Depositional and Diagenetic Effects on Reservoir Properties in Carbonate Debris Deposits: Comparison of Two Debris Flows within the Berai Formation, Makassar Strait, Indonesia*

Chrisna Asmiati Tanos[1], Julie Kupecz[2], Sri Lestari[2], John Keith Warren[3], and Alaa Baki[4]

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[1]Exploration, Mubadala Petroleum, Jakarta, Indonesia (chrisna.tanos@pearlenergy.com)
[2]Exploration, Mubadala Petroleum, Jakarta, Indonesia
[3]Department of Geology, Chulalongkorn University, Bangkok, Thailand
[4]PT Eksindo Pratama, Tangerang, Indonesia

Abstract

After the successful discovery and appraisal of the “M” field, interpreted as a debris flow carbonate reservoir in the Late Oligocene Berai Formation of the “S” Block, South Makassar Basin, a subsequent exploration well in an adjacent feature (NW-1) was unexpectedly dry. The dry NW-1 well was a surprise as previous work indicated that this was a favourable structural location to drill. This study shows that the Berai limestone has a complex depositional framework and that it has experienced a multistage diagenetic evolution. In order to reduce the risk in any future exploration drilling, this integrated study was done, using data from all the existing wells in the “M” Field and the NW-1 well.

Stage 1 of this study incorporated available cores and thin sections, and stable C and O isotopes. The dry NW-1 well, comprising clasts of reefal carbonate platform host, was cemented under marine conditions prior to re-sedimentation, as evidenced by thin section and isotopic data. In contrast, the productive well (M-4), also a carbonate debris flow, though of a different provenance, exhibited little syn-depositional cementation. Importantly, it experienced a phase of post-depositional leaching that significantly enhanced the reservoir quality. Depleted oxygen isotopic data from M-4, in conjunction with the paragenesis, are consistent with dissolution/re-precipitation by higher temperature fluids in a post-depositional setting, while NW-1 isotopic data indicate little diagenetic alteration.

In stage 2 of the study, results from the isotopic study were used to high-grade samples for cathodoluminescence petrography, which were in turn used to select sampling sites for total Sr and $^{87}Sr/^{86}Sr$ analyses. In addition, drill cuttings from the sections above and below the reservoir

were analyzed for biostratigraphy; these data were used to aid in identification of major flooding surfaces and condensed intervals, and incorporated with 3D seismic data to help constrain timing of debris flow deposits, depositional water depths, and the nature of the overlying seal.

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Comparison of Two Debris Flows within the Berai Fm., Makassar Strait, Indonesia

Chrisna Asmiati Tanos, Julie Kupecz and Sri Lestari (Mubadala Petroleum, Indonesia)
John Keith Warren (Chulalongkorn University, Thailand)
Alaa Baki (PT Eksindo Pratama, Indonesia)

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Outline

- Background
- Objectives
- Study Area
- Data & Methodology
- Results
- Conclusion
- Acknowledgement
- Q & A

Background

- An unexpected dry well after one gas-discovery and three successful appraisal wells; drilled on what was thought to be the same play fairway

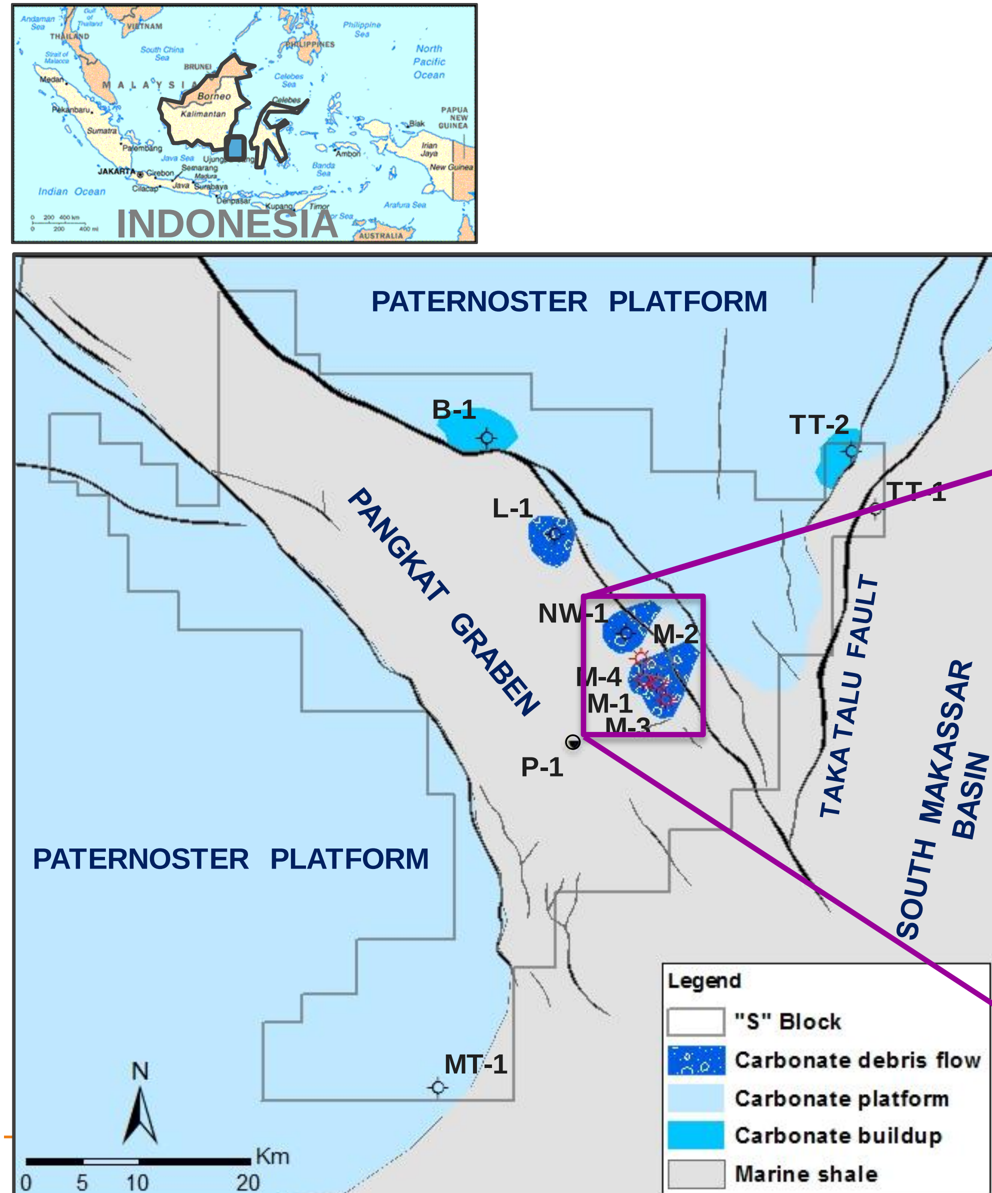
- Controls on porosity and permeability are not well understood

Objectives

Dryhole Analysis

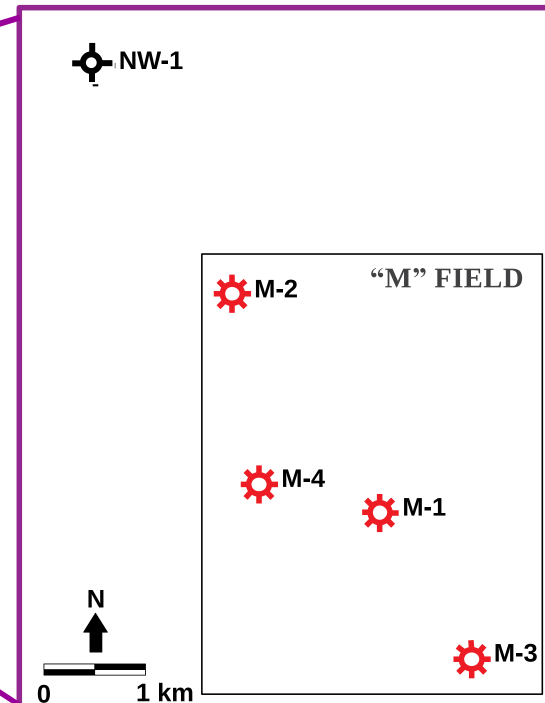
- Determine relationship between lithofacies and diagenetic overprints
- Define how the diagenesis controls reservoir properties (porosity and permeability)
- Understand vertical and lateral migration pathways and timing

Study Area



- Located in the Pangkat Graben, Paternoster Platform, offshore Southeast Kalimantan, Indonesia

