Laboratory Book

Carbonate Reservoirs

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Practical 1. Grain and Rock Description and Classification
Context Log Table

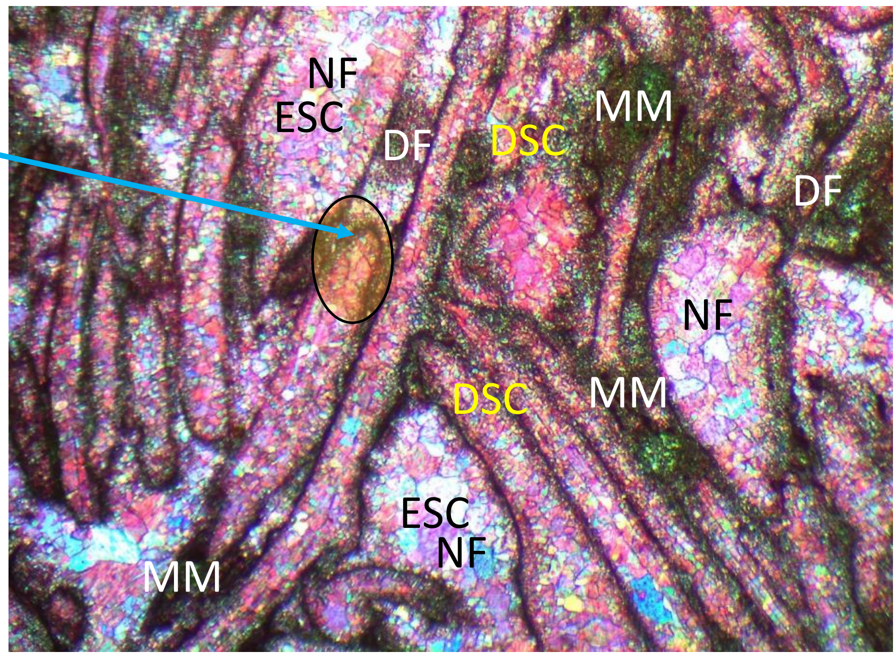
Sample	Description (Dunham and Folk)	Interpretation Processes	Interpretation Environment	Pore types Porosity history
414A Limestone	Packstone/ Unsorted biosparite	High energy, Aragonite replacement, disarticulation, micritization. Spar cementation and possible compaction.	Mid ramp platform, benthic, heterozoan factory	Intercrystalline, Low-porosity. Compaction and cementation affected.
7-409 Oolite	Oolitic grainstone / Oosparite	High energy affection of tidal agitation from super saturated warm water.	Warm shallow sea. Isolated flat top platform or ramp. Abiotic factory	Interparticle. High-porosity. Sorted rounded grains
405 Chalk	Mudstone-Wackestone / Biomicrite	Low energy. Burial in place of pelagic shells.	Warm deep water. Planktonic factory. Passive drape.	Microporosity grains. Medium-porosity.
188 Chalk with stylolites	Mudstone / Micrite	Low energy	Planktonic factory of the deep sea envrm.	Low porosity. Affected by compaction.
417 Crinoidal Limestone	Packstone / Packed biosparite	Low energy. Micritisation. Some cementation.	Cool water shallow marine system.	Interparticle. Microporosity. Medium porosity.

Limestone 414A

Observation:

- 0.5-1mm spary cemented grains with some micrite matrix
- Intact fragmentation with possible disarticulation of bivalves
- Grain supported fabrics
- Pore types present in the rock: low porosity
- Dunham: ***Packstone***
- Folk: ***Packed Biosparite***

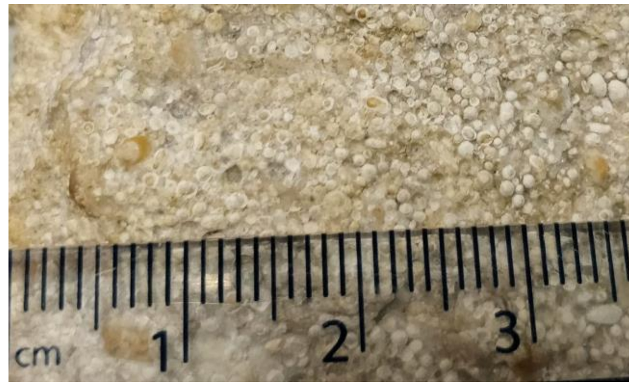
- Micrite Envelope
- Micrite Matrix (MM)
- Equant Spar Cement (ESC),
- Drusy Spar Cement (DSC),
- Dissolution Fabric (DF),
- Neomorphic Fabrics (NF)



Interpretation:

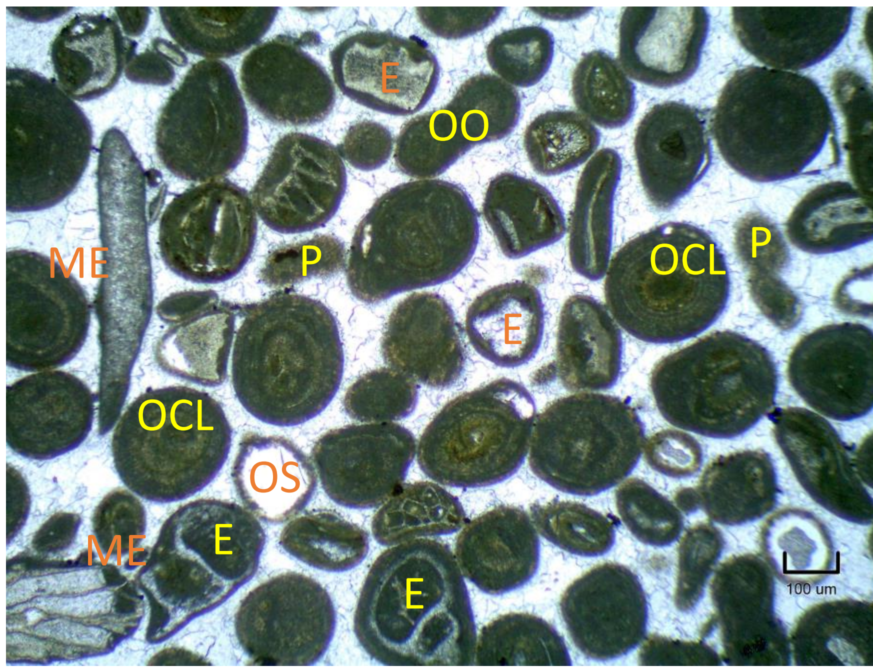
- High wave-energy based heterozean factory.
- Micritisation, originally possibly were aragonitic bivalves, can be affected by compaction after deposition as grains have adjusted to each other
- Diagenesis of grains have been replaced to sparitic cement
- Can be packstone from the mid-ramp. Aragonite time environment.

