

PS Evidence of Exposure of the Upper Cretaceous Congost Carbonate Platform and Implications for Emergent Surfaces Identification from Subsurface Data*

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Search and Discovery Article #30512 (2017)**

Posted August 14, 2017

*Adapted from poster presentation given at AAPG 2017 Annual Convention and Exhibition, Houston, Texas, United States, April 2-5, 2017

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Abstract

Understanding the nature of emergent surfaces is critical to the development and production of carbonate reservoirs as they can coincide with areas of high porosity and permeability (e.g. thief zones) or degradation of reservoir properties (flow baffles). They can also be key surfaces for field- and basin scale correlation. Nevertheless, emergent surfaces are highly variable in character. Although it is possible for karstic terrain to form during geologically short time periods, on some platforms several million years of exposure can be invisible in the succession. The Congost Platform in the Tremp Basin, Spanish Pyrenees, is Turonian-Coniacian in age. It developed basinward of the underlying Pradina Platform after a fall in global sea level and comprises two principle successions. The lowermost succession comprises coral-rudist rich skeletal grainstones interbedded within skeletal wackestone, deposited within a shallow water lagoon fringed by a platform margin shoal. A subsequent fall in sea level in the mid-late Turonian led to a further basinward shift in facies belts, forming a platform fringed by corallgal boundstones. Platform growth was terminated by emergence in the early Coniacian. The emergent surface at this upper bounding surface shows little evidence for karstification. Petrographical data indicates dissolution and cementation of precursor aragonitic shell fragments by sparry calcite cements. Under CL, most pore filling cements show a dull-non luminescent-dull-bright-dull concentric zonation, with a gradual evolution from non-ferroan to ferroan calcite. It is possible that the oldest, non-ferroan calcite was precipitated from meteoric water, but it is a volumetrically minor phase. Residual porosity has been occluded by burial calcite cements. A slight depletion in d13C beneath the unconformity is the only other evidence for diagenetic modification by meteoric water. Consequently, despite a humid climate and a lengthy period of emergence, the unconformity at the top of the Congost Platform is subtle; stabilization of aragonitic grains created minor amounts of mouldic porosity, but this is not visible at a macroscale. This has implications to the correlation of carbonate platforms from subsurface data, since such surfaces will have a weak petrophysical response, and may be hard to consistently identify from rock physical data. It also implies that in equivalent subsurface settings, contrasts in petrophysical properties may not occur.

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Introduction

- Understanding the nature of emergent surfaces is critical to the development and production of carbonate reservoirs as they can coincide with areas of high porosity and permeability (e.g. thief zones) or degradation of reservoir properties (flow baffles). They can also be key surfaces for field- and basin scale correlation. Nevertheless, emergent surfaces are highly variable in character. Although it is possible for karstic terrain to form during geologically short time periods, on some platforms several million years of exposure can be invisible in the succession.
- The development of the Upper Turonian to Middle Coniacian Congost platform, located in the Spanish Pyrenees is believed to have ended by a period of subaerial exposure (Booler 1994). However, there is a limited macro-scale evidence of emergence on the platform-top.
- The aim of this project is to determine why evidence for emergence is scarce and assess how similar, correlative surfaces might be identified from subsurface data. This was achieved through the following objectives:
 - Field mapping and logging of the Congost Platform
 - Petrographical characterisation of the platform to describe microfacies, diagenetic overprint and porosity evolution
 - Stable isotopic analysis to assess whether there is geochemical fingerprint that can be related to platform emergence

Workflow



Field / Basin Scale

Logging, mapping and correlation of Cenomanian-Campanian carbonate platforms within the Tresp Basin to reconstruct platform growth within the context of the Tresp Basin.



Depositional History

Detailed logging, mapping, digital outcrop modelling and sampling of the Congost Platform in order to define microfacies, lithofacies and gross depositional environment. From here, the sedimentary architecture of the platform was reconstructed.



Petrographical analysis

Description of 62 polished thin sections using transmitted light and cathodoluminescence to qualitatively describe the paragenetic history of the Congost Platform. Changes in cement history with distance from the top Congost unconformity were also noted.

Geochemistry

Stable isotopic analysis ($\delta^{13}\text{C}$, $\delta^{18}\text{O}$) and major element analysis (in situ electron microprobe analysis) to identify geochemical variability beneath the top Congost unconformity.



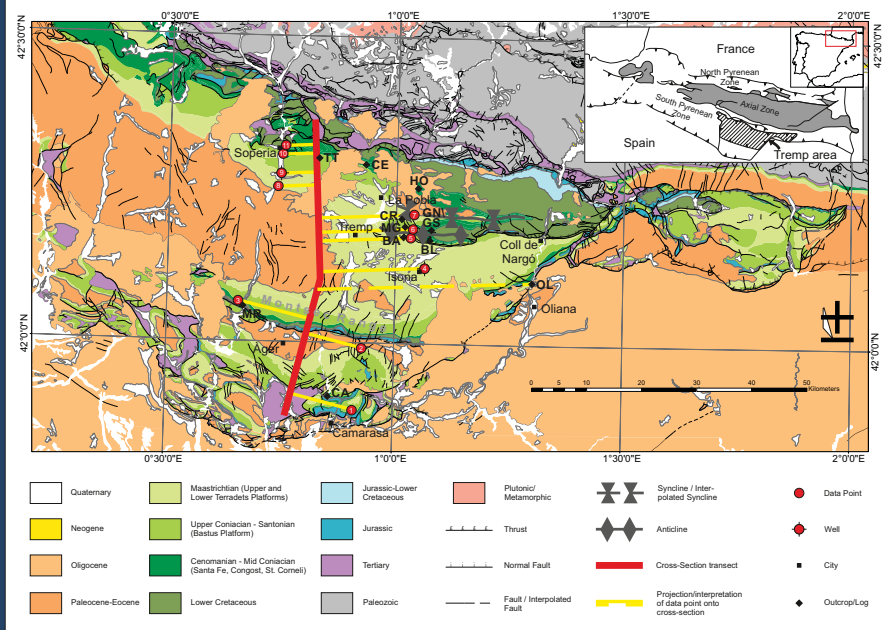
Diagenetic Pathways and Porosity evolution

Integration of all datasets to interpret the evolution of porosity within the Congost Platform, and in particular beneath the top Congost unconformity.