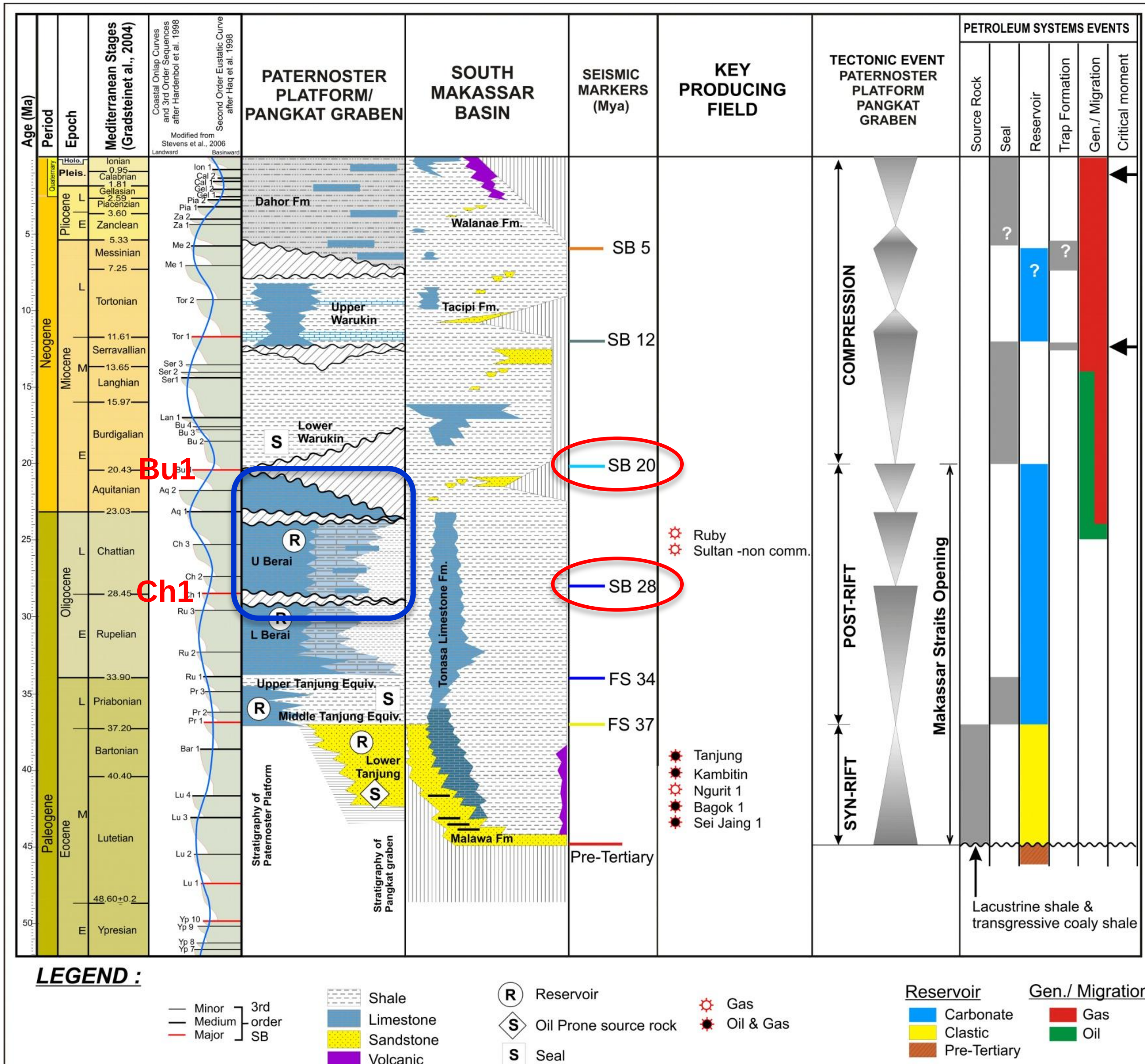
- The first gas-discovery exploration well was in 1974



Data & Methodology

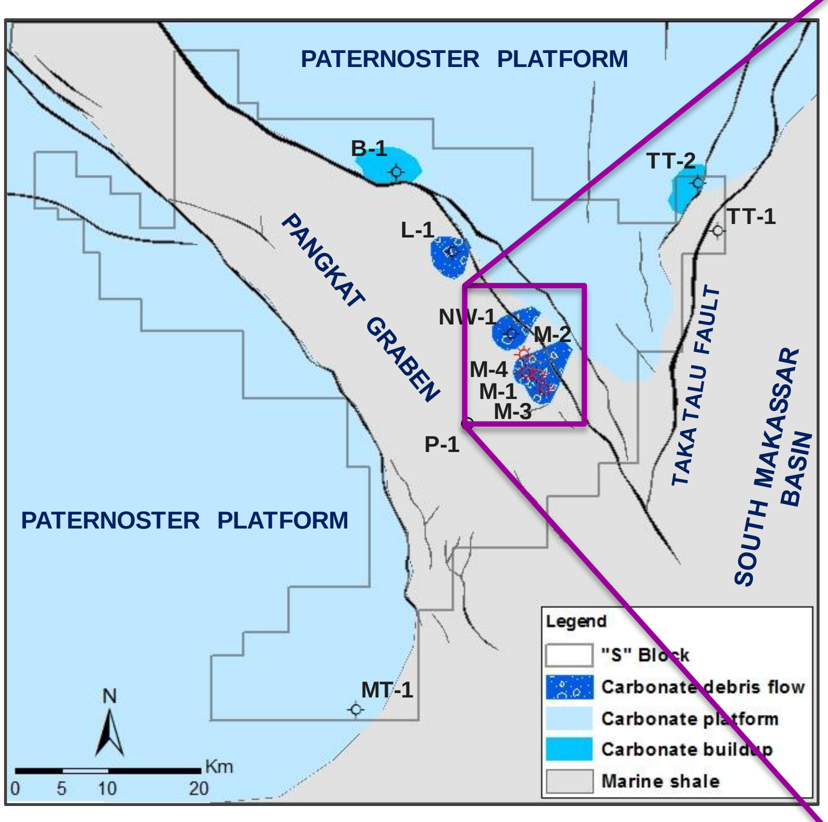
- Core
  - M-4 (22.7 m)
  - NW-1 (3.96 m) and 25 sidewall cores
- Thin sections from cores and sidewall cores
  - M-4 (n = 19)
  - NW-1 (n = 25)
- Carbon and oxygen stable isotopes
  - M-4 (n = 61)
  - NW-1 (n = 15)
- Cathodoluminescence petrography
  - M-4 (n = 15)
  - NW-1 (n = 16)
- Core analysis data (porosity and permeability)
- Biostratigraphy
  - M-4 (1150 m)
  - NW-1 (1200 m)
- Seismic 3D