Oolite 409-7



Observation:

- Medium-sorted rounded sand sized grains (0.3-1mm)
- Medium consolidated with some fragmentation and radial structure
- Grain supported fabrics
- Pore types present in the rock: high porosity
- Dunham: ***Oolitic grainstone***
- Folk: ***Oosparite***

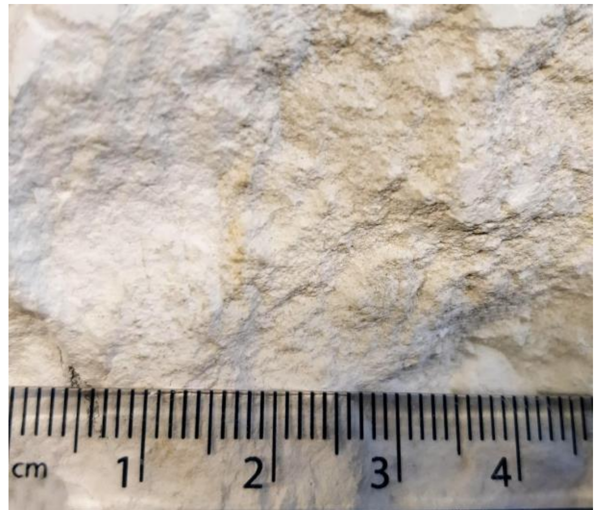


- 2 nuclei ooid OO
- Superficial ooid OS
- Ooid with concentric lamellae OCL
- Echinoderm fragments E
- Gastropods G
- Micrite envelope ME
- Peloids P
- Sparry cemented pore space

Interpretation:

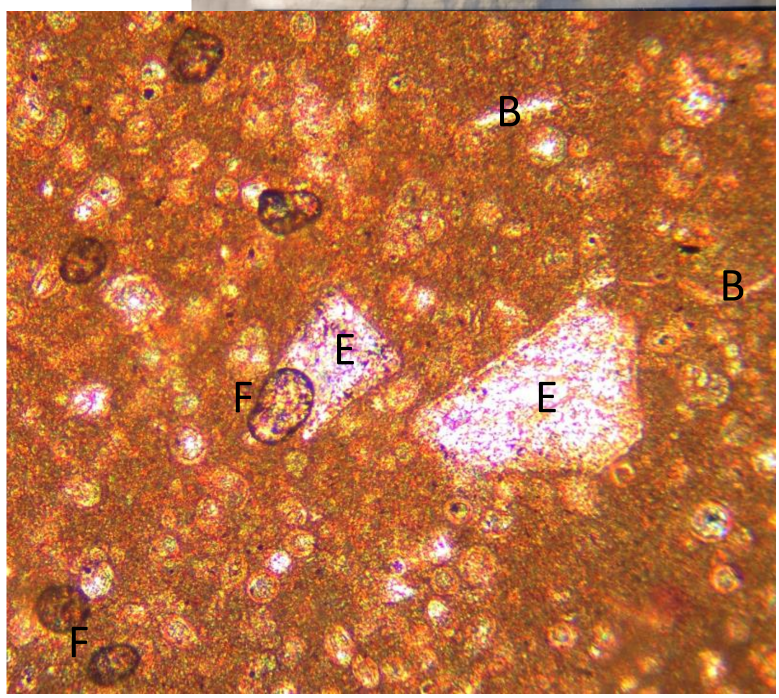
- High agitated from super saturated water. Transported from far distance.
- Absence of aragonite needles can tell that these ooids from calcitic time
- Abiotic factory. Ramp/isolated flat top platform

Chalk 405



Observation:

- Very fine silty grains
- Medium consolidated with some fragmentation
- Matrix supported fabrics
- Pore types present in the rock: medium porosity
- Dunham: ***biomicrite***
- Folk: ***mudstone***



- Mostly consist of coccoliths shell (main grain type)
- Echinoderms E
- Foraminifera F
- Bivalves B
- Micritic matrix supported

Interpretation:

- Sediment transport is low,
- Photic pelagic production of shells
- Planktonic factory in photic zone produces fine-grained sediment that settles from suspension into low-energy deep-marine environment

Chalk with styloliotes 188

Observation:

- Very fine grains
- Well consolidated with no fragmentation
- Matrix supported fabrics
- Pore types present in the rock: low porosity
- Dunham: ***biomicrite***
- Folk: ***mudstone***

- White colour
- Dense rock
- Stylolites features

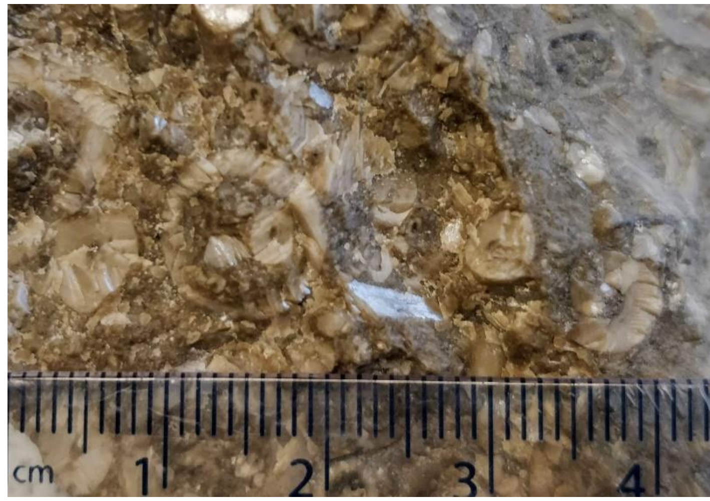
Interpretation:

- Environment of the deposition can be the same as for previous sample: low energy deep sea.
- After that the sample was affected by diagenetic processes because of the presence of stylolites, well consolidation and porosity comparing to the previous chalk. (tested by pouring the water on sample – low porosity)
- Rock affected by compaction that changed the property of grains due to stylolites
- Stylolites form perpendicular to maximum stress direction, can be vertical due to overburden
- Absence of the Thin section for this sample restricts the interpretation (especially cannot assess the degree of cementation due to low porosity)

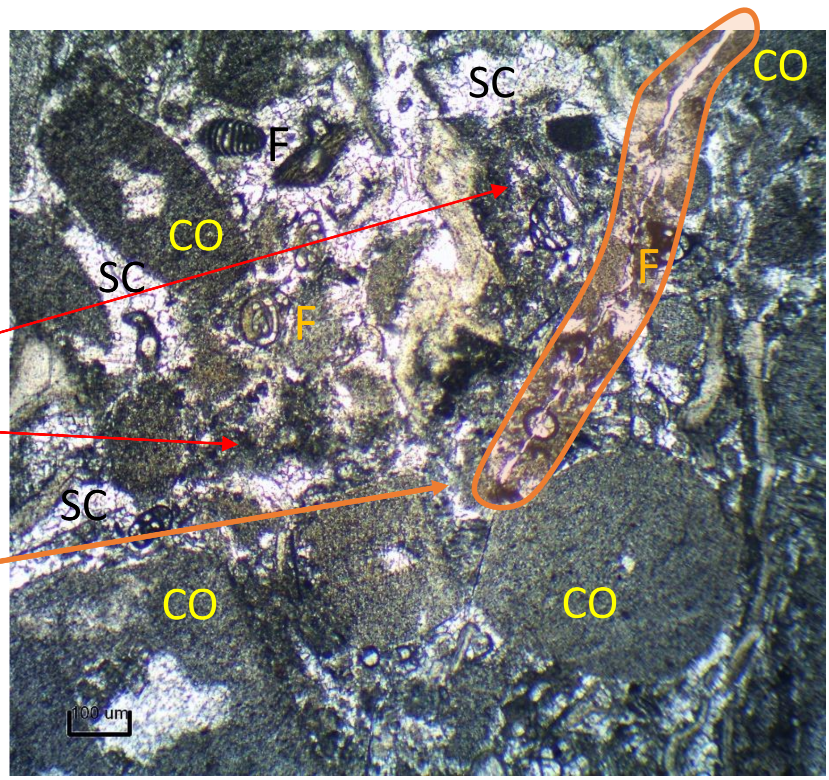
Crinoidal Limestone 417

Observation:

- 3-5mm grains buried in a micritic matrix
- Medium-Intact fragmentation with well preserved ossicles
- Grain/Matrix supported fabrics
- Pore types present in the rock: medium porosity
- Dunham: ***Packstone***
- Folk: ***Packed Biosparite***



- Crinoid ossicles as well preserved grains CO
- Abundance of fine skeletal grain fragments with micrite
- Forminifera F
- Syntaxial Cement SC
- Microstylolite (can be artefact in this section) – not common



Interpretation:

- Low energy – well preserved grains.
- Micritisation of rich calcitic environment
- Cool water shallow low energy system.

