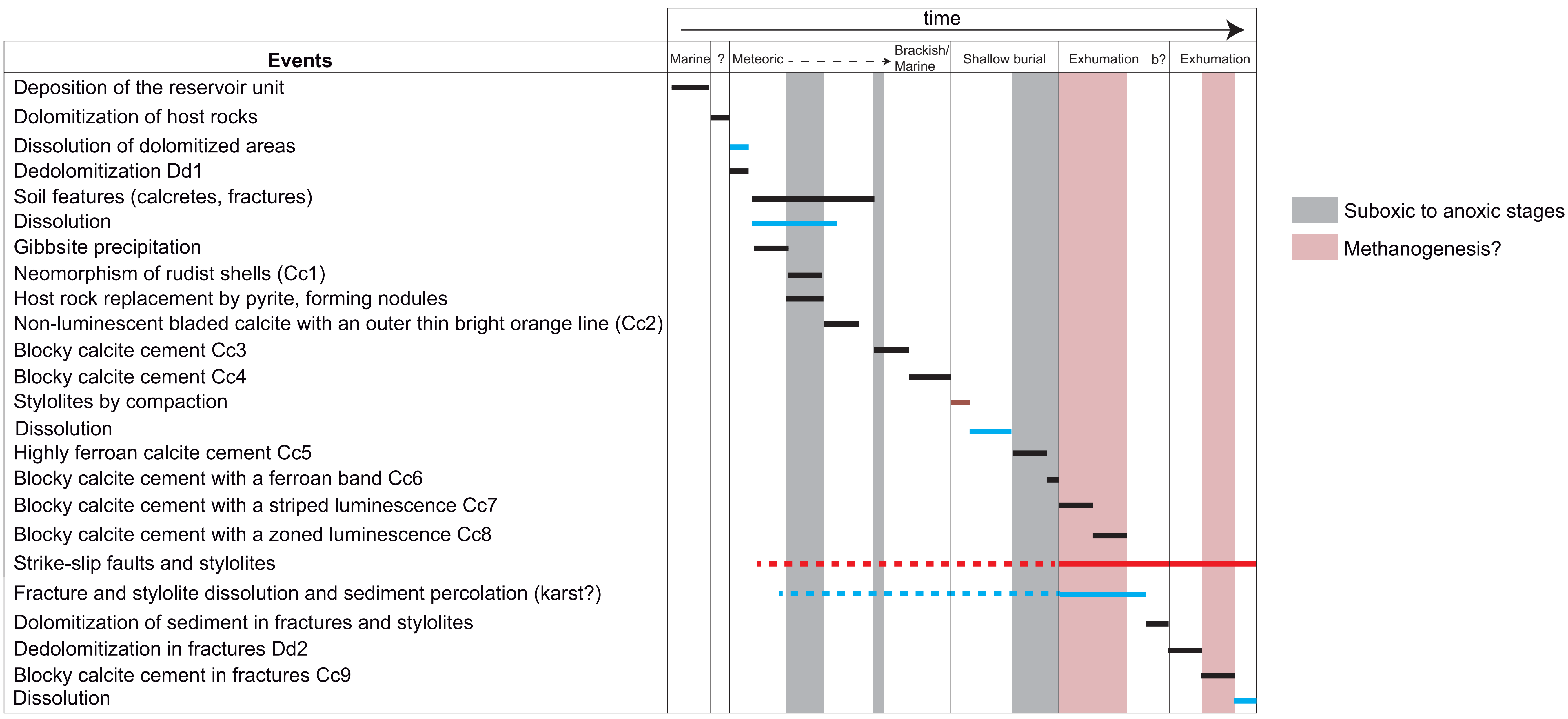


Figure 17. Preliminary diagenetic sequence proposed from wells 4, 7 and 8.

Meteoric diagenesis is very important as demonstrated by the high presence of rhizocretions, vugs and early fractures, especially in well 4. Meteoric cements not only occlude the aforementioned mesoporosity but also the matrix microporosity by means of gibbsite precipitation. These processes generate an early high heterogeneity in the spatial distribution of porosity and permeability.

Bioclasts, such as rudists and corals, which generate big moulds, control the presence of late cements related to burial and possibly later exhumation.

Methanogenesis could be triggered by the percolation of meteoric water through unconformities and fractures, carrying in surface bacterial communities, and its mixing with Ca-rich formation waters within an organic-rich unit. This mixing may explain the covariance between O and C-isotopes observed in calcite cements Cc7 and Cc8.

Tectonic fractures show karstic features (i.e. laminated sediment) and have acted as conduits for dolomitizing and later dedolomitizing fluids. Up to now, cements in tectonic fractures seem to be different from those in moulds and vugs, pointing to the absence of a cross-fault flow and a minimal effect on the small-scale porosity of the host rock.

Strike-slip activity increased during the Upper Cretaceous, linked to the Alpine 1 tectonic phase (Zampetti et al. 2014). Therefore, calcite cement Cc9 might be related to this time.

In conclusion, dissolution and calcite cementation are the most important processes in controlling reservoir properties. The net effect of early calcite precipitation is the partial reduction of porosity but a significant decrease in permeability.

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ACKNOWLEDGEMENTS

This work is part of ongoing studies on Al Shaheen field being carried out under a PSA with QP.

The stable isotopy, the electron microprobe, and the SEM analyses were carried out at 'Centres Científics i Tecnològics (CCiT)' of the Universitat de Barcelona. DGICYT Spanish project CGL2010-18260 and 2009SGR-1451 Consolidated Sedimentary Geology Research Group are also thanked.