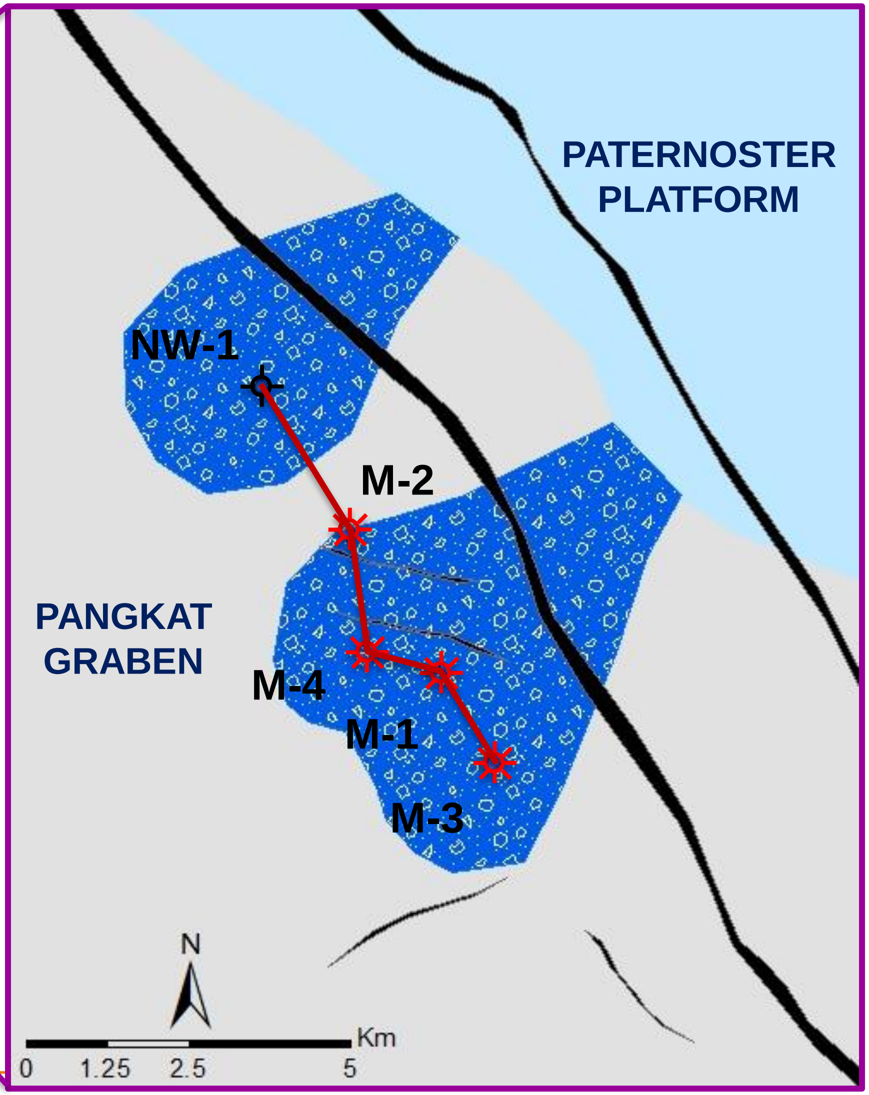
Regional Setting



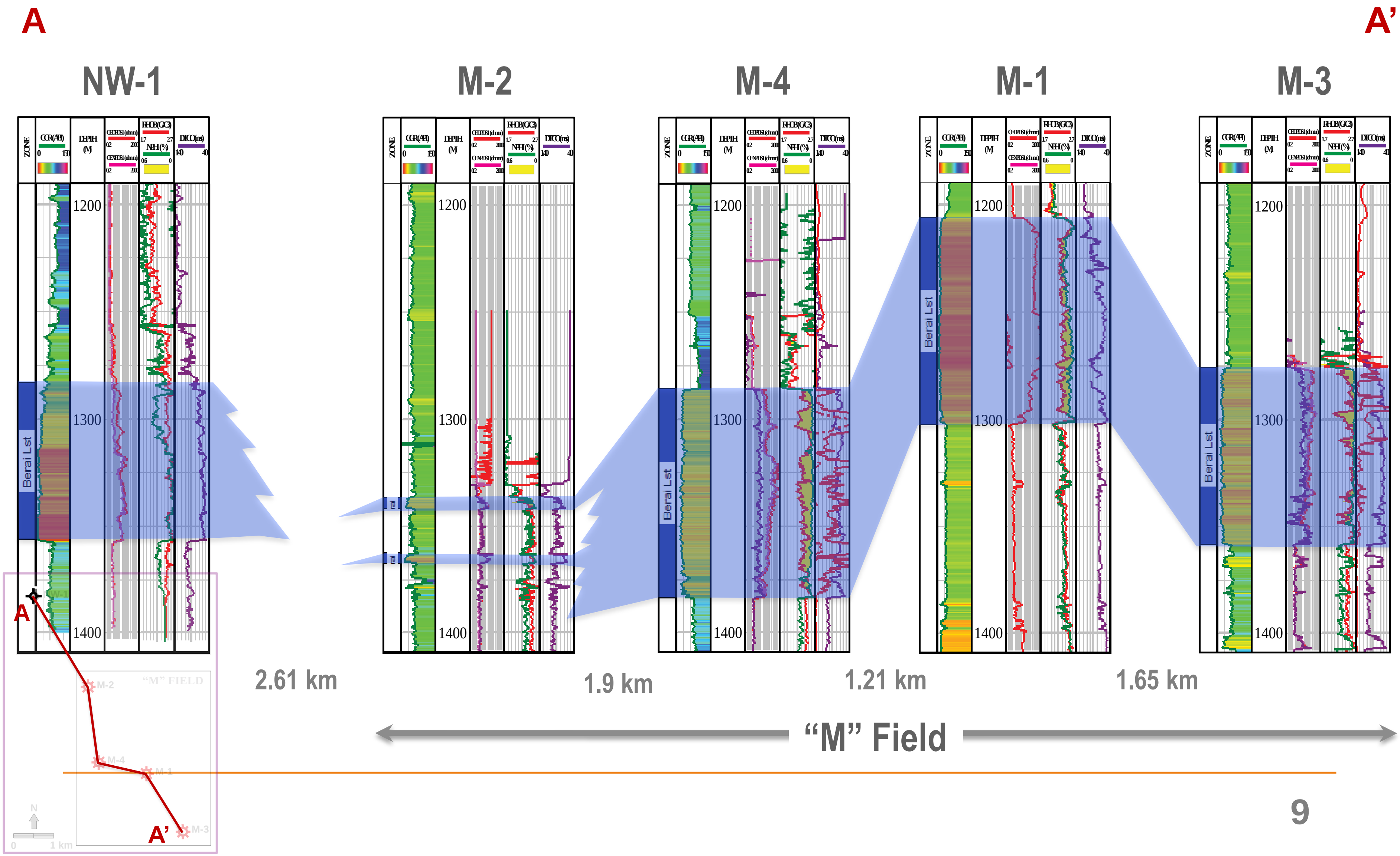
- Upper Berai Fm.
- 28 – 20 mya
- Debris Flows
- Associated with global SL Lowstands