Summary

- Table at the beginning shows the context of the practical. 5 samples were classified by the description, interpretation and porosity types.
- Samples are different one from another to understand the variety of carbonate types.
- Observation was performed in two ways: hand specimen description and thin section analysis using microscope.
- All the samples were defined using Dunham and Folk classification systems.
- Interpretation of the data collected was attempted in this practical. Synthesis to the lecture material helped to understand the environment of the deposition and processes by which samples were formed. The reservoir quality such as porosity determination was assessed for all sections as well as processes that affected the samples after deposition such as diagenesis.

The takeaway points from this practical is:

- The size and the type of grains can define the rate of energy of deposition and the type of carbonate factory
- Dunham and Folk methods are the main classification systems for carbonates
- Diagenesis of the carbonate rock can be assessed by thin section analysis – matrix fabrics, type of cement, stylolites and grain dissolution for example.
- Interpretation of the samples can be done using mineralogy, porosity history and depositional and diagenetic environment.

Practical 2 – Jurassic Core description

Interval	Sketch Log	Brief Sedimentological Description	Pore types/Potential reservoir characteristics
Drawer 1 9.3 – 8.3	8.3-8.6 Wackestone/ Packstone 8.6-9.1 Wackestone 9.1-9.3 Packstone	All sections are well consolidated. On the top section matrix is dark mudstone. "Ripples" on the middle wackestone. Little fractures are present. Grains are Ooids and intraclasts	Microporosity grains. Low porosity
Drawer 2 13.1-11.9	11.9-12.85 Wackestone 12.85-13.1 Mudstone	From well consolidated on top to medium and weak strength to the bottom. High energy patterns. Strong diagenesis.	Big vug and fracture not connected and filled by spar cement. Porosity, therefore primarily interparticle. Medium/low porosity.
Drawer 3 14.3- 13.15	13.15-14 Mudstone 14-14.3 Wackstone/ Packstone	From white mud on top to dark muddy wackstone on the bottom. Fractures have a common presence. Non skeletal packstone on the bottom	Secondary vugs connected with fractures. High porosity

Practical 2 – Jurassic Core description

Interval	**Sketch Log**	**Brief Sedimentological Description**	**Pore types/Potential reservoir characteristics**
Drawer 4 16.47-14.6	Wackestone	Different grain types are present: oolitic, intraclast, foraminifera, chert?. All of them are mud-supported. Some floatstone/packstone in the middle of the section.	Some Moldic pores are filled by spar cement. Fractures are common. Medium porosity.
Drawer 5 17.4-16.6	Wackestone/ Mudstone	Dark grey on the top. Large bioclast prints. Dark brown floatstone on the bottom of the section. Mud supported all of the section, a thin beds of foraminiferous skeletal packstone.	Local vertical fracture on the bottom half of the section that is cemented in spar. Sparitic moldics. Low porosity
Drawer 6 18.6-17.7	17.7-17.9 Packstone/Floatstone 17.9 -18.4 Mudstone 18.4-18.6 Packstone	Fractures are common. Weak rocks espessialy where mudstone present. Well consolidated on the thin bottom packstone. Mudstone with white cement filled vugs. Dissollution	Small fractures, vugs are filled with cement. Medium porosity

Practical 2 – Jurassic Core description

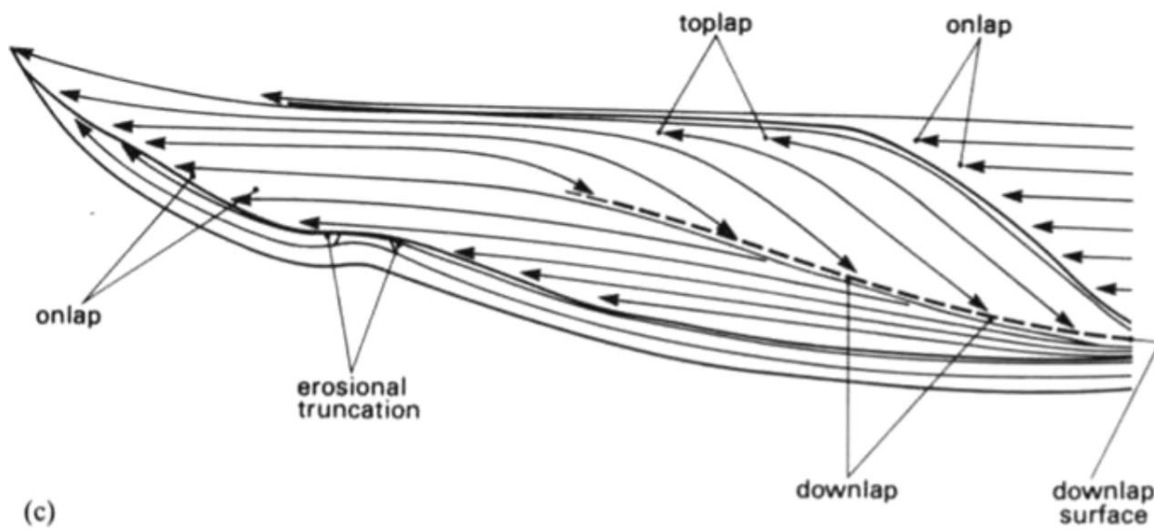
Interval	Sketch Log	Brief Sedimentological Description	Pore types/Potential reservoir characteristics
Drawer 7 27-18.9	18.9-19.1 Packstone 19.1-19.4 Wackestone 26.3-27 Mudstone	Intraclasltic grains with foraminifera in packstone. Wackestone with weak grey mud fabrics. Dark homogenous well consolidated mudstone on the last section. Dark and white prints.	Spartic vugs connected with fractures. Dissolution in grains
Drawer 8 44.4-42.7	Oolitic grainstone	Homogenous fine-medium oolitic grainstone. On the bottom beds of oolitic packstone are present. Poor sorting on the top. Well consolidated in the middle. A slight lamination on the bottom. Mostly ooids with other intraclasts and bioclasts.	Fracture and vugs are present but not common. High inter- and intra-granular porosity. Have a potential reservoir quality. A further study is needed.
Drawer 9 45.7-44.4	Packstone	Heterogeneous fine grained packstone. Thin beds of oolitic packstone. Lamination is present. Beds of skeletal grainstone (ooids 50%). On the bottom separation of ooids and skeletal layers.	Strong intragranular porosity in packstone. Fractures through pore spaces filled by spar. Medium porosity.

Practical 3 – Seismic stratigraphy and Forward modelling

Aims:

- Understanding the carbonate strata – what controls the stacking and the formation of stratal termination – Exercise 3.1
- Basic seismic interpretation of carbonate stratigraphy by identification of isolated carbonate platforms as exploration target – Exercise 3.2
- Running and interpretation of stratigraphic forward modelling by the establishment of carbonate platform accumulation. – Exercise 3.3

Exercise 3.1 – Stratal termination



Stratal termination type	Stacking pattern	Change in accommodation	Accom./Supply ratio
Onlap	Retrogradational	increase	<1
Downlap	Retrogradational	increase	<1
Toplap	Progradational	decrease	>1
Erosional truncation	Forced progradational	decrease	>1

- Stratal termination means the reflection of seismic responses affected by the change in velocity of seismic waves due to the architecture of the carbonate stratigraphic formations (discontinuity of reflection patterns) (Boggs, 2001).
- Processes that control this architecture of seismic reflections are the ratio between accommodation and supply that affects the deposition of the carbonate rock.