References

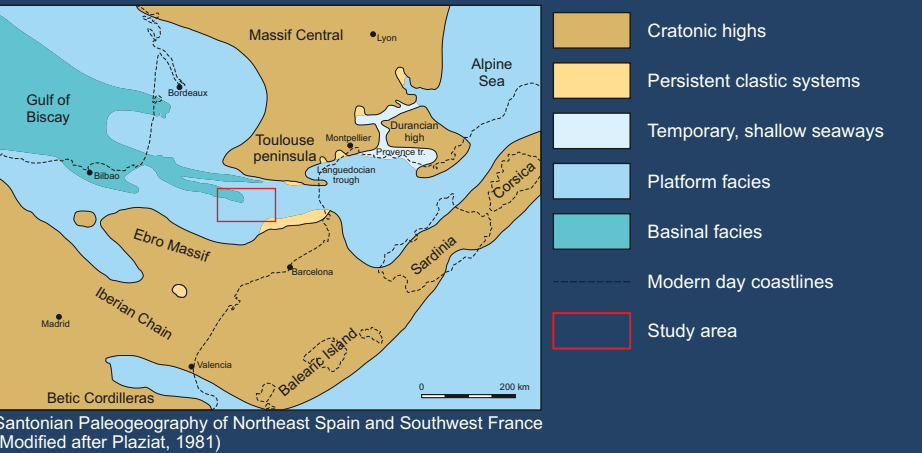
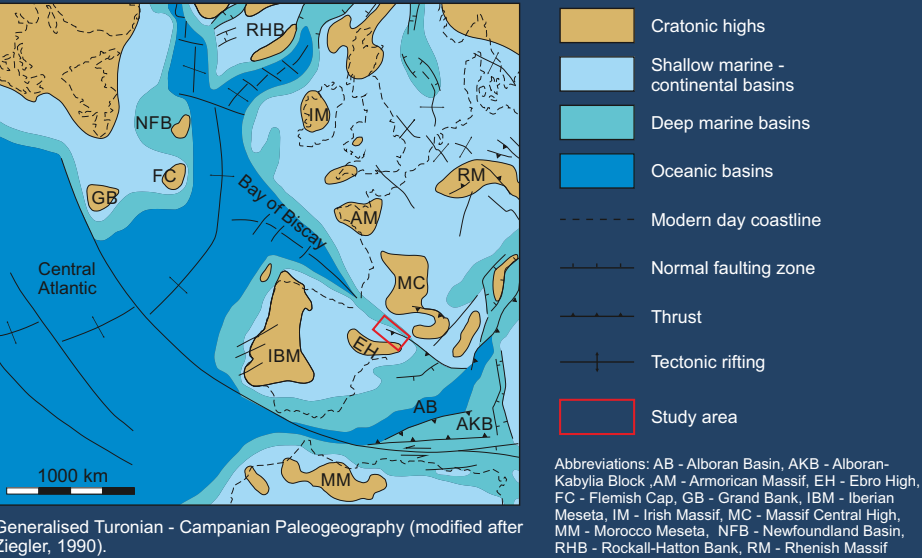
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Geological Background



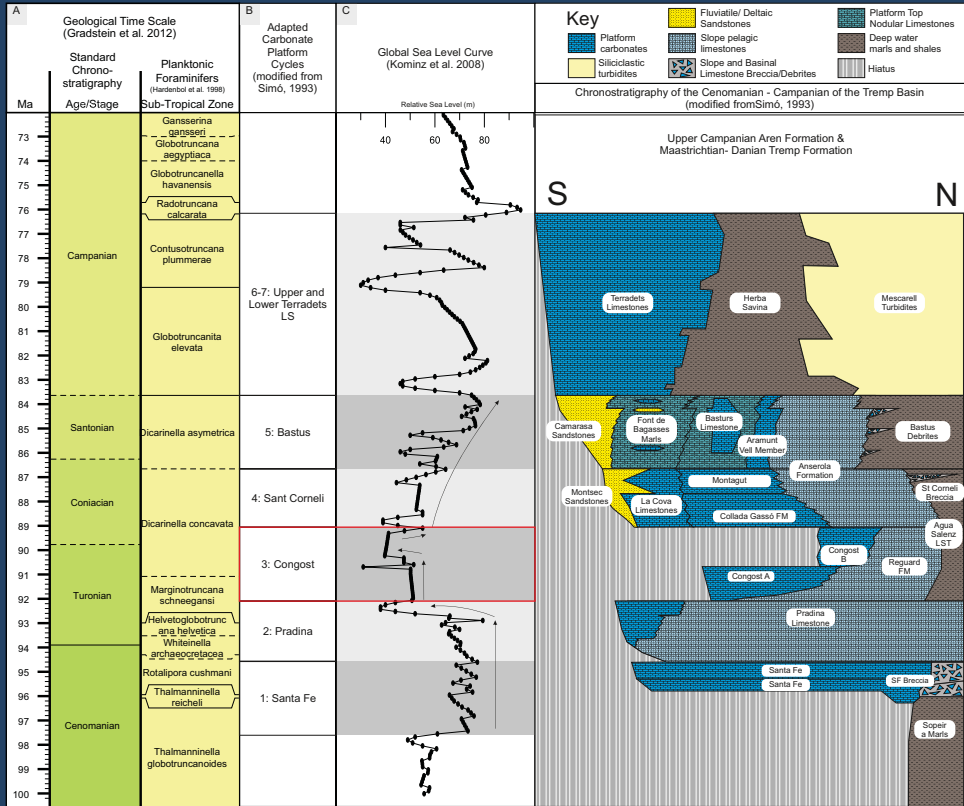
Geological map of the study area (Modified from Institut Cartogràfic i Geològic de Catalunya, 2015). Top right: structural framework (modified from Simó, 1986). Marked in red line is the transect along which cross-sections were constructed. Numbers in red circles represent the data points used to construct the cross-section.

Paleogeography



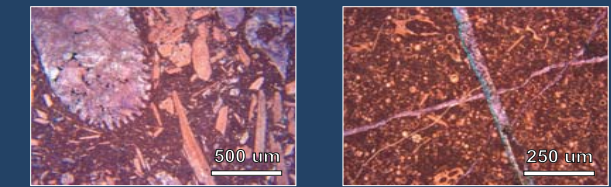
- Carbonate deposition in the study area during the late Cretaceous was strongly influenced by the anti-clockwise rotation of the Iberian plate and convergence with the European plate, which eventually led to the Pyrenean Orogeny.
- A narrow seaway formed between the Tethys Ocean and the North Atlantic, where several sequences of carbonate platforms were sequentially established.
- South of the study area, the Ebro High served as a source of clastic sediment input, which resulted in mixed carbonate-siliciclastic sedimentation during the Coniacian and Santonian.
- The sub-tropical paleo-latitude (30-40° North), with largely clear light conditions, was favourable for coral and rudist growth within a shallow water lagoon.