Depositional Schematic



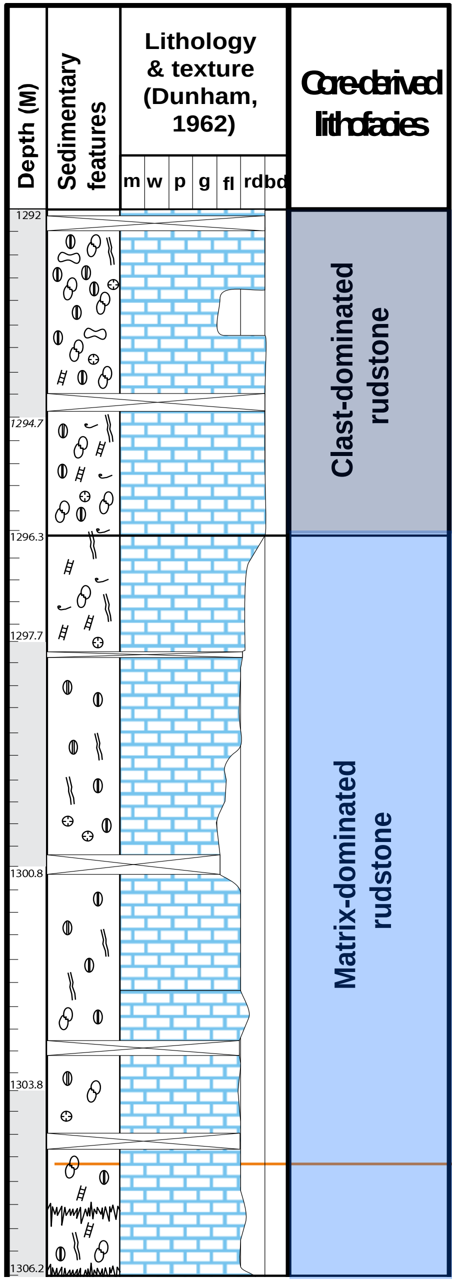


Well Correlation

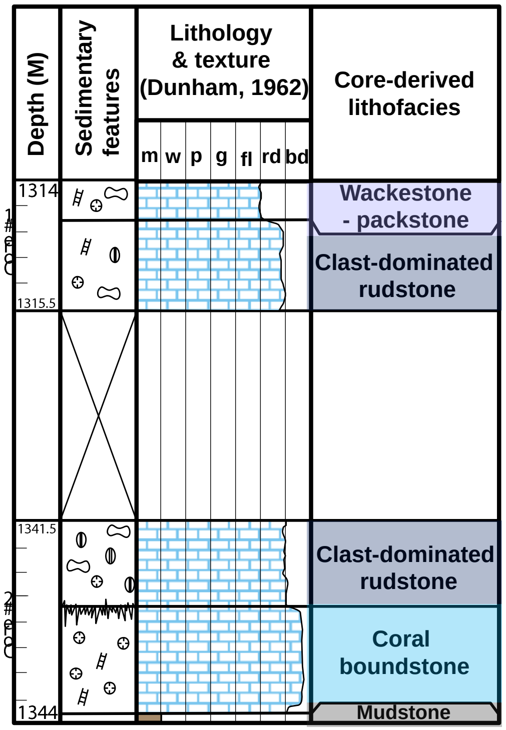


Core Facies

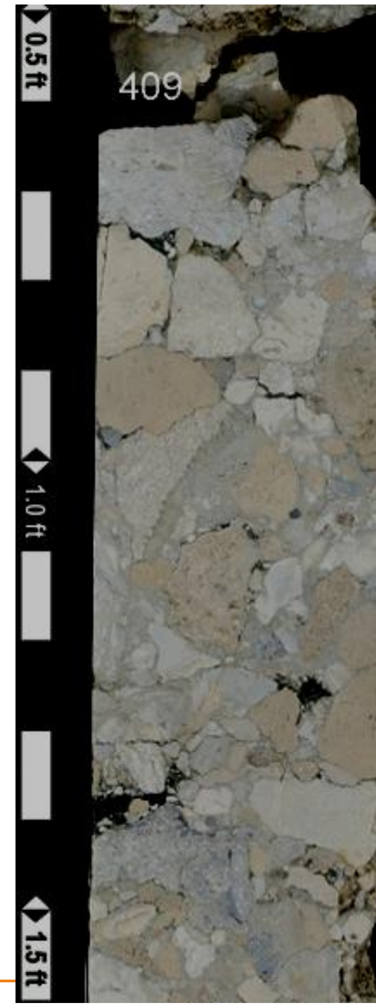
M-4



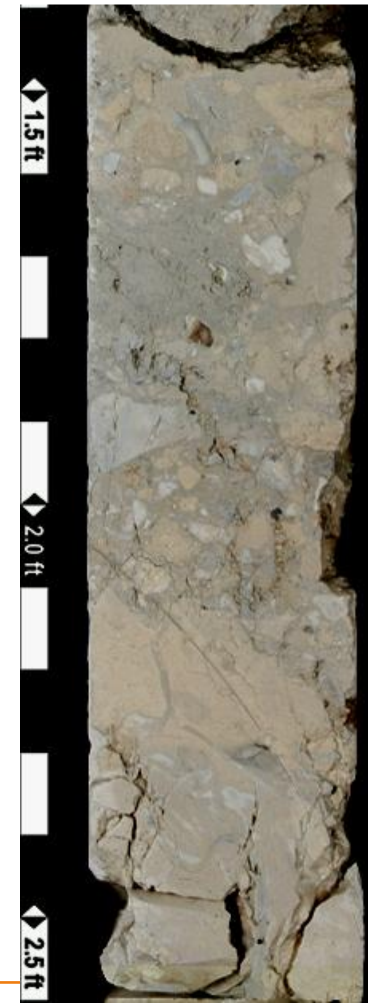
NW-1



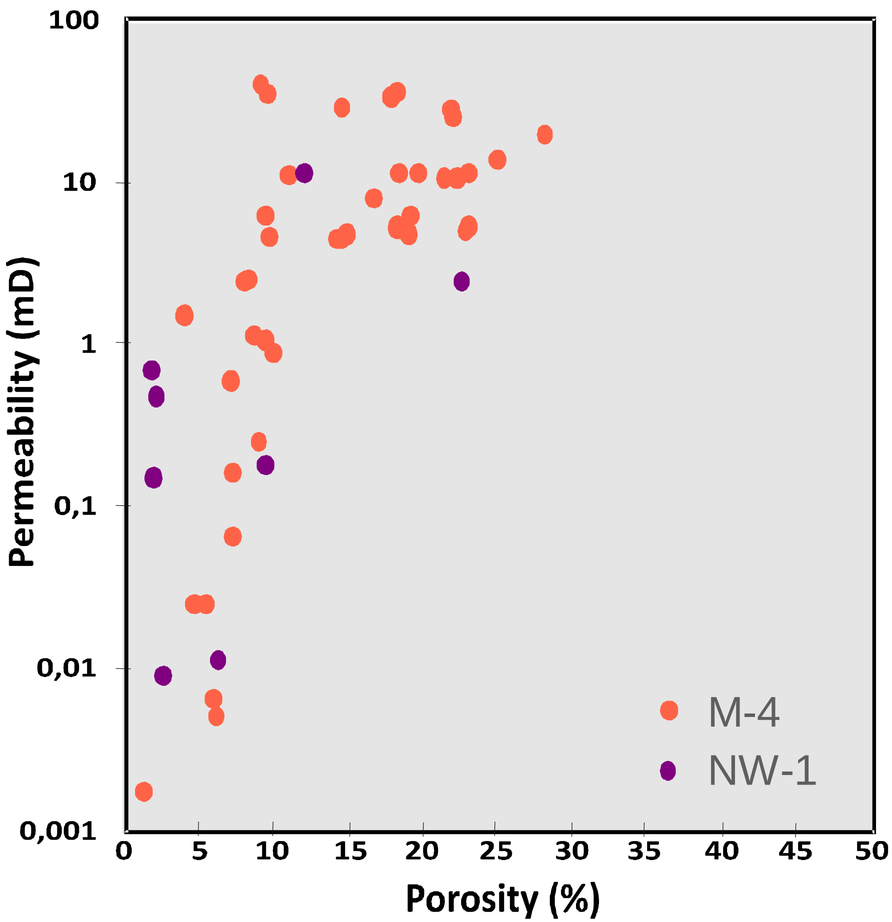
Clast - dominated rudstones

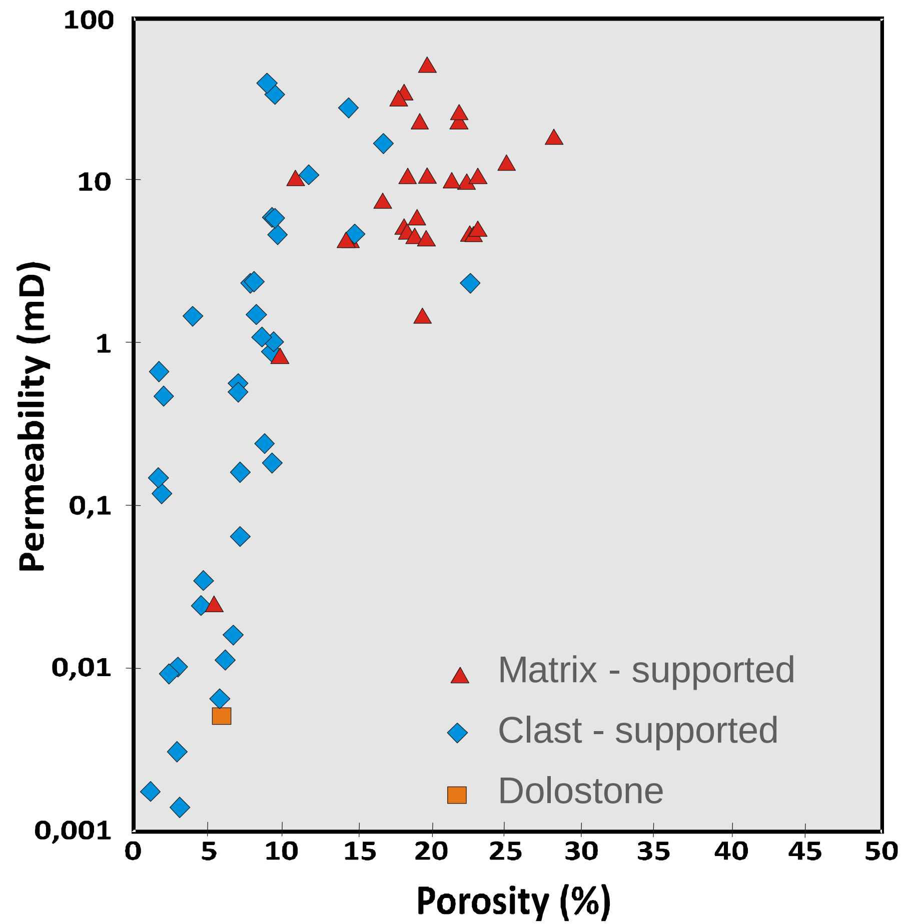


Matrix - dominated rudstones



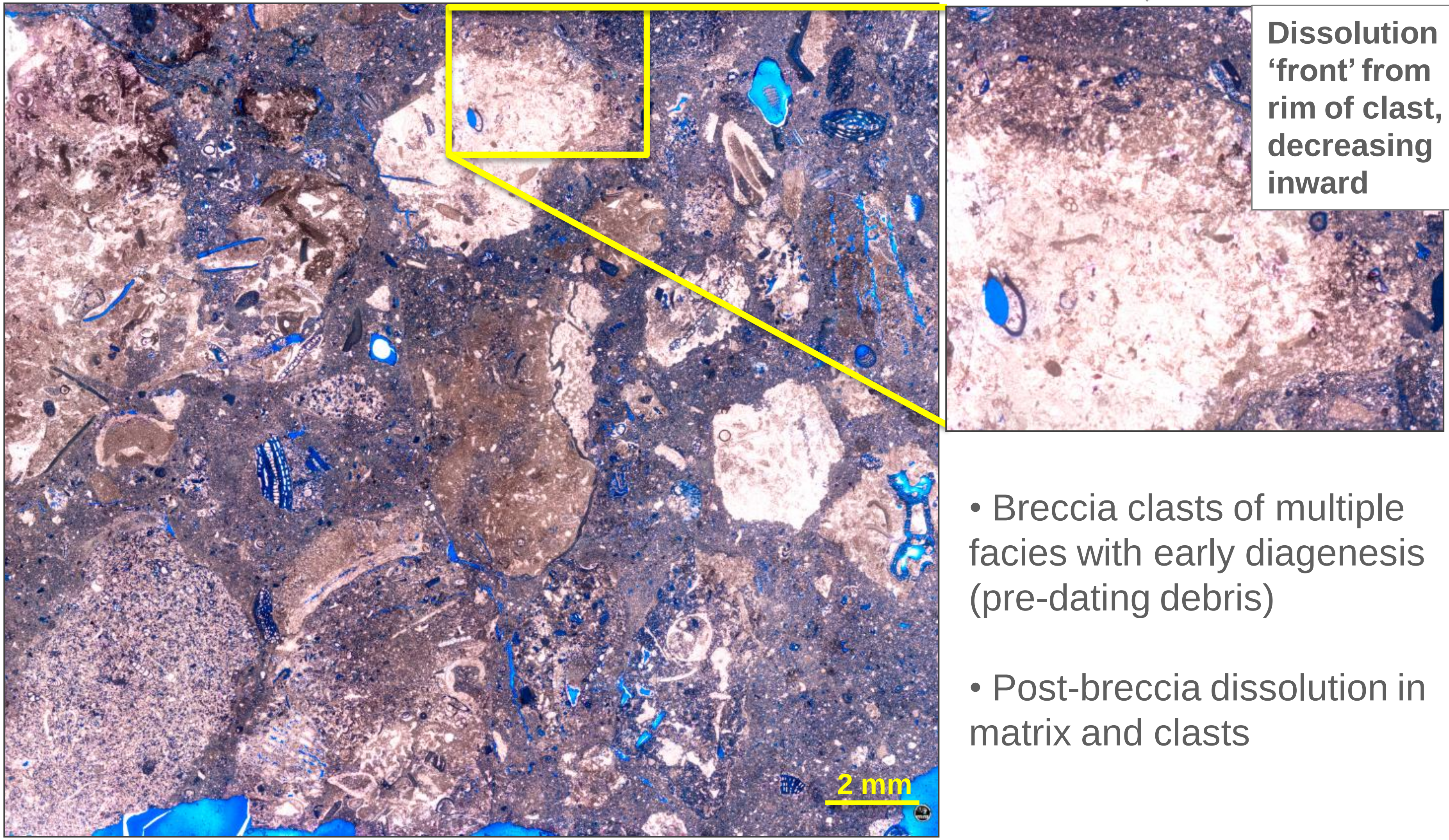
Core Phi & K





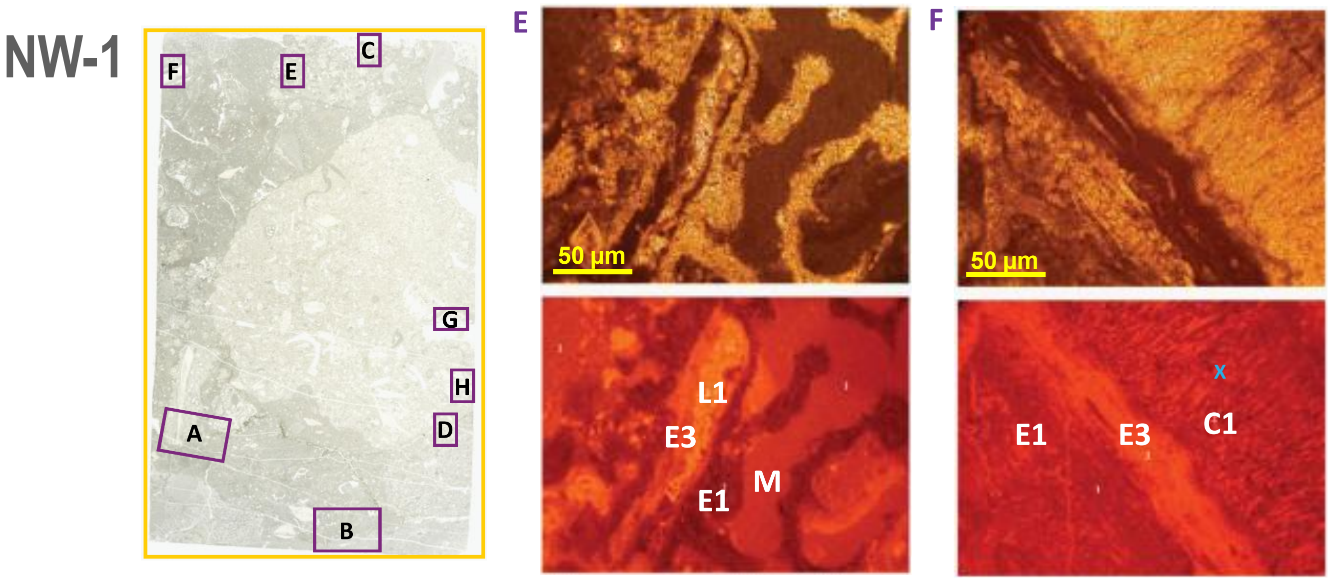
M-4 → better reservoir properties (Phi & K) related to Matrix - supported facies