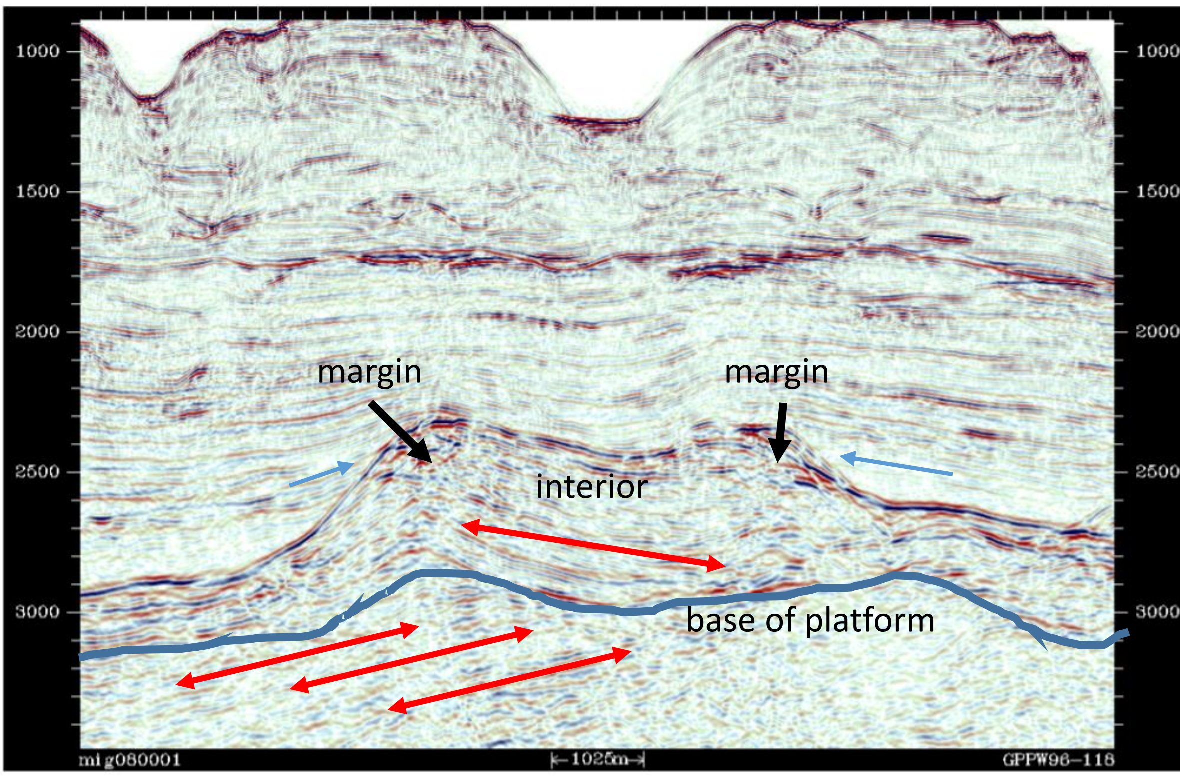
Exercise 3.2 – Isolated platforms scoring

- 12 seismic shots were analysed whether these images can have properties that are principal for isolated carbonate platforms.
- Isolated Platform scoring is the criteria based excel spreadsheet where any possible platform can be interpreted through the assessment of the detailed carbonate features.
- To better represent the results of the assessment, table below is created:

Buildup Name	**Comments (Green – the best 3 platforms to drill Yellow – have some potential to be a carbonate plarform, Red – no potential / minimum features)**	Single ID criteria Score (min -16 max 16)	Single criteria & combined ID criteria Score (min -16, max 55)
Lead 1-A		5.5	15.5
Lead 2-B		-5	-5
Lead 3-C	Good quality seismic image with almost all basic seismic interpretation features except that it is not very steep to nearly vertical flanks. From advanced interpretation, minimum "maybe" ticks and only "no" for interfingering with basin fill on flanks of feature	10	20
Lead 4-D		6	6
Lead 5-E	Detailed high quality image. All basic interpretation features are ticked. Limitations are that mounds do not coalesce and no interferation with basin fill on flanks	10	20
Lead 6-F		1.5	11.5
Lead 7-G		3.5	3.5
Lead 8-H	Seismic shot of Kashagan field. Despite that is already existed IP, assessment of the image was attempted. In addition, salt structures above the carbonate platforms act as good sealing unit.	10.5	20.5
Lead 9-I		8	18
Lead 10-J		-3	-3
Lead 11-K		7.5	7.5
Lead 12-L		6.5	6.5