Chronostratigraphy



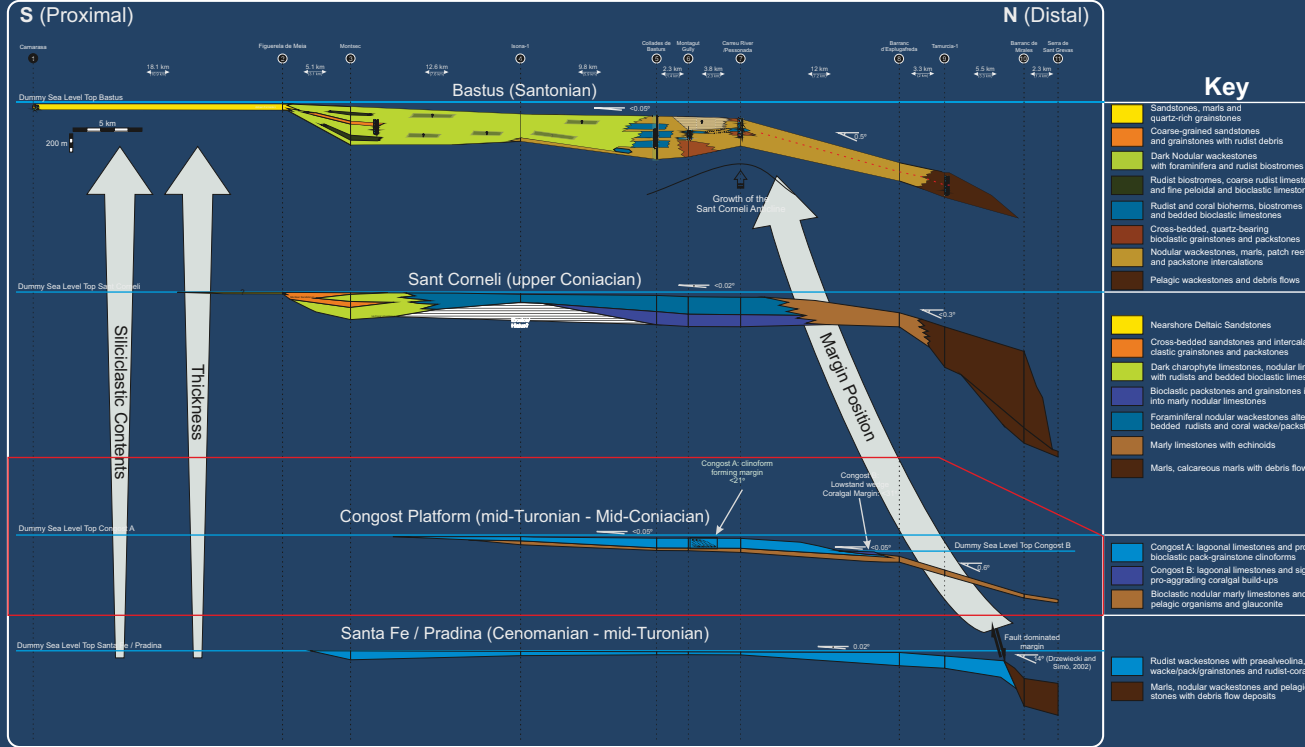
- During the Upper Cretaceous, carbonate sedimentation dominated in the Tresp Basin. A succession of six separate platforms separated by unconformities have been mapped.
 - A fall in relative sea level in the Turonian led to a basinward migration of carbonate sedimentation during growth of the Congost Platform, resulting in a lowstand wedge.
 - Through the combination of local subsidence and net global sea-level rise, the margins of the successive platforms back-stepped from the mid Turonian-Santonian.
- ### The Congost Platform
- Duration ca. 1.5-2.5 Ma.
 - Produced a total of 200 m of sediment column (compacted thickness).
 - The Congost Platform is divided into two sub-platforms, A and B, with the younger Congost B platform interpreted as a Lowstand wedge that formed through a fall in relative sea level.
 - The Congost A Platform is characterised by skeletal grainstone-dominated platform margin with steeply dipping clinoforms (up to 21 degrees).
 - The margin of the Congost B platform is defined by a prograding-aggrading corallgal buildup.
 - A constant, minor supply of siliciclastic sediment source is evidenced by a consistent amount of silt-grade, mono-crystalline, angular, quartz (<7%), and is interpreted to have been derived from the southeast of the platform.

The underlying Santa Fe and Pradina Platforms



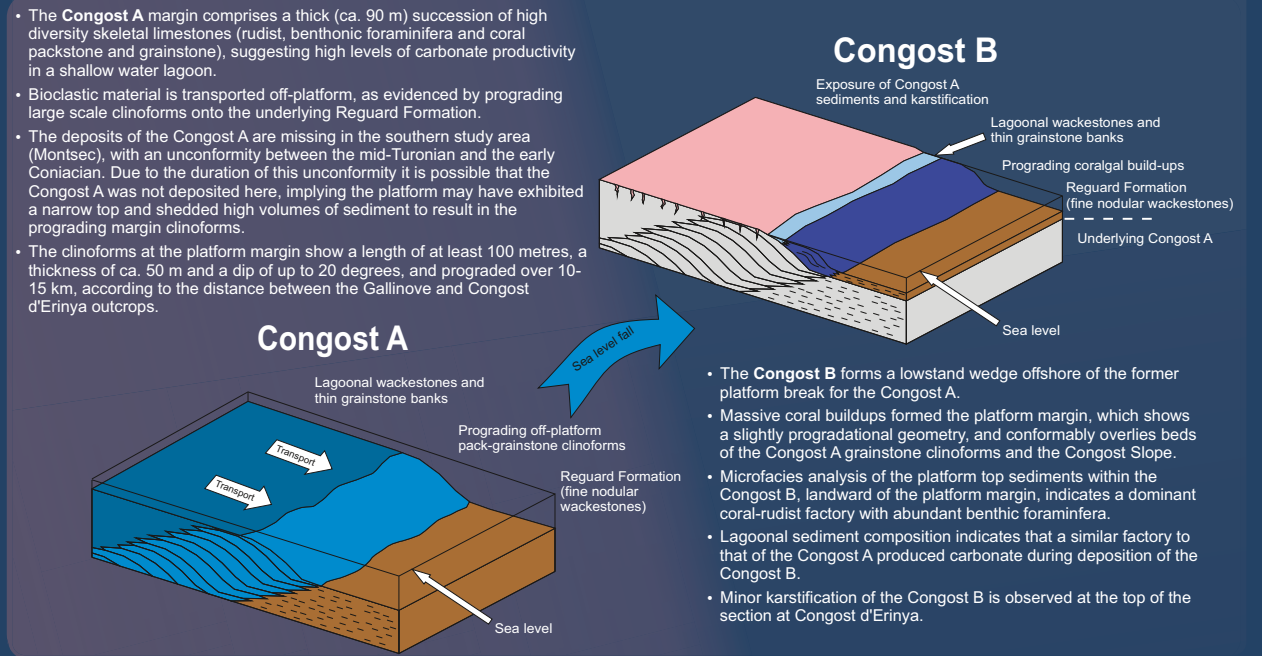
- The Santa Fe shows a very consistent thickness across the study area, thickening only in the very north.
- It is composed almost exclusively of skeletal wackestones and floatstones (left), dominated by poorly sorted rudist debris, echinoderms and benthic foraminifera, interpreted to have been deposited within a low energy lagoon.
- The Pradina Platform has a uniform thickness across the entire study area and consists exclusively of pelagic-wacke and packstones, suggestive of deposition on a eutrophic platform (right).