Petrography – M-4

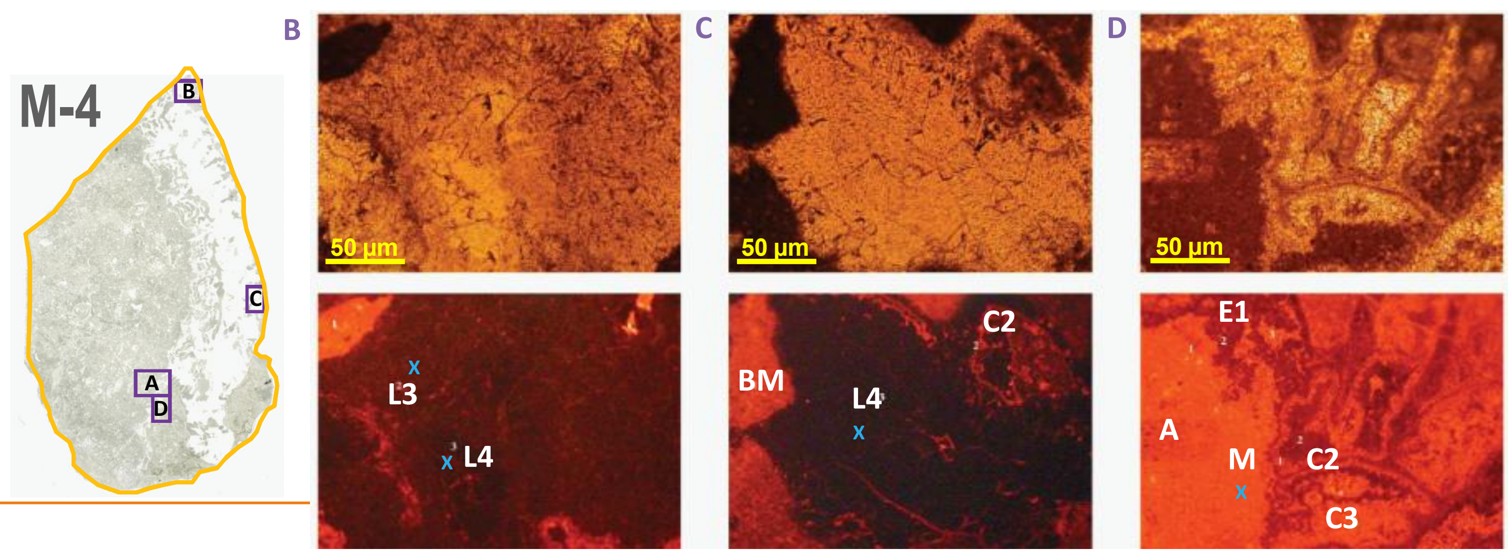


- Breccia clasts of multiple facies with early diagenesis (pre-dating debris)
- Post-breccia dissolution in matrix and clasts

CL Petrography



- Early Diagenesis observed in both wells
- Latest diagenesis only in M-4 well



Paragenesis

Well	Event	PARAGENETIC SEQUENCE					Younger →
		$\delta^{18}O$: -0.45 to -4.5 $\delta^{13}C$: +2.0 to 0	$\delta^{18}O$: -4.5 to -10.42 $\delta^{13}C$: +2.0 to -4.0				
NW-1 / M-4	A	Allochems					
NW-1 / M-4	M	Syn-sedimentary matrix					
NW-1 / M-4	E1	Allochems replaced / micritized					
NW-1 / M-4	E2	Syntaxial cement					
NW-1 / M-4	E3	Algal binding					
NW-1 / M-4	C1	Fibrous calcite					
NW-1 / M-4	C2	Isopachous calcite					
NW-1 / M-4	C3	Equant calcite					
			DEBRIS FLOWS				
M-4	BM		Breccia Matrix				
NW-1 / M-4				Compaction, Stylolitization			
NW-1 / M-4	DM				Dolomite, matrix replacive		
NW-1	DC				Dolomite cement		
NW-1 / M-4	L1				Pore-filling calcite (Bright-CL)		
NW-1 / M-4						Fracturing	
M-4						Dissolution, Enlargement of Fracts	
M-4						Dissolution of matrix	
M-4	L2						Fracture filling calcite
M-4	L3						Non-CL repl. calcite
M-4	L4						Non-CL pore-filling calcite

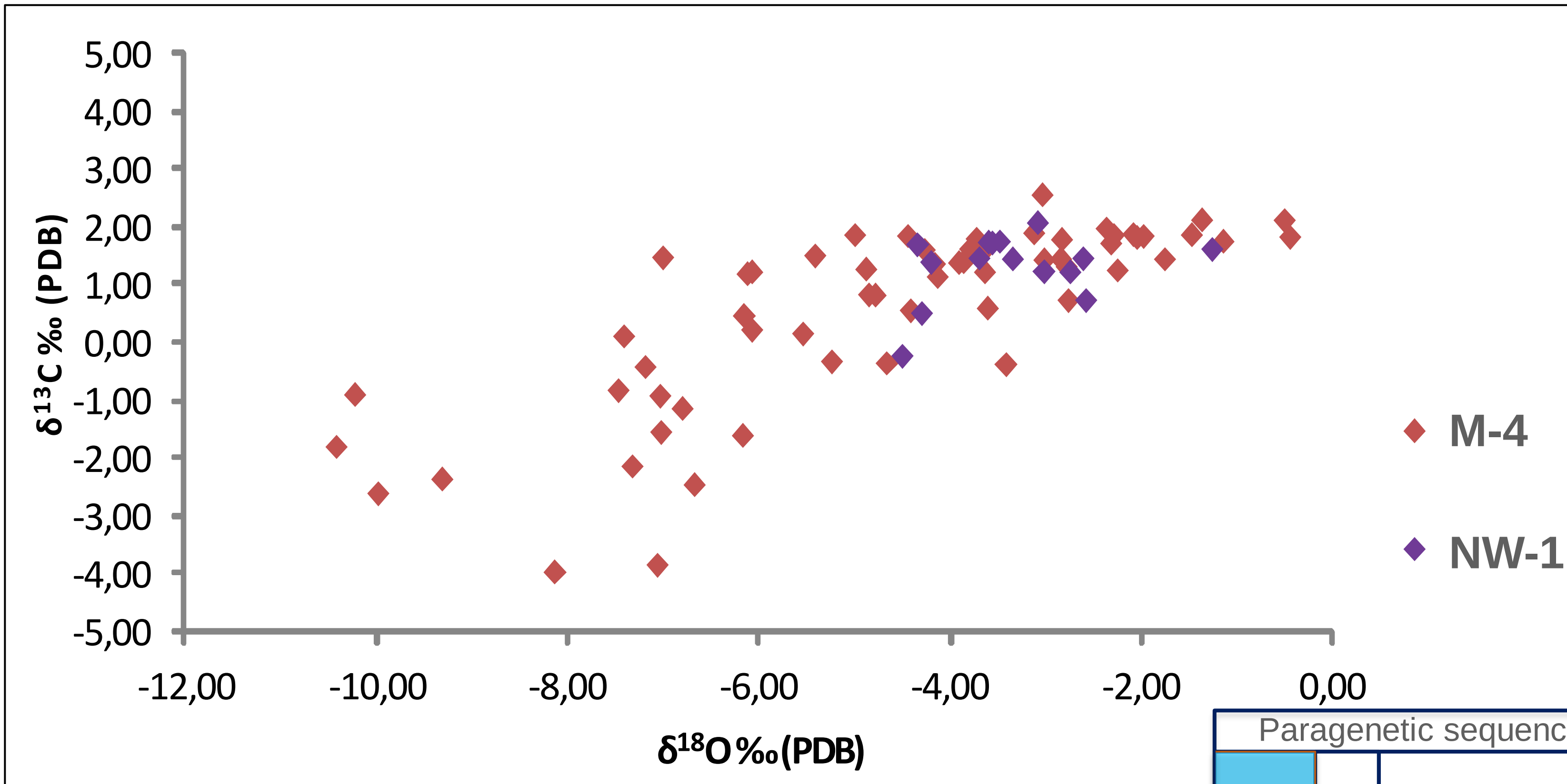
Paragenesis

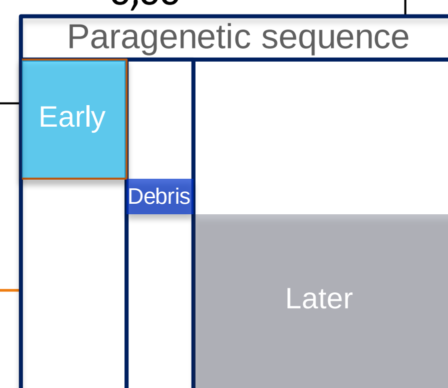
Well	Event	PARAGENETIC SEQUENCE					Younger →
		$\delta^{18}O$: -0.45 to -4.5 $\delta^{13}C$: +2.0 to 0	$\delta^{18}O$: -4.5 to -10.42 $\delta^{13}C$: +2.0 to -4.0				
NW-1 / M-4	A	Allochems					
NW-1 / M-4	M	Syn-sedimentary matrix					
NW-1 / M-4	E1	Allochems replaced / micritized					
NW-1 / M-4	E2	Syntaxial cement					
NW-1 / M-4	E3	Algal binding					
NW-1 / M-4	C1	Fibrous calcite					
NW-1 / M-4	C2	Isopachous calcite					
NW-1 / M-4	C3	Equant calcite					
			DEBRIS FLOWS				
M-4	BM		Breccia Matrix				
NW-1 / M-4				Compaction, Stylolitization			
NW-1 / M-4	DM				Dolomite, matrix replacive		
NW-1	DC				Dolomite cement		
NW-1 / M-4	L1				Pore-filling calcite (Bright-CL)		
NW-1 / M-4						Fracturing	
M-4						Dissolution, Enlargement of Fracts	
M-4						Dissolution of matrix	
M-4	L2						Fracture filling calcite
M-4	L3						Non-CL repl. calcite
M-4	L4						Non-CL pore-filling calcite

Paragenesis

Well	Event	PARAGENETIC SEQUENCE					Younger →
		$\delta^{18}O$: -0.45 to -4.5 $\delta^{13}C$: +2.0 to 0	$\delta^{18}O$: -4.5 to -10.42 $\delta^{13}C$: +2.0 to -4.0				
NW-1 / M-4	A	Allochems					
NW-1 / M-4	M	Syn-sedimentary matrix					
NW-1 / M-4	E1	Allochems replaced / micritized					
NW-1 / M-4	E2	Syntaxial cement					
NW-1 / M-4	E3	Algal binding					
NW-1 / M-4	C1	Fibrous calcite					
NW-1 / M-4	C2	Isopachous calcite					
NW-1 / M-4	C3	Equant calcite			Post-date Debris Flows		
			DEBRIS FLOWS				
M-4	BM	Pre-date Debris Flows	Breccia Matrix				
NW-1 / M-4				Compaction, Stylolitization			
NW-1 / M-4	DM				Dolomite, matrix replacive		
NW-1	DC				Dolomite cement		
NW-1 / M-4	L1				Pore-filling calcite (Bright-CL)		
NW-1 / M-4						Fracturing	
M-4						Dissolution, Enlargement of Fracts	
M-4						Dissolution of matrix	
M-4	L2						Fracture filling calcite
M-4	L3						Non-CL repl. calcite
M-4	L4						Non-CL pore-filling calcite