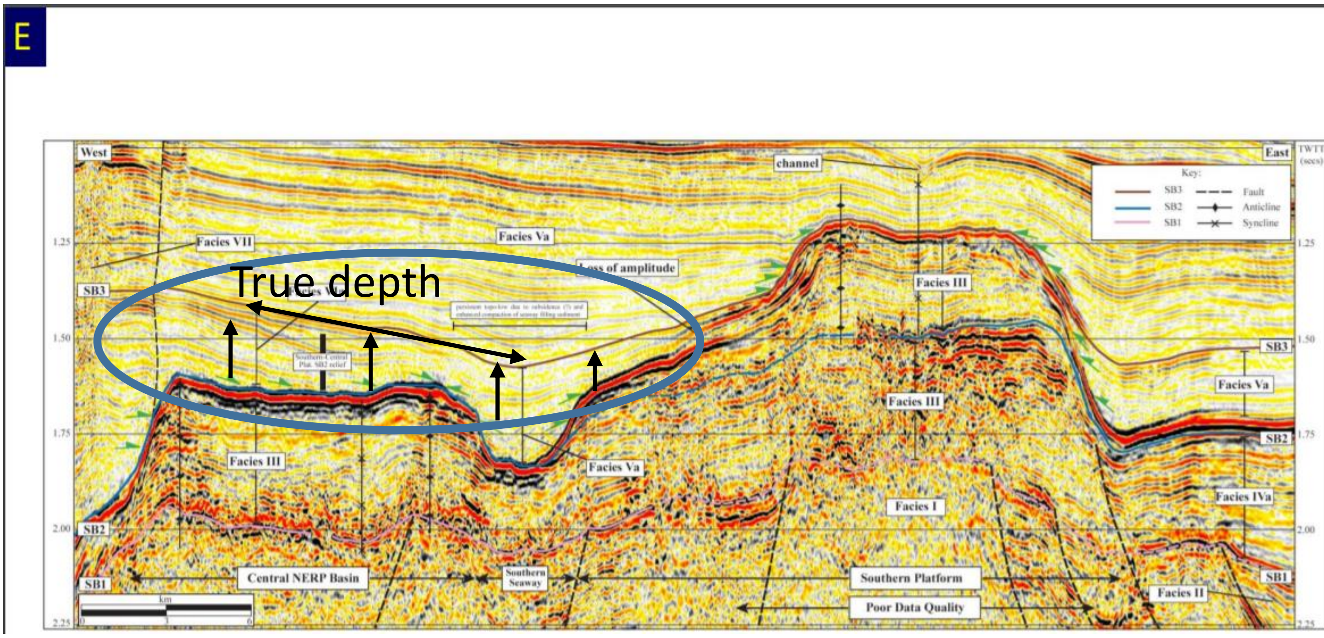
Target C

C



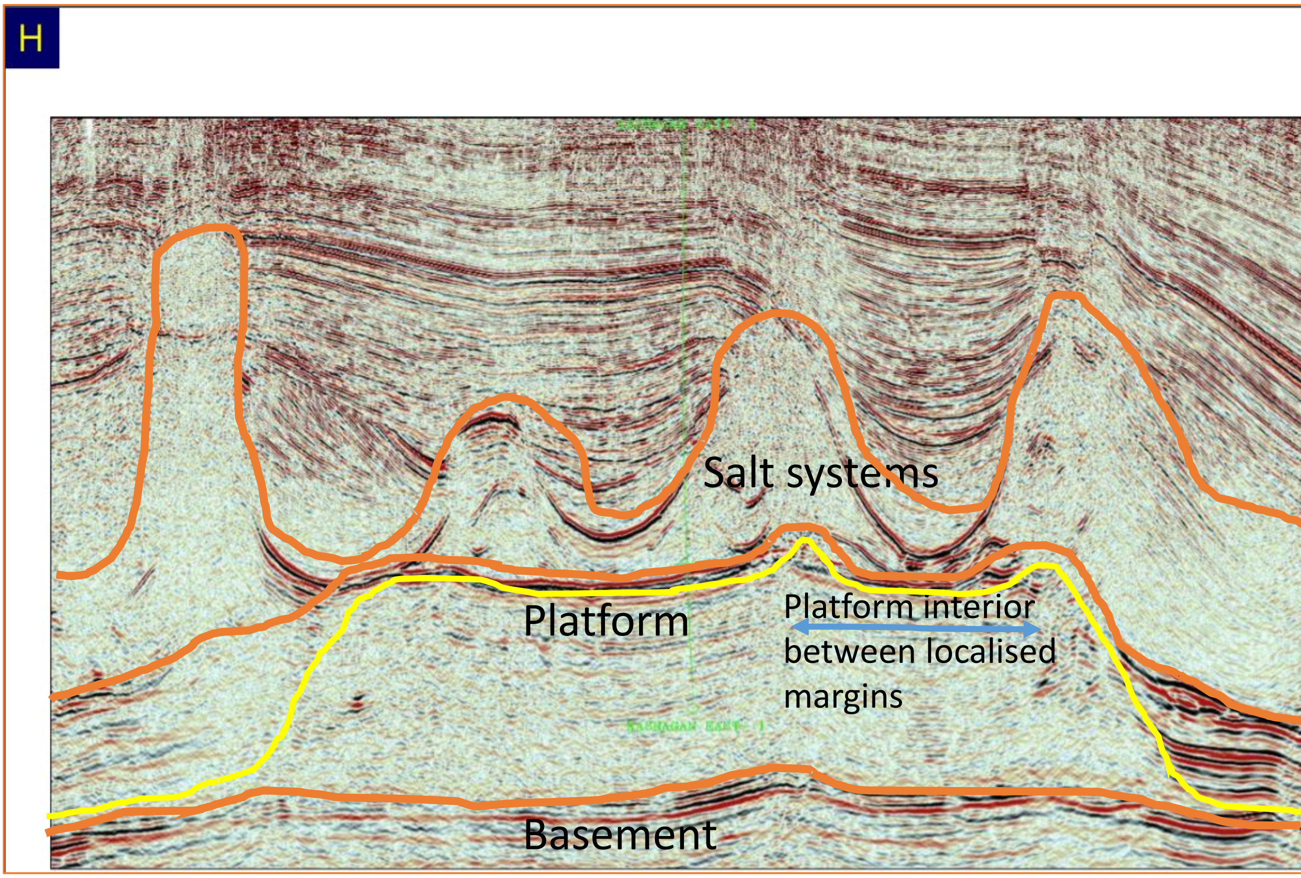
- Clear structure of possible carbonate platform.
- Arrows represent bedding orientation
- Overlying masses of possible sealing units

Target E



- Detailed seismic shot with good annotations
- Basement could have been rifted creating the architecture for possible carbonate platform formation
- The specific of seismic waves could misplaced the data (attempted to present the true depth)

Target H

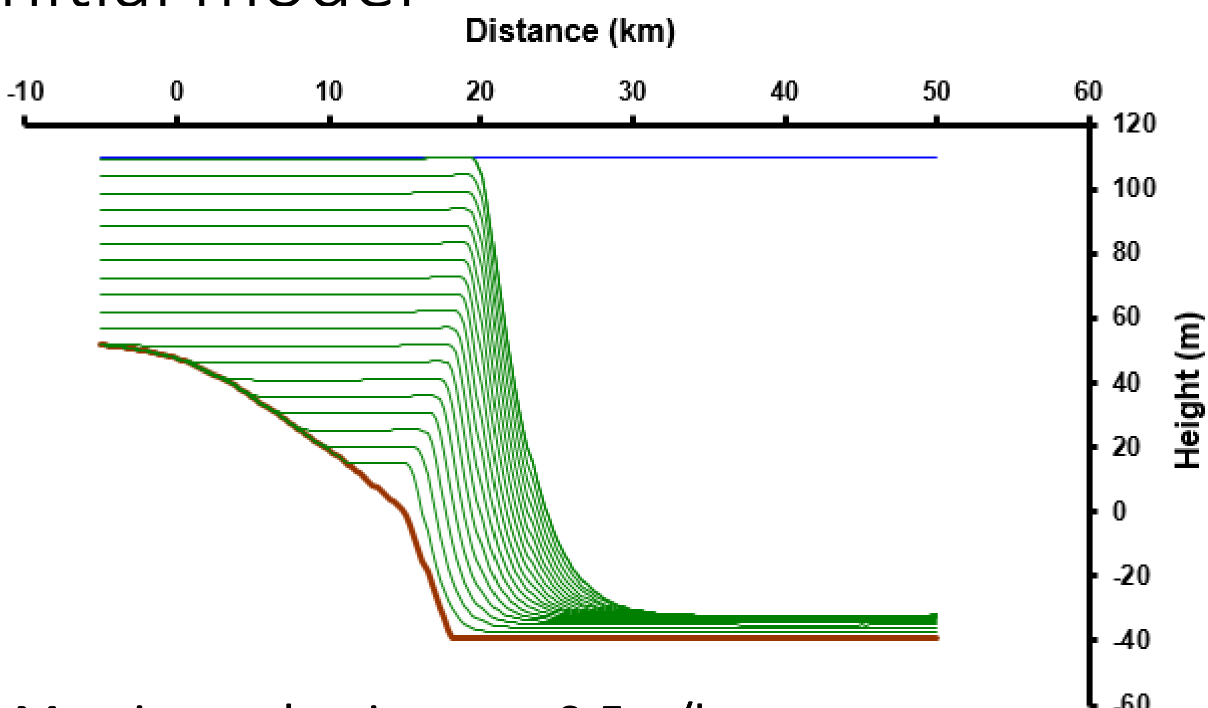


- Quality of seismic image was affected by the presence of the salt structures above the possible carbonate platform
- Salt diapirs can be as a good sealing units
- Basement strata can be differentiated
- Not clear slope degree (yellow line as a suggestion)