Platform and Basin Evolution

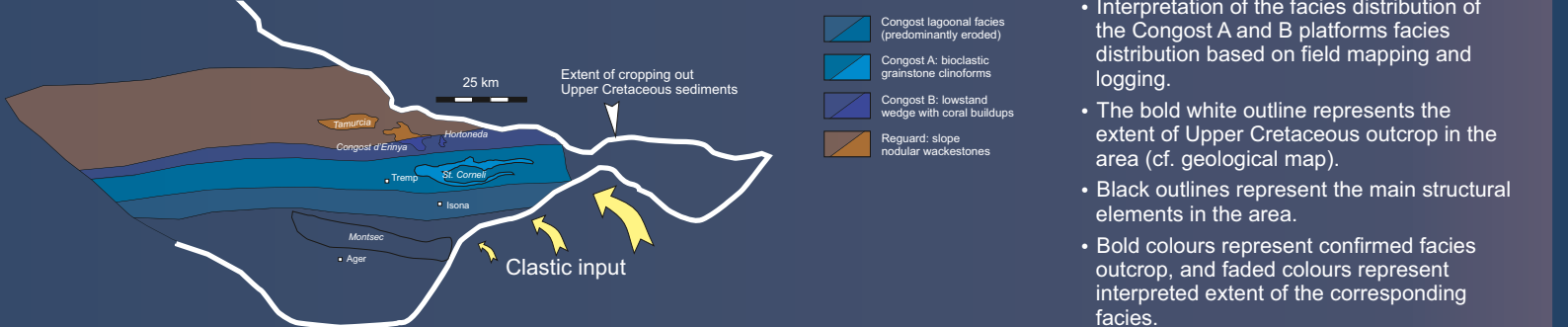


- Cross section of the Cenomanian-Santonian carbonate platforms of the Tresp basin. For localities refer to geological map. From bottom to top:
- The Santa Fe Platform, showing a thin, low energy platform top and a steep fault-controlled margin with rudist and coral build-ups, and the Pradina Platform, posing a thin pelagic drape following the Cenomanian-Turonian OAE.
 - The Congost Platform, showing a lower phase of progradational packstone-grainstone clinoforms and an upper phase of a lowstand wedge and corallgal buildups
 - The Sant Corneli Platform, a distally steepened ramp with rudist and coral communities
 - The Bastus Platform, a low angle rimmed shelf with rudist buildups, a gentle slope, and a deltaic system landwards

Depositional Environments



Facies Distribution Map



- Interpretation of the facies distribution of the Congost A and B platforms facies distribution based on field mapping and logging.
- The bold white outline represents the extent of Upper Cretaceous outcrop in the area (cf. geological map).
- Black outlines represent the main structural elements in the area.
- Bold colours represent confirmed facies outcrop, and faded colours represent interpreted extent of the corresponding facies.

Evidence of Exposure of the Upper Cretaceous Congost Carbonate Platform and Implications for Emergent Surfaces Identification From Subsurface Data

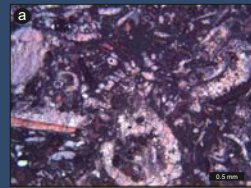
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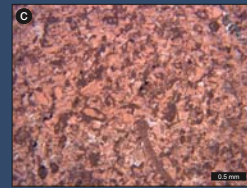
Congost A

Platform Top



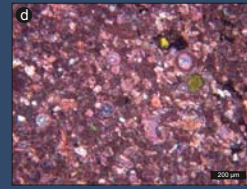
- Coral and Rudist Float/Rudstones and wackestones with intercalations of bioclastic grainstones.
- Diverse biota: mainly rudist and coral fragments, but also abundant miliolids and various other foraminifera, echinoids, bivalves, bryozoans and algae
- Interpretation: Shallow platform-top carbonate factory dominated by corals and rudists.

Margin



- Large-scale cross-bedded packstones and grainstones. Majority of the grains are finely fragmented bivalve shells and rare calcispheres.
- Textures grading from packstones to grainstones within the internal coarsening up sequences. Glauconite enriched in distinct horizons.
- Interpretation: Large-scale clinoforms of well-sorted bioclastic material being transported off-platform.

Slope



- Nodular marly limestones and marl with glauconite.
- Fine grained bioclasts, grains of quartz and locally glauconite. Thoroughly bioturbated. Planktonic foraminifera, calcispheres, hyaline foraminifera, sponge spicules, ostracods, echinoderms, some bivalves. Large oyster fragments locally.
- Interpretation: Bioturbated slope deposits with pelagic fauna and periods of low sedimentation (glauconite formation)

Summary

- The development of the Congost Platform followed the recovery of carbonate production above the OAE2 (manifested in the calcisphere wackestones of the Pradina Platform). The deposits are mostly shallow marine, bioclastic carbonates, with the slope occurring as fine grained nodular wackestones with occasional glauconite grains.
- There are two phases for the Congost platform evolution: the first phase is characterised with oblique, large scale prograding clinoforms (Congost A) and the second phase poses a lowstand wedge with sigmoidal marginal coralgal buildups (Congost B).
- This implies that the Congost A would have been exposed during the formation of the Congost B lowstand wedge. This is estimated at ca. 1.5 My, based on sediment thickness of the Congost B and a combined duration of the Congost A&B of 3 My.
- At the Borrell locality, the Congost A platform top deposits are overlain by the Sant Corneli platform. The boundary is observed in the field to be sharp (cf. log on the left), and there is no evidence of karstification.
- The Sant Corneli Platform shows reddish bioclastic nodular wackestones and packstones, with common organisms being miliolids, oyster and other bivalve shells, and occasional in-situ domal and platy corals. These are interpreted as shallow platform interior deposits
- At Congost d'Erinyà, the boundary between the Congost B and the overlying Sant Corneli Platform is observed to be sharp (cf. log on the right).
- The top of the Congost B shows an interval of 12.5 m characterised by brecciated limestones consisting of Congost B platform top material. This is interpreted as karstification occurring as a result of emergence of the platform.
- The total duration of emergence of the Congost B platform is unknown.
- Siliciclastics are present throughout the Congost in minor amounts (<2%), and there is no evidence of clastic incursions during lowstands.

Platform Top



- Sheet-like coral and rudist wacke/pack/float/rudstones with intercalations of bioclastic grainstones.
- Diverse biota dominated by in-situ corals and rudists. It includes benthic foraminifera, gastropods, brachiopods, peloids and rare calcispheres. Intercalations of well sorted grainstones: rudist and coral fragments, foraminifera and peloids
- Interpretation: Platform Top facies. Backreef lagoon forming behind build-ups at the margin of a lowstand wedge.

Margin



- Internally massive coralline floatstones/ boundstones
- Relief forming build-ups dominated by micrite and in-situ corals, and abundant coralline red algae
- Interpretation: Coralline Build-ups forming at the margin of a lowstand wedge.

Slope



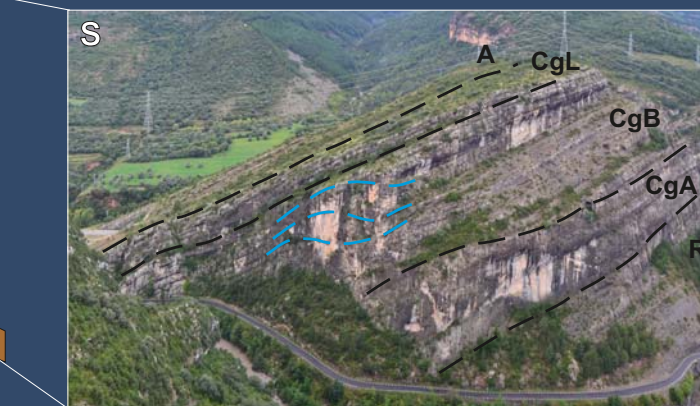
- Nodular marly limestones and marl with glauconite.
- Fine grained bioclasts, grains of quartz and locally glauconite.
- Thoroughly bioturbated.
- Planktonic foraminifera, calcispheres, hyaline foraminifera, sponge spicules, ostracods, echinoderms, some bivalves.
- Large oyster fragments locally.
- Interpretation: Bioturbated slope deposits with pelagic fauna and periods of low sedimentation (glauconite formation).