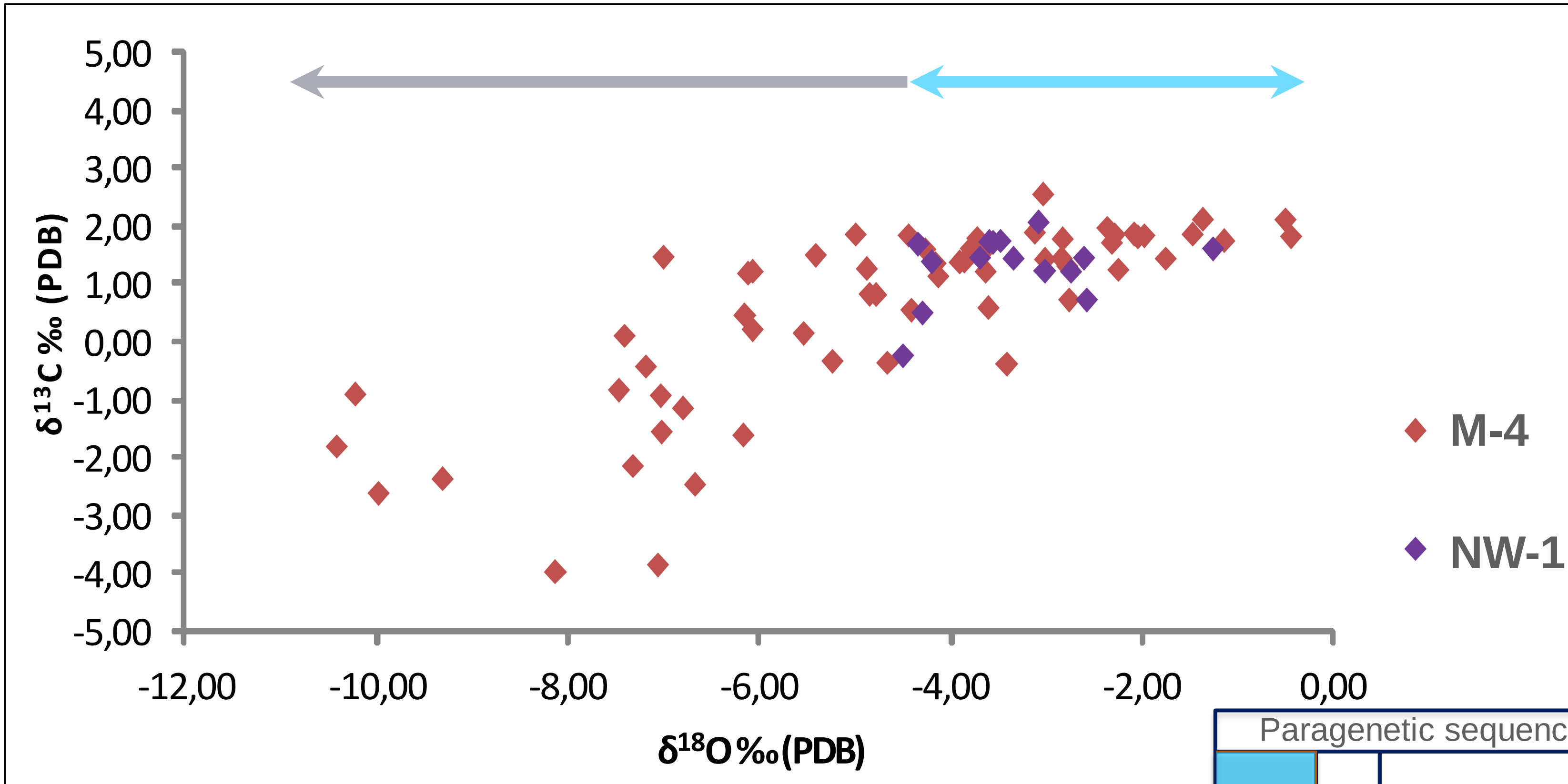
Isotopes Indicate Shorter vs Longer Diagenetic Histories



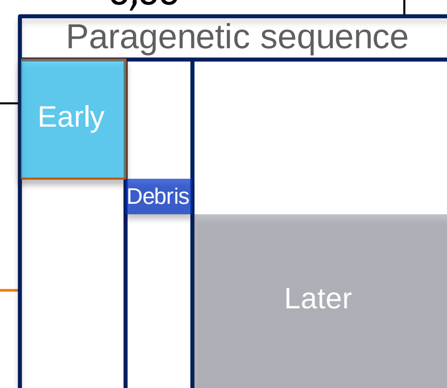


Isotopes Indicate Shorter vs Longer Diagenetic Histories

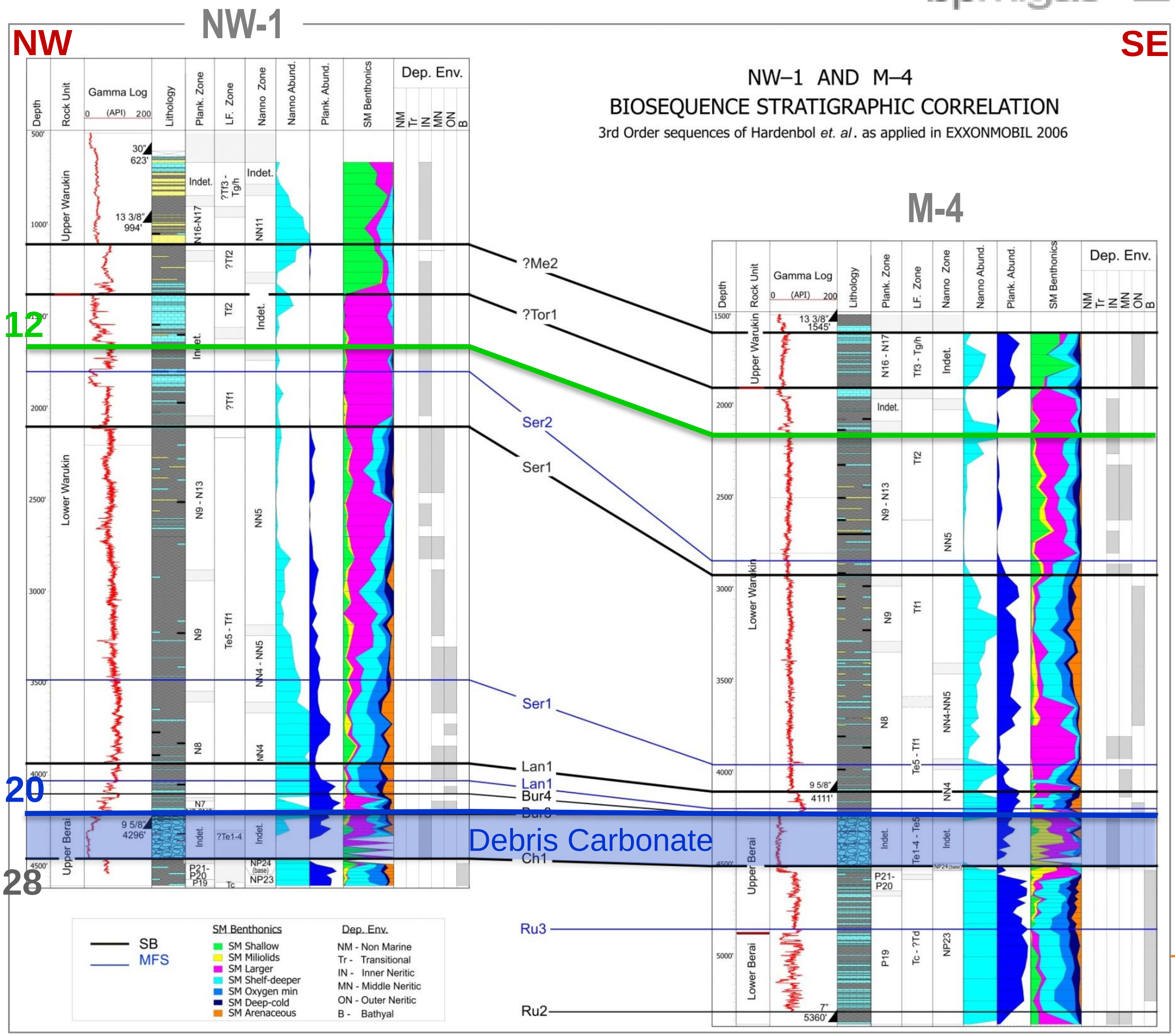
bpmigas Mubadala Petroleum



M-4 → underwent post-burial diagenesis
NW-1 → dissolution / latest cements not observed