Exercise 3.3 – Forward modelling of carbonate stratigraphy

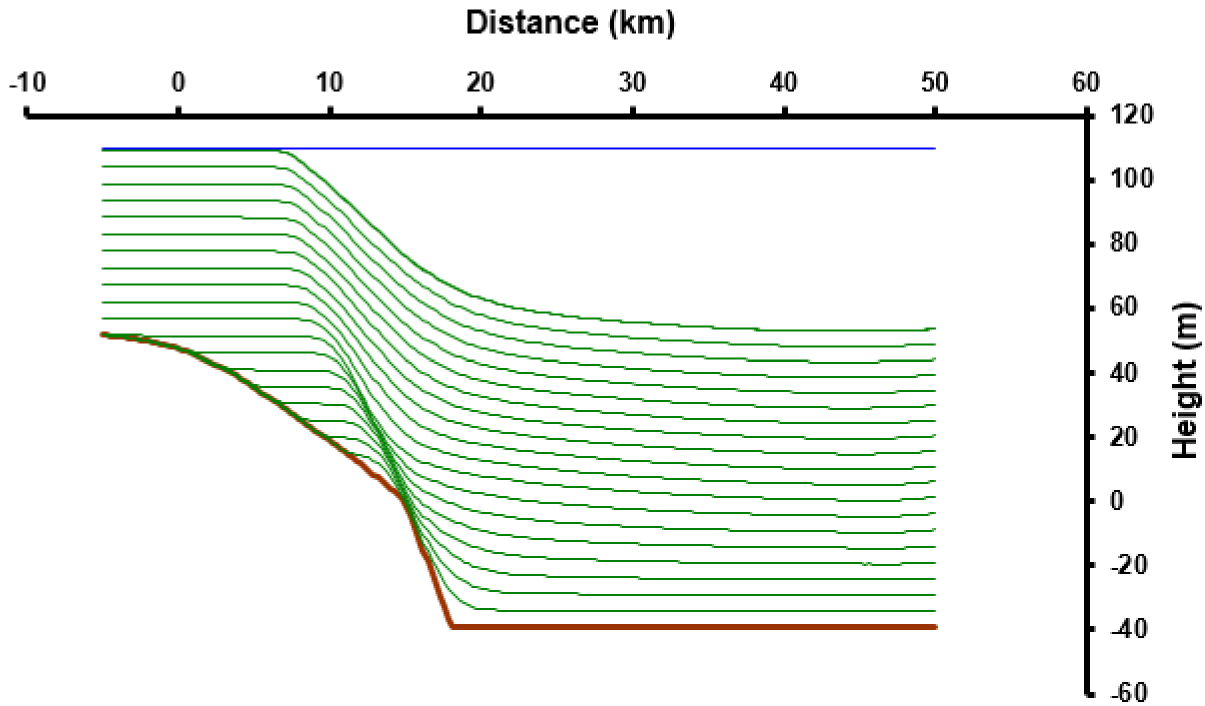
- For this exercise an excel spreadsheet was used. Model was programmed using initial controls such as the rate of accommodation and change in sea level to produce the carbonate build-up

Initial model



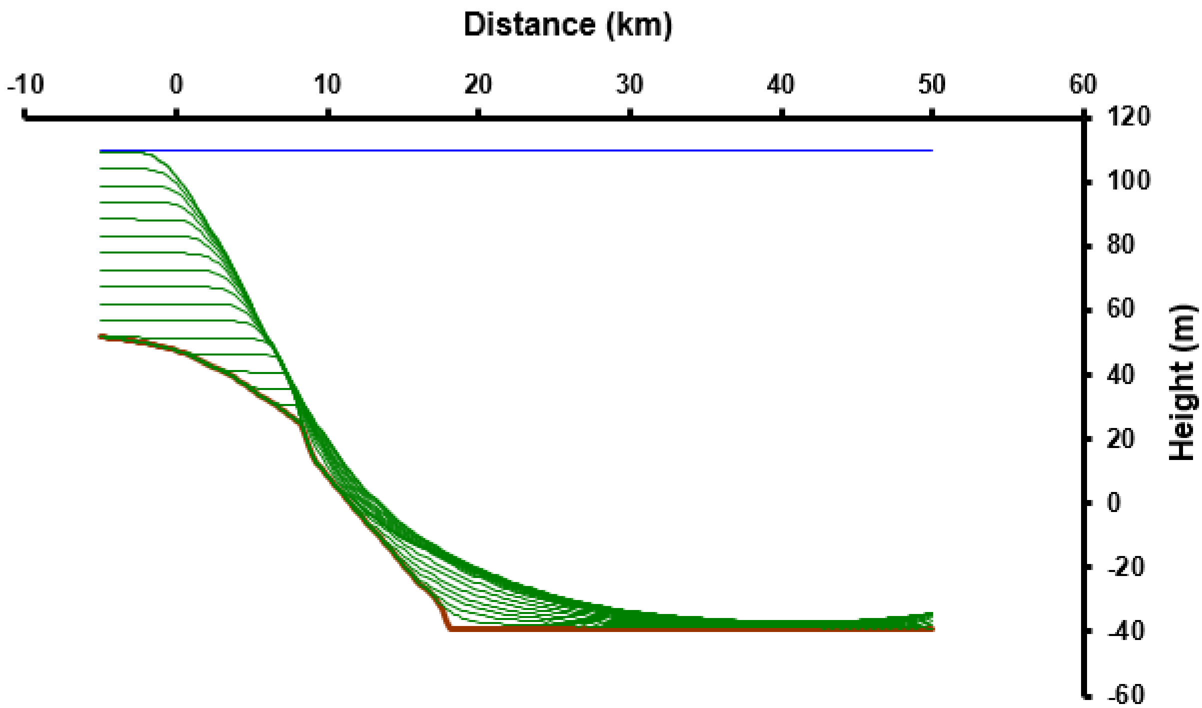
- Margin production rate 0.5m/ky
- Light attenuation 15m
- Interior production 0.1m/ky
- Progradational (close to aggradational) because the rate of the supply slightly higher than the rate of accommodation

Changing the margin settings



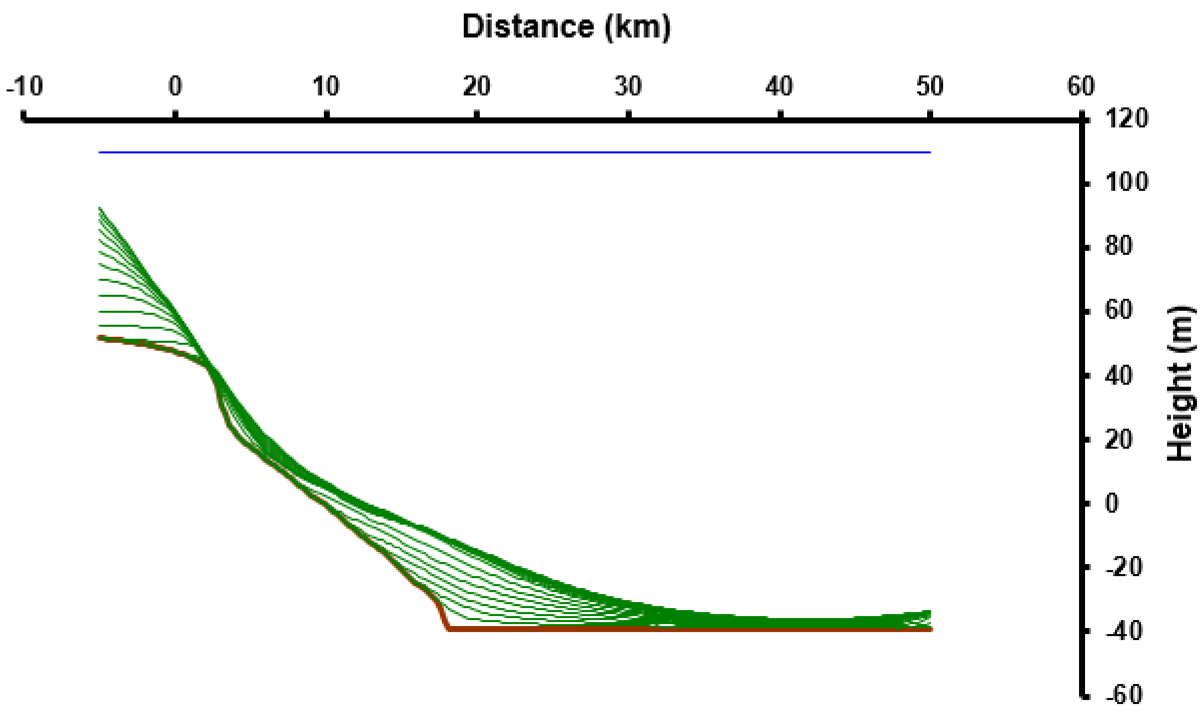
- Margin production rate 0.05m/ky – *was reduced*
- Light attenuation 500m – *was changed; the main reason why carbonate platform prolonged basinwards*
- Interior production 0.1m/ky
- Strong progradational the rate of interior higher than the margin production