Congost B

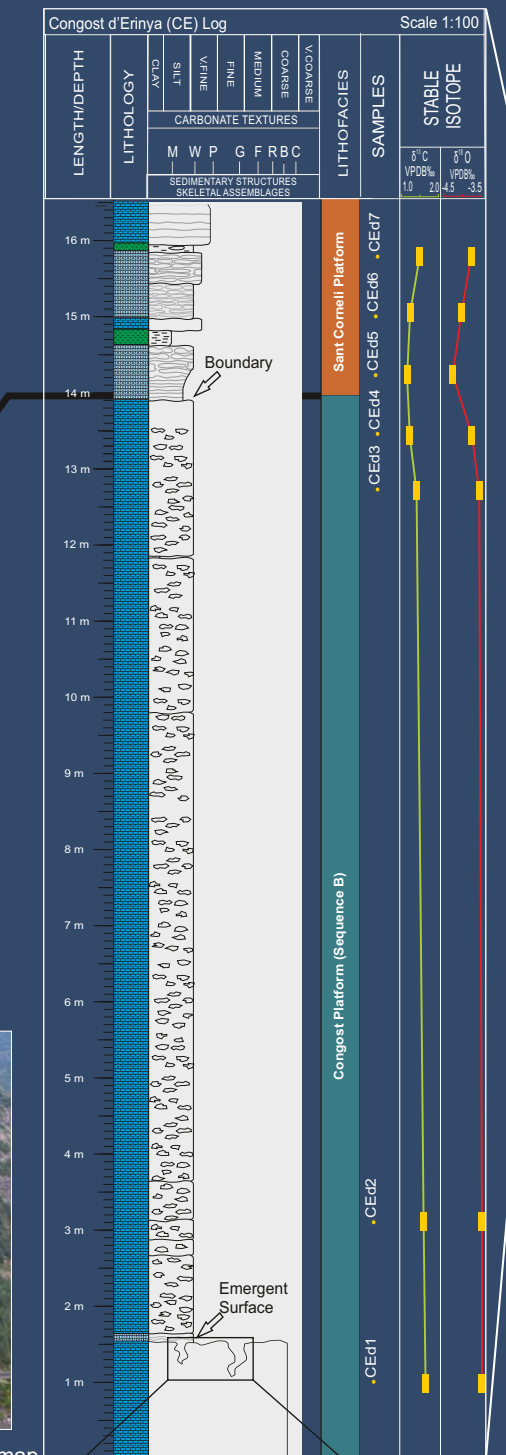
N (Distal)

Boundary 2

Congost B Lowstand Wedge

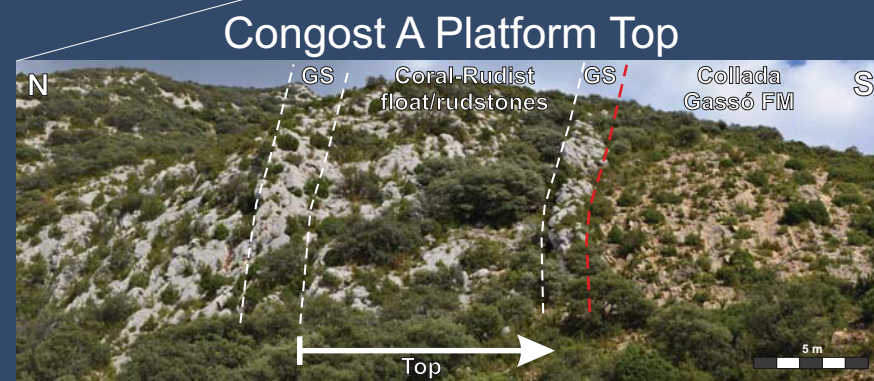


- The outcrop in the Congost d'Erinya gorge (for locality see geological map on left panel) shows an exposure of the Congost B platform margin.
- The outcrop is tilted towards 130/60 SW
- Five major units are recognisable in this 200m tall outcrop:
 - R: Slope nodular packstones and wackestones ("Reguard Formation")
 - CgA: Congost grainstone beds (equivalent to Congost A)
 - CgB: Congost B coralline units
 - CgL: Congost lagoonal wackestones, floatstones and grainstone bars
 - A: Nodular pelagic slope deposits of the overlying Sant Corneli Sequence ("Anserola Formation")
- The outcrop was digitised using photogrammetry applications in order to allow quantitative study of the exposed geometries



Photograph of brecciated limestones at the top of Congost B Platform. The brecciation is interpreted to be the result of subaerial exposure of the platform top.

S (Proximal)
Boundary 1

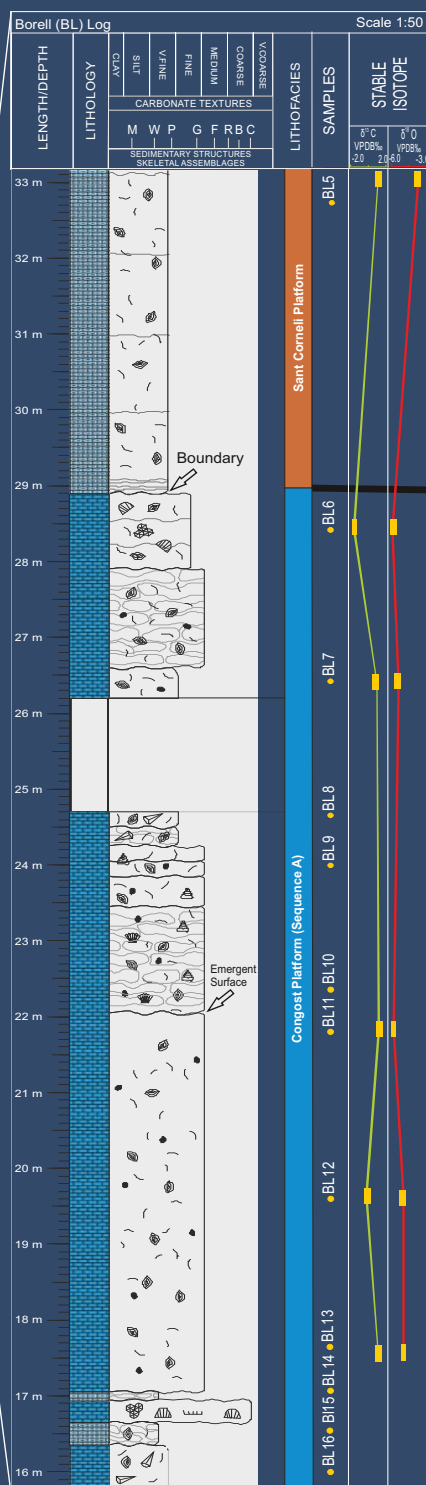
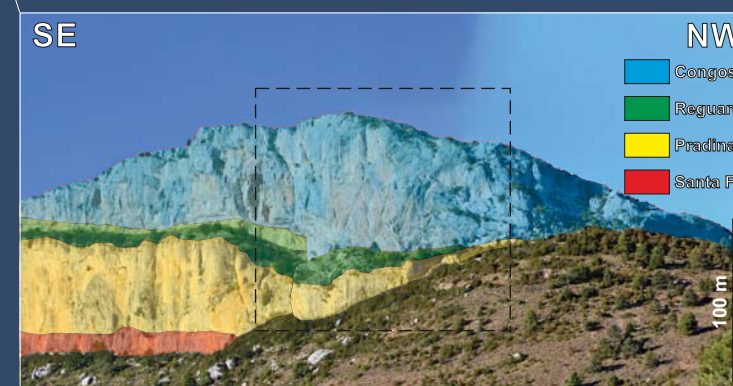


