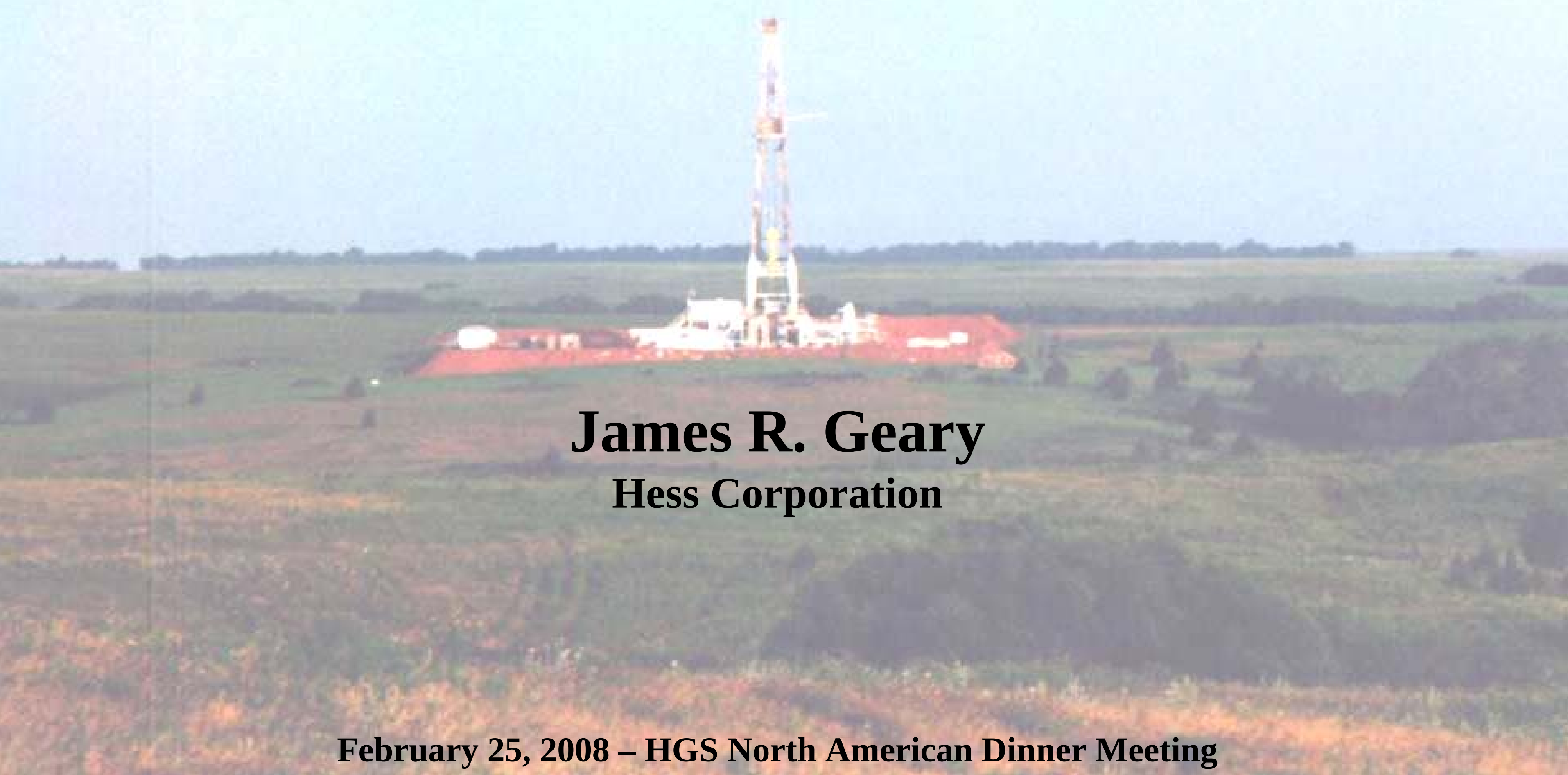
Controls on Hydrocarbon Entrapment and Reservoir Distribution: the Pennsylvanian Big Lime and Oswego Limestone in the Putnam Field Area, Anadarko Basin, Oklahoma



James R. Geary
Hess Corporation

February 25, 2008 – HGS North American Dinner Meeting

ACKNOWLEDGMENTS

- Baylor University
  - Dr. Stacy Atchley
- Apache Corporation
  - Brad Johnson
- Spartan Resources, LLC
  - Tim Munson
- Duncan Oil Properties
  - Brian Branesky
- Oklahoma Geological Survey
- Riley Electric Log
- Hess Corporation