Changing the light attenuation



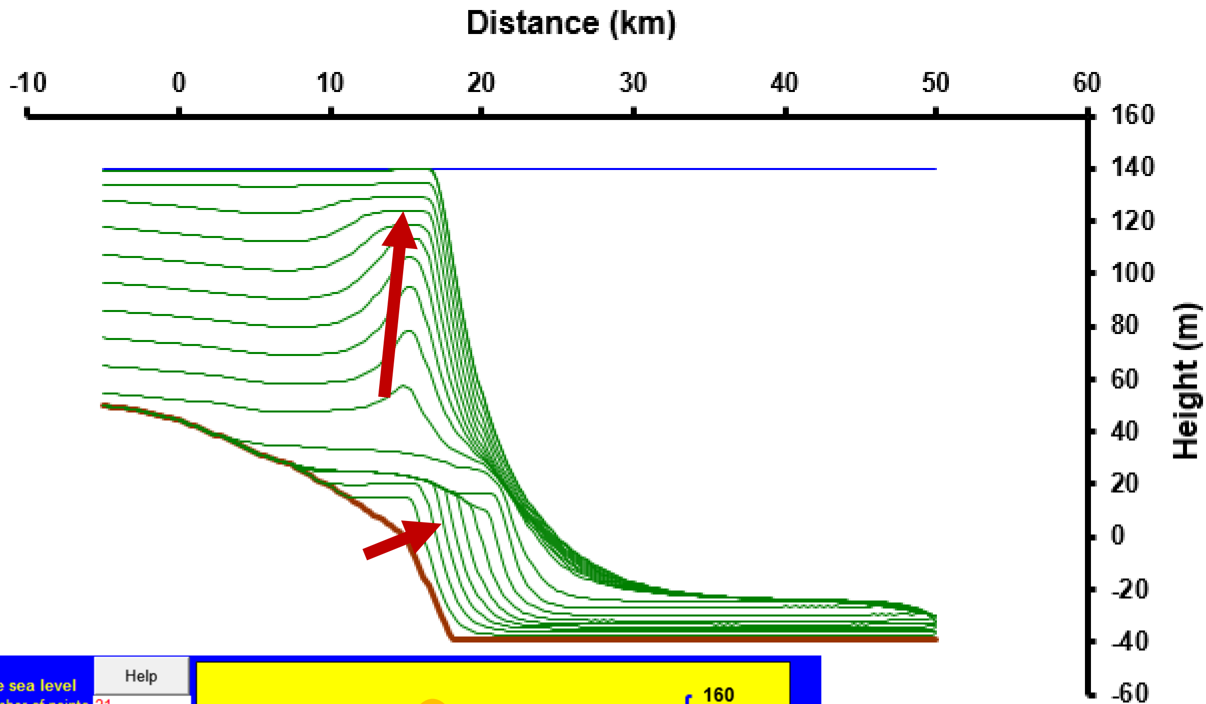
- Margin production rate 0.05m/ky
- Light attenuation 15m – *returned to the previous degree*
- Interior production 0.1m/ky
- Retrogradational
- Slope could transport sediment to the deep basin

Reducing the interior production



- Margin production rate 0.05m/ky
- Light attenuation 15m
- Interior production 0.05m/ky
- Drowning the platform
- Less production, more transportation

Final model

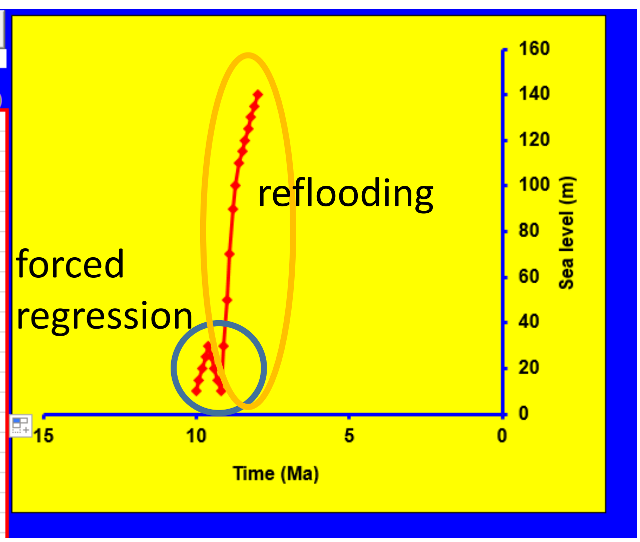


Relative sea level

Help

Number of points 21

Time (Ma)	Sea level (m)
10	10
9.9	15
9.8	20
9.7	25
9.6	30
9.5	25
9.4	20
9.3	15
9.2	10
9.1	30
9	50
8.9	70
8.8	90
8.7	100
8.6	110
8.5	115
8.4	120
8.3	125
8.2	130
8.1	135
8	140



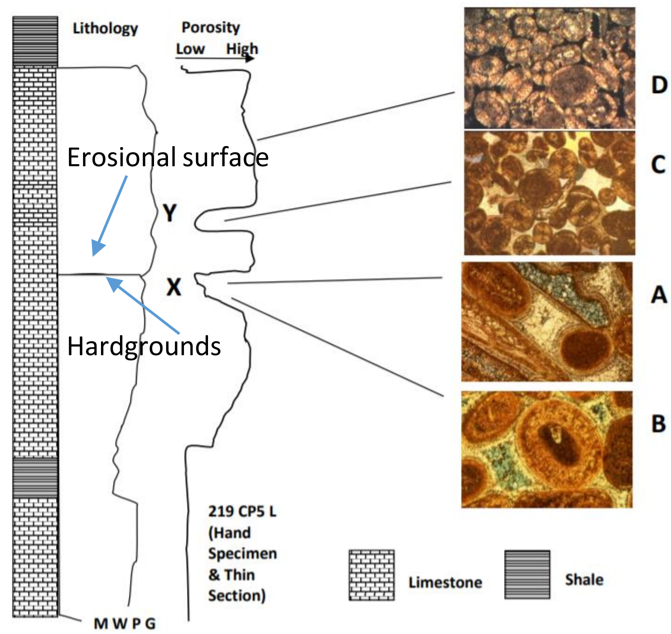
- Margin production rate 0.5m/ky
- Light attenuation 15m
- Interior production 0.1m/ky