- The platform top section at Borell shows intercalations of rudist-coral float/rudstones and units of bioclastic grainstones (GS).
- The termination of the Congost A and change to the overlying Collada Gassó Formation (Sant Corneli Platform) is clearly visible (red dashed line). Note outcrop is tilted.
- It is marked by an abrupt facies change to fine-grained marly nodular wackestones with shell fragments, miliolids, rare oysters and corals



- The Platform margin section of the Congost A at Gallinove shows large-scale northward-prograding clinoform structures.
- These are ca. 100 m, up to 8.8 m thick and show a relief of up to 10 m. Their maximum angle is 20.8°
- The limestones consist of fine grained bioclastic packstones and grainstones.
- They are interpreted to be the result of margin progradation through offshore sediment transport from the platform top.
- Horizons enriched in glauconite imply periods of low sedimentation rates.

Congost A Margin

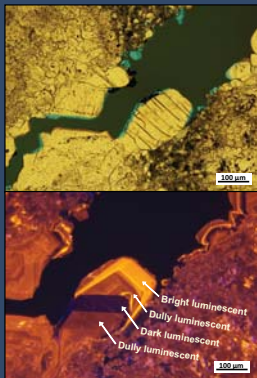


- Limestone
- Nodular Cement
- Shell fragments
- Peloids
- Miliolid foraminifera
- Platy Coral
- Echinoderms
- In-situ Rudist
- Rudist Colonies
- Corals
- Coral fragments
- Gastropods
- Bivalves

Pore Filling Cements

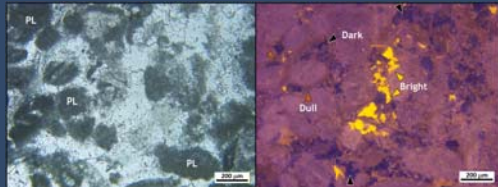
- Blocky and sparry calcite cements are the most common cement types in the Congost facies. Blocky cements were encountered mainly in moldic pores of former aragonitic allochems, and they are characterised by a dull-luminescent – non-luminescent – bright luminescent sub-zonation in CL.
- Sparry calcite cements filled moldic porosity as well as inter-particle pore space. They are limpid and have a non-luminescent inner zone and an outer, bright luminescent zonation under CL.
- Zonation is characteristic of blocky/equant calcite spar with distinct dull luminescent – bright luminescent subzonation.
- These cement types are more abundant in sections beneath the unconformity with the zoned calcite cement only encountered in Congost B.

Zoned Calcite Cement



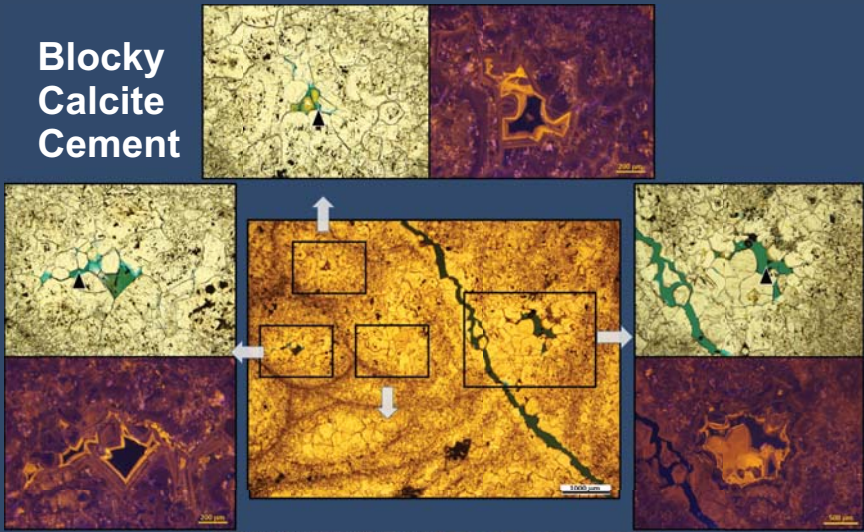
Paired TL and CL images of a large calcite crystal showing clear zoning, typical of blocky calcite cements.

Sparry Calcite Cement

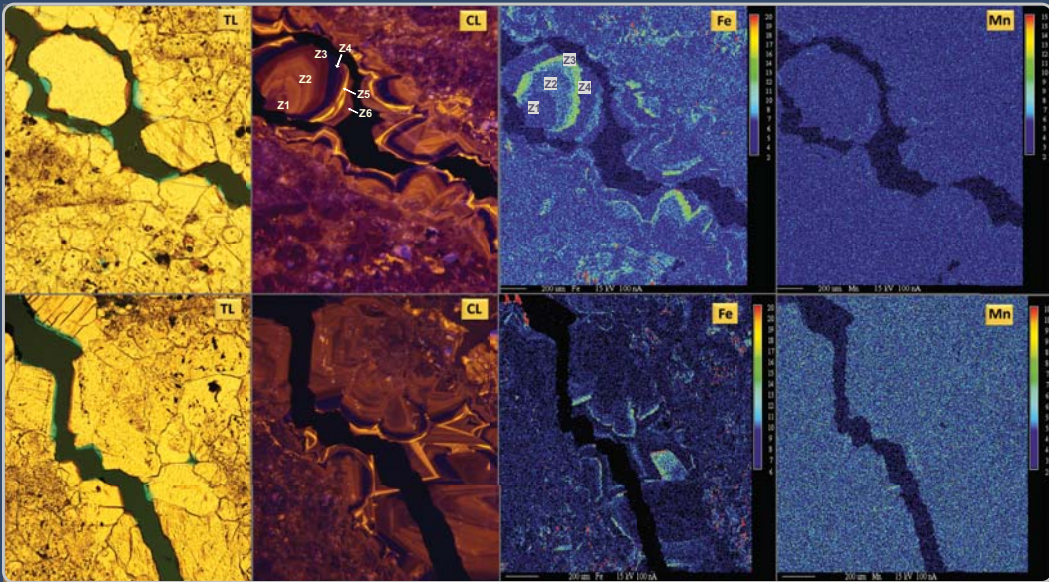


TL image clearly shows the micritised peloids (PL). The interparticle cement has two CL signals; earlier non-luminescent (black and orange arrows) and a later bright yellow to orange towards the centre of the image (yellow arrows).