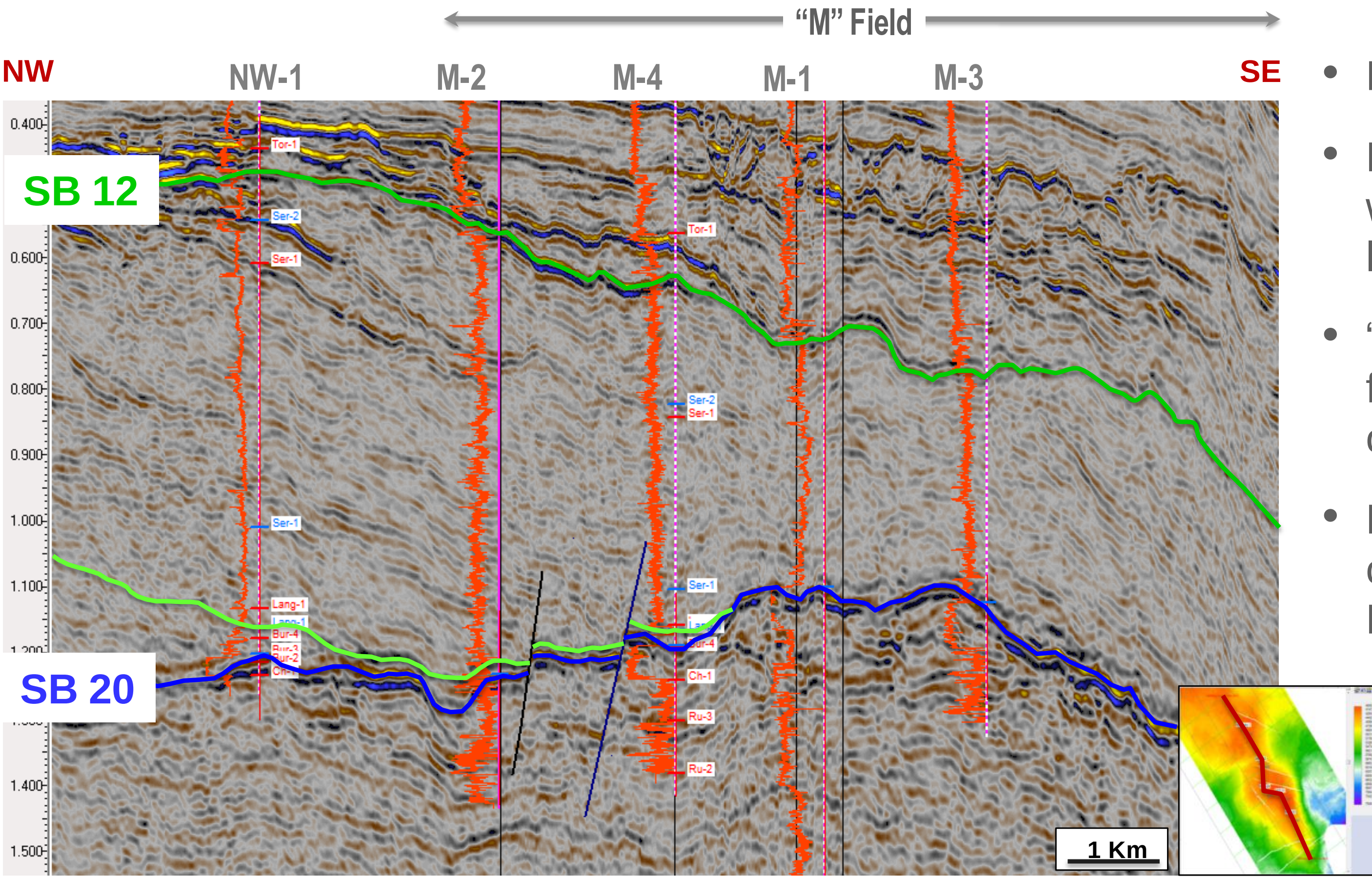


Biostratigraphy



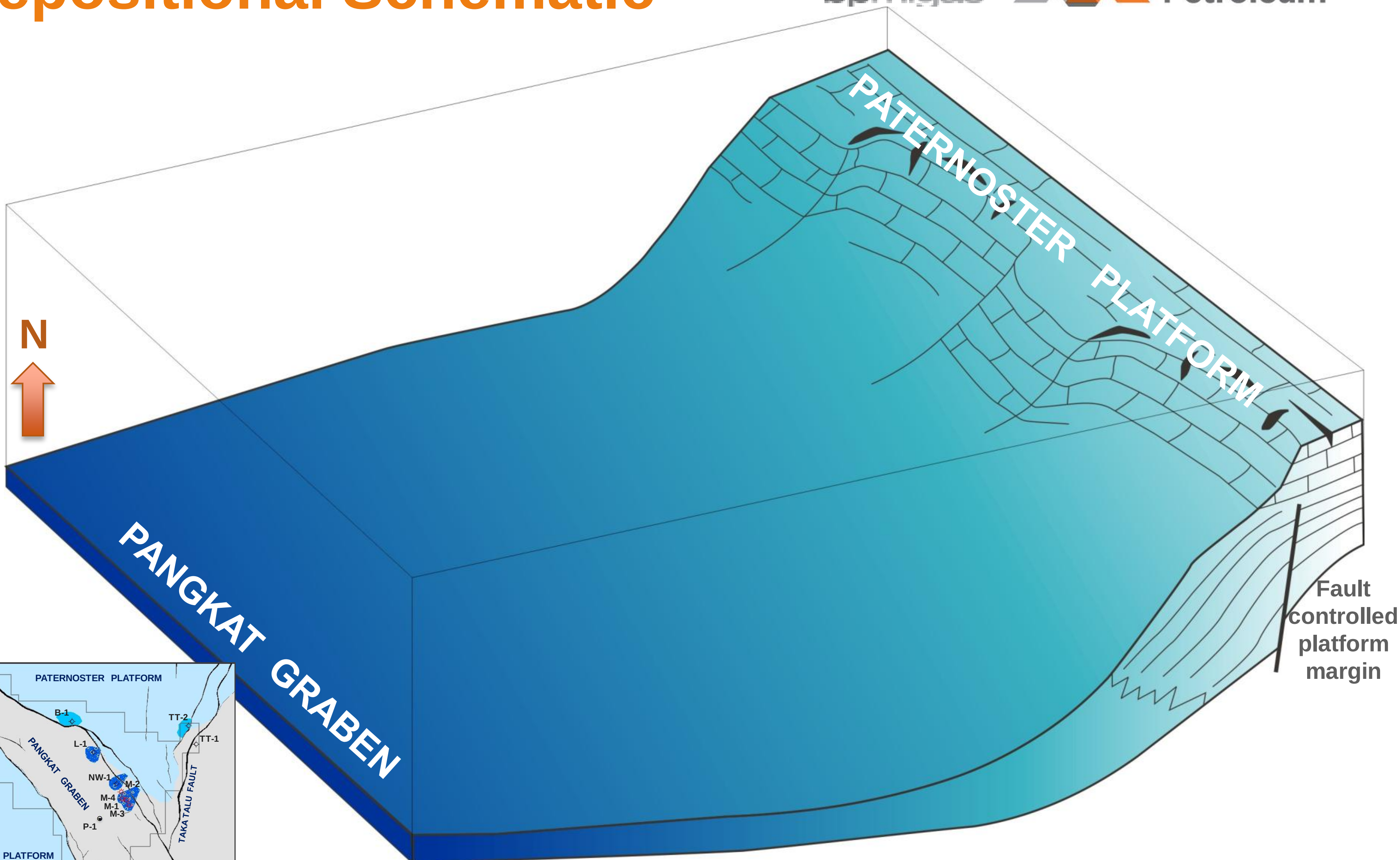
- Reservoir and seal during global sealevel lowstands
- Bathyal deposits in the Pangkat Graben during Lower Oligocene
- Overlain by debris flows of inner neritic (platform) provenance
- Condensed section above
- Downlapped by Lower Miocene lowstand delta deposits

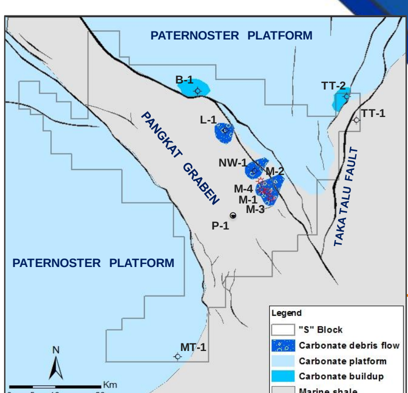
Seismic Consistent with Biostratigraphy and Diagenesis



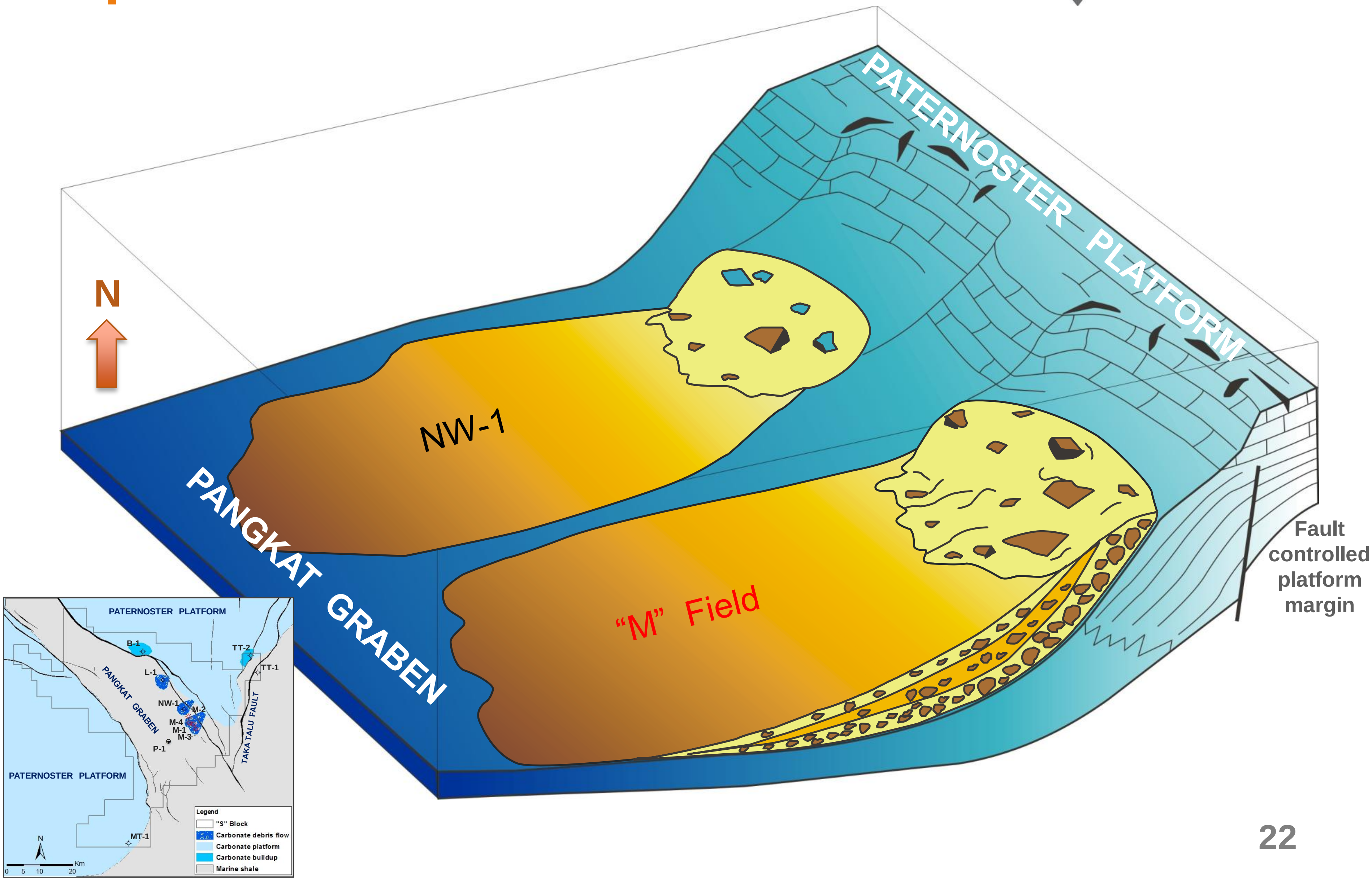
- Lowstand progradation
- NW-1 sealed prior to "M" wells; Buildups not in lateral communication
- "M" Field buildup is faulted; faults not observed in NW-1
- Lack of vertical or lateral charge access likely for NW-1 failure