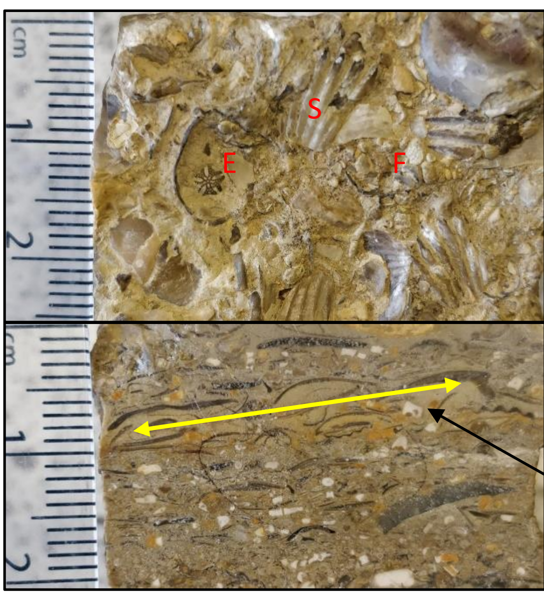
- Sea level drop at the begging and following rise of the sea level have influenced the architecture
- Progradational setting downwards, while aggradational platform margin upwards
- Sea level plays the key role in building carbonate platforms
- Platform margin have a potential to be a reservoir because it is commonly transported grainstone, and can produce a trap with a possible overlying seal unit and migration of hydrocarbon.

Practical 4 – Paragenesis report

Introduction

- The aim of the report is petrological investigation for the assessment of reservoir potential.
- It will be done by the understanding of diagenetic processes and paragenetic (porosity) history
- Samples: A, B, C, 219 – low porosity
- D - high porosity (reservoir)
- X, Y – tightly cemented zone



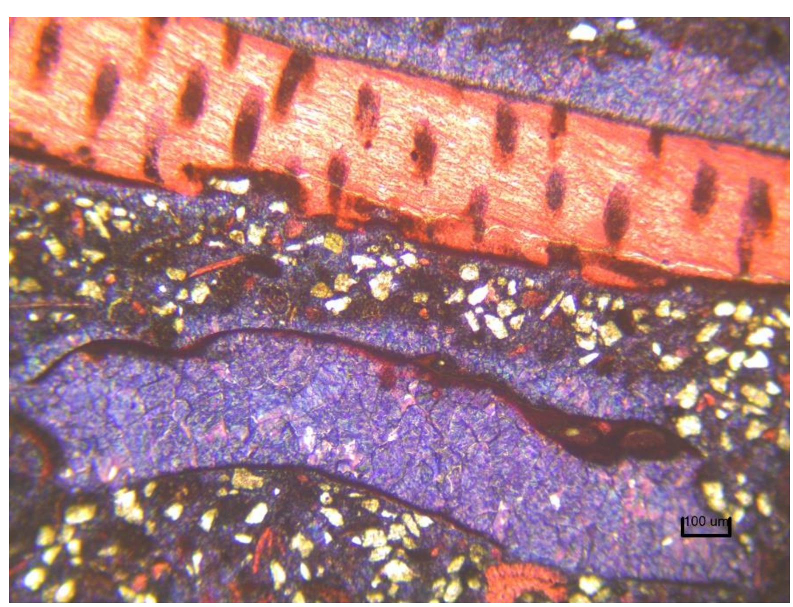


219 Hand specimen description

- Top is the horizontal view of the specimen.
- Bottom is the vertical view of the polished side of the specimen
- Heterogeneous skeletal grains - Size from 1cm to 0.5-1mm
- Packstone / Cemented at place?
- Colour – beige / Strength - strong
- Abundance of well preserved skeletons (shelves S and echinoderms E, foraminifera F)
- Preferred orientation of fossils / High energy?
- Micritic cement / Oxidized laminae

219 Petrographic description

- Red staining – iron-poor calcite
- Blue staining - iron-rich calcite
- Mixed carbonate/siliciclastic matrix
- Well preserved shells – brachiopods
- Drusy sparite – no internal structure preserved - bivalves



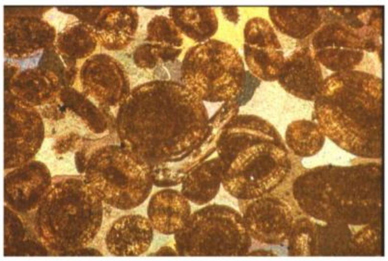
Description

- Despite that all these petrographic images represent oolitic grainstone above previous sample, they are different from each other:
- A, B – stained sections; elongate fibrous cement F. Cristalline (C) of shell in A and of pore space in B
- C – equant or braided calcite circumgranular crust cementation in space between grains. Microfracture in top
- D – pore spaces filled with black material (hydrocarbon?) grains are compacted

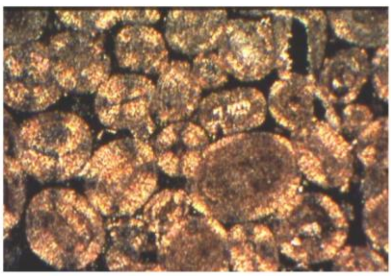
A

B

C

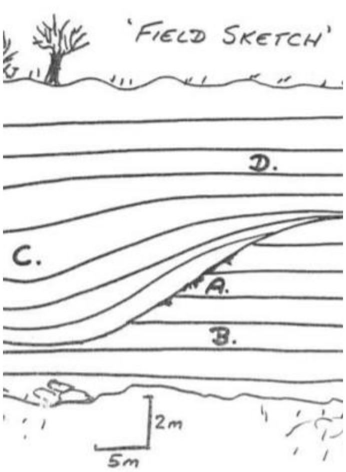


D



Discussion

- Each sample have a slightly different paragenesis that is affected the reservoir quality
- 219 sample from the bottom of the log have a mixed fabric. It means that presence of aragonite bivalves and calcite brachiopods were affected differently due to cementation and dissolution (aragonite dissolved to sparry cementation; calcite preserved the shell). Siliciclastic very fine (sand) grains are mixed with drusy sparite matrix. It leads to high energy system packstone.
- Samples A and B have features of marine vadose/phreatic dissolution. Samples C more meteoric vadose zone. Meniscus calcite cementation.
- Sample D according to log have a high porosity, even though grains are compacted to each other. Suggestion that hydrocarbon can preserve the porosity from cemenation
- Field sketch below shows the position of the samples within the channel feature (Marshal and Ashton, 1980).
- It can relate to the channel between open sea and interior platform within the platfrom margin. Tide/wave (fluid) movement can seriously controlled the type of diagenesis below the channel. (Vahrenkamp and Swart, 1994) – samples A,B
- Hardground can be present just below the erosional surface of the channel due to this environment. It normally occur as a part of ooid platform margin sequence (Halley et al., 1983).



Conclusion

- Paragenesis is a history of porosity under the different types of diagenesis.
- Cementation, Dissolution, Compaction are the main processes that were involved in the samples A,B,C,D and 219.
- Below the hardground the samples were affected by the marine zone, phreatic for B (cementation), vadose for A (dissolution and cementation).
- C is also from 'tight' zone and was affected by meteoric zone - cementation.
- D is high porosity unit with the only affection of compaction.

References

- *Halley, Robert B., Paul M. Harris, and Albert C. Hine. "Bank Margin Environment: Chapter 9: PART 1." (1983): 463-483.*
- *Marshall, J.D. & Ashton, M. (1980), Isotopic and trace-element evidence for submarine lithification of hardgrounds in the Jurassic of Eastern England. Sedimentology, 27, 271-289.271-289*
- *Vahrenkamp, V. C., & Swart, P. K. (1994). Late Cenozoic dolomites of the Bahamas: metastable analogues for the genesis of ancient platform dolomites. Dolomites: A volume in honour of Dolomieu, 21, 133-153.*