Blocky Calcite Cement



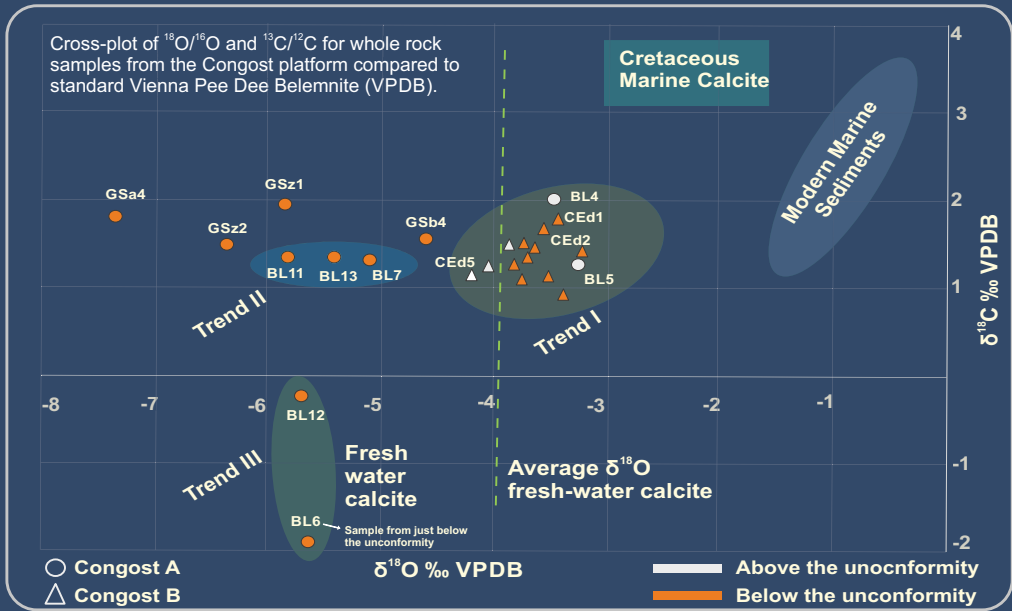
TL and CL images taken from a sample just below the sequence boundary. Blocky calcite cement, filling a former coral colony, shows delicate growth zoning defined by differing brightness of the phases. Some moulds were completely occluded while others still have some porosity (arrowed).



TL: Transmitted light CL: Cathodoluminescence

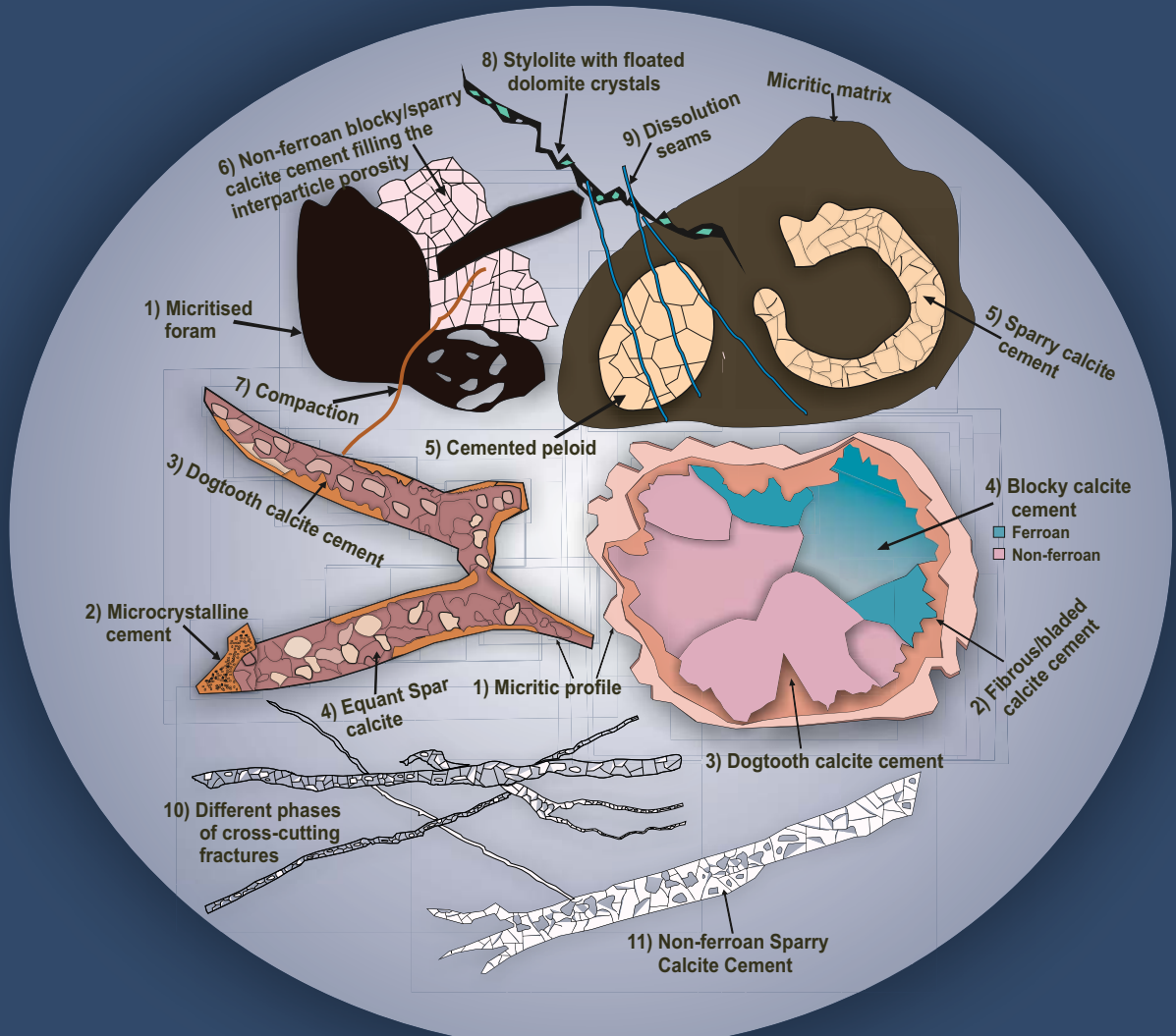
Stable Isotope Geochemical Analysis

- $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ were measured on bulk rock samples from Gallinove, Borell (Congost A) and Congost d'Erinya (Congost B) localities, sampled at various intervals beneath the uppermost Congost unconformity.
- Most samples show a slight depletion in both $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ compared to marine calcite (Trend I), which could reflect slight modification of samples by meteoric water.
- A cluster of samples (Trend II), 2-10 m below the unconformity, are more depleted in $\delta^{18}\text{O}$. It is interpreted that they either contain abundant burial calcite cements or they have undergone cementation from meteoric water in a system where $\delta^{13}\text{C}$ is rock buffered.
- Two samples (Trend III) show distinctly depleted carbon and oxygen isotope ratios. These samples come from 1 m and 9 m beneath the Congost unconformity, implying localised precipitation of meteoric cements.
- The majority of the cementation is interpreted to have occurred either at the surface or in the shallow phreatic environment.