Depositional Schematic

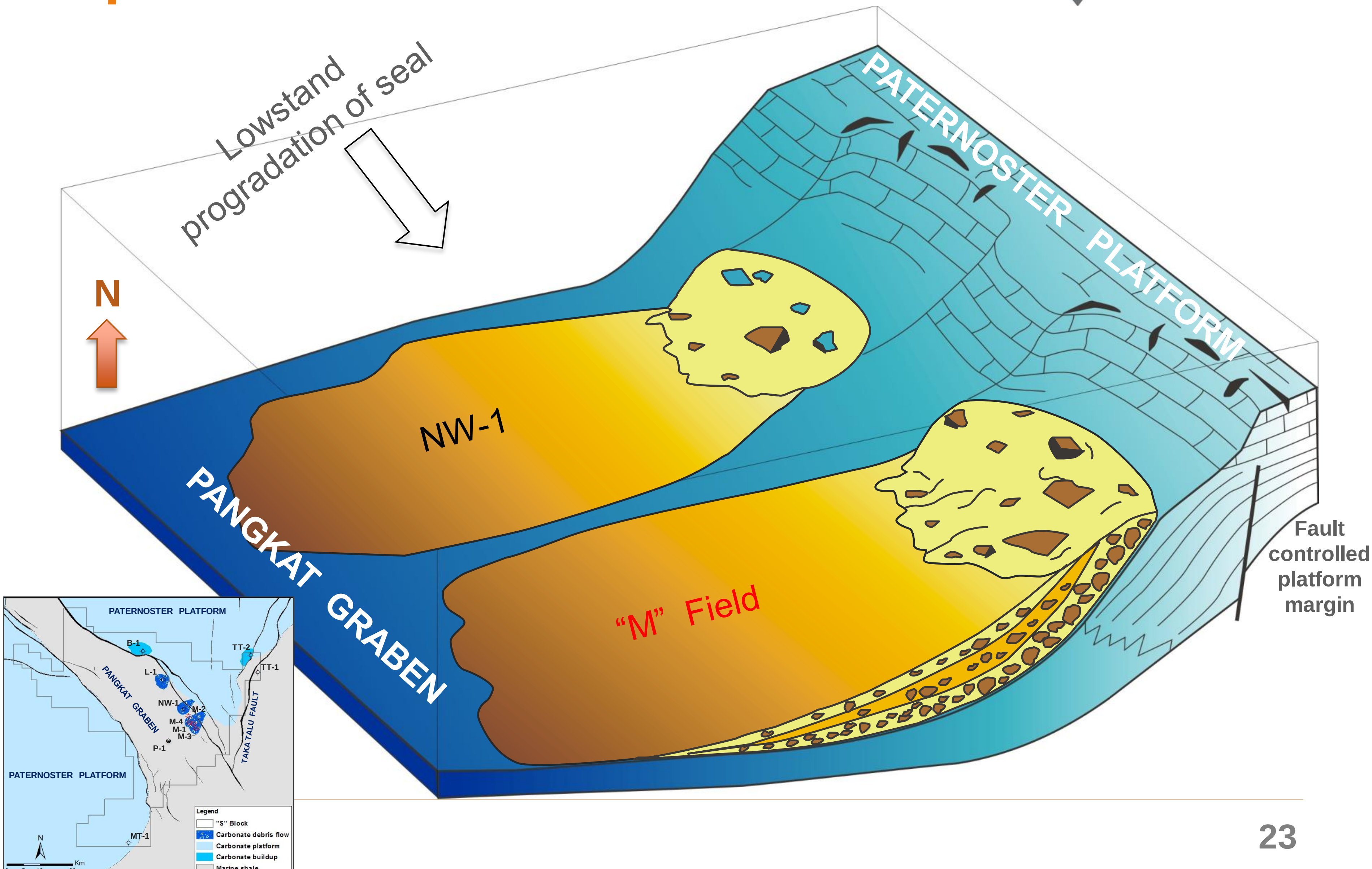




Depositional Schematic



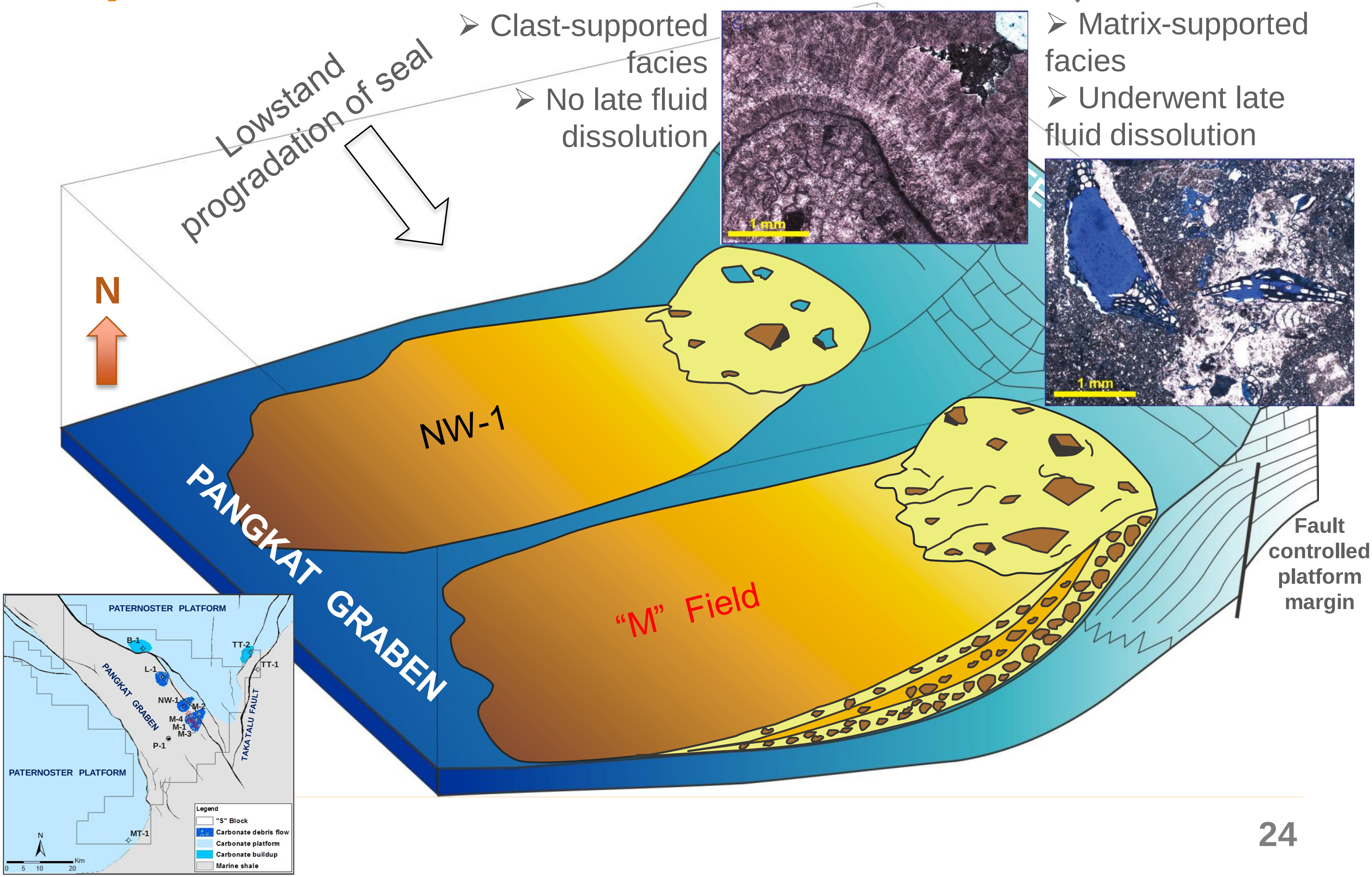
Depositional Schematic



Depositional Schematic

➢ Clast-supported facies
➢ No late fluid dissolution

➢ Matrix-supported facies
➢ Underwent late fluid dissolution



Implication

- The “M” Field is the first gas field in Indonesia from carbonate debris-flow facies.

- The study result is a new model to explain creation and retention of economic porosity in carbonate debris flow systems in Indonesia and opens a new play opportunity in carbonate targets.

Conclusion

- The diagenetic overprint in the Upper Berai carbonate section was more extensive within the M-4 well than the NW-1 well.

- Post-debris flow dissolution in the M-4 well explains the better reservoir quality.

- Faults and fractures are important fluid conduits; “M” Field has more than NW-1.

- Micro-porosity in the matrix-supported breccia acts as conduits for later diagenetic fluids.

- Lack of vertical and lateral fluid access into NW-1 is consistent with dry hole analysis

Acknowledgement

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- Mubadala Petroleum colleagues