Abstract

Putnam Field, located along the northern margin of the Anadarko Basin and extending through Custer and Dewey counties in western Oklahoma, USA, has produced over 400 BCF and 13 MMBO from the Pennsylvanian (Desmoinesian) Oswego Limestone and Big Lime. Hydrocarbons are stratigraphically trapped within phylloid algal mound complexes that are isolated within shallowing-upward parasequence sets; mound complexes generally trend west-east across the study area parallel to the northern structural margin of the Anadarko Basin. Reservoir quality within phylloid algal mounds is controlled by variations in the abundance of moldic, vuggy, and fracture pore types (average porosity = 2%, median permeability = 0.2 md). Eleven parasequence sets occur within the study interval and from the section base to top stack progradationally within the Oswego Limestone, and aggradationally to retrogradationally within the overlying Big Lime. The change from progradational to retrogradational stacking of parasequence sets most likely reflects an accelerating rate of subsidence during deposition that was induced by thrust-loading along the Ouachita foldbelt. Furthermore, retrogradational stacking within the Big Lime suggests that undiscovered hydrocarbon reserves may exist updip (northward) of the Putnam Trend in slightly younger deposits.

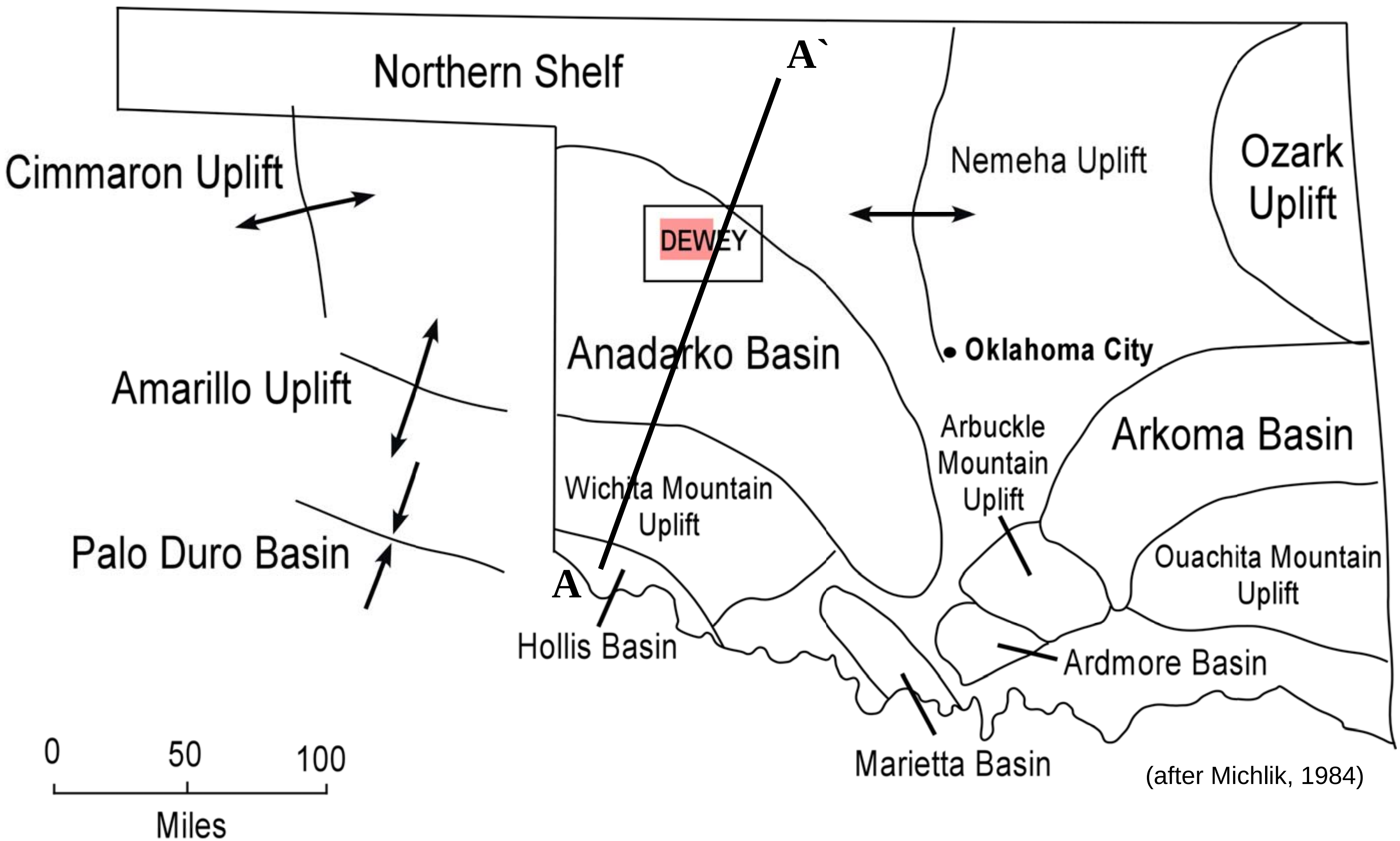
Detailed maps of structure, facies, gross pay, and pore volume were generated for each parasequence set, and compared with the spatial distribution of producing wells and their associated drainage radii. From these attributes, a geologic risk assessment was completed across the Putnam Trend to determine the most prospective areas for future step-out development.

PURPOSE