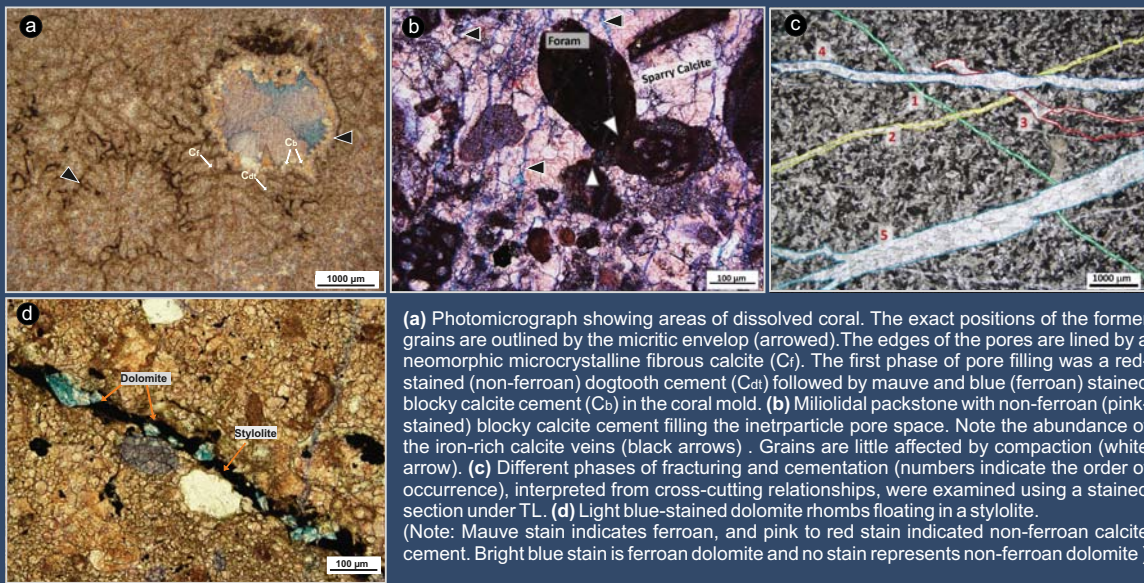


Diagenesis

- The grains within the Congost platform are pervasively micritised, consistent with formation within a shallow water lagoonal environment. Micritic envelops were developed upon almost all formerly aragonitic bioclasts. Micritisation normally occurs near the sediment/water interface.
- The neomorphic replacement of rudists and corals and precipitation of microcrystalline fibrous calcite was overgrown by dogtooth cement of varying sizes.
- In addition to the pore filling cements described filling primary and secondary macropores, calcite cements were also observed filling fractures.
- The fractures are encountered mainly in the grain-dominated facies (e.g. rudistid skeletal packstone and bioclastic grainstone).

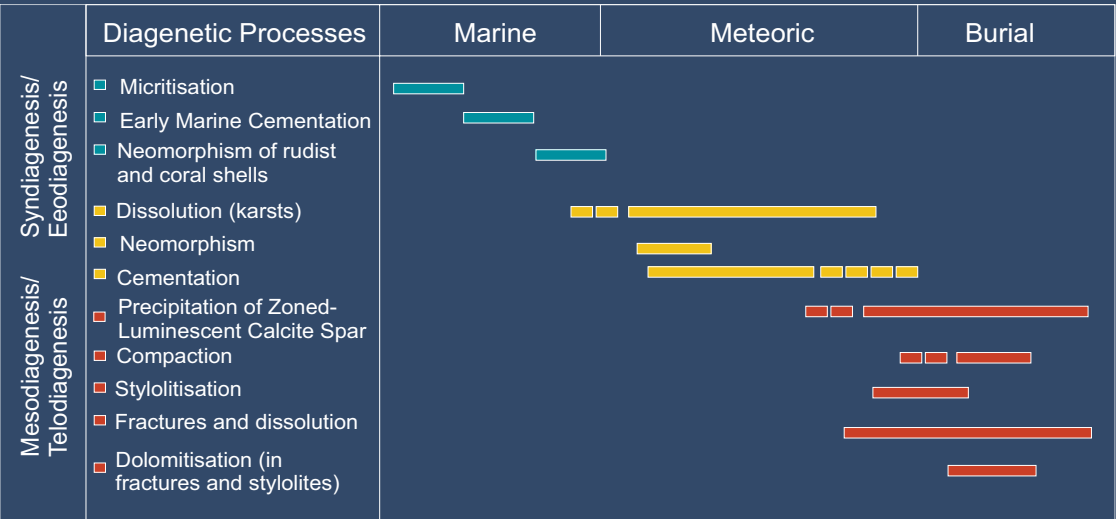


Sketch showing the main diagenetic features and their related cements observed in a number of thin sections from the Congost platform outcrops. The features are numbered to show their order of occurrence relative to other features in this diagram, they are not their absolute orders.



Conclusions and Outlook

- The Congost Platform showed two stages of development. The lower Congost A reached a thickness of ca. 90 metres, and the platform top is interpreted to have extended over few 10s km. The Congost A is characterised by a margin of prograding bioclastic packstone and grainstone clinoforms (> 100 m wide, ca. 50 m tall and <20 degrees steep), and a shallow-water platform top with a diverse biota.
- The later Congost B forms a narrow (few km wide, ca. 80 m thick) lowstand wedge with a steep margin (<30 degrees) of sigmoidally dipping coralg al build-ups.
- During the deposition of the Congost B lowstand wedge, the platform top of the Congost A is estimated to have been subject of emergence for ca. 1.5 Ma.
- Porosity generation was controlled by the dissolution of the aragonitic allochems (e.g. rudist). This pore space was largely occluded by pore filling calcite cements, which show evidence for continuous precipitation from the meteoric into the burial realm.
- The porosity enhancement at the top of the Congost platform, increasing towards the unconformity, is possibly a product of subaerial exposure. The low isotope ratios shown by samples from both Congost A and B could reflect slight modification by isotopically depleted pore-fluids, e.g. meteoric water.



Paragenetic sequence proposed from the petrographical and geochemical analyses of thin sections from Congost A and Congost B.

- Extensive dissolution, neomorphism and cement precipitation, in the presence of oxidised meteoric waters, probably took place under vadose/phreatic conditions resulting from meteoric exposure.
- Brecciated limestones at the top of Congost B suggest that Karstification took place during platform emergence.
- It is suggested that these features have resulted from multiple exposure events of short duration, taking into account the shallow nature of the aforementioned lagoons.
- The results of this study show that even when carbonate platforms undergo periods of emergence of ~1 Ma, this may be manifested by only subtle diagenetic features. As such they are unlikely to be resolvable on seismic data, and may be difficult to correlate with confidence from borehole data.

Acknowledgements

We would like to express our sincere gratitude to Dr Cathy Hollis for her supervision, help and support in this project and to Dr Richard Dixon for his advice and feedback. We are grateful to Jonathan Lavi for preparing the thin sections along with other field data used in this study, and for providing valuable insights into the study area. For help in the Cathodoluminescence and Electron Microprobe labs we would like to thank Dr Jonathan Fellowes. Further thanks are due to Aurelien G. Meyer for the fruitful discussions.

Special thanks to BP for providing the data and for the permission to publish this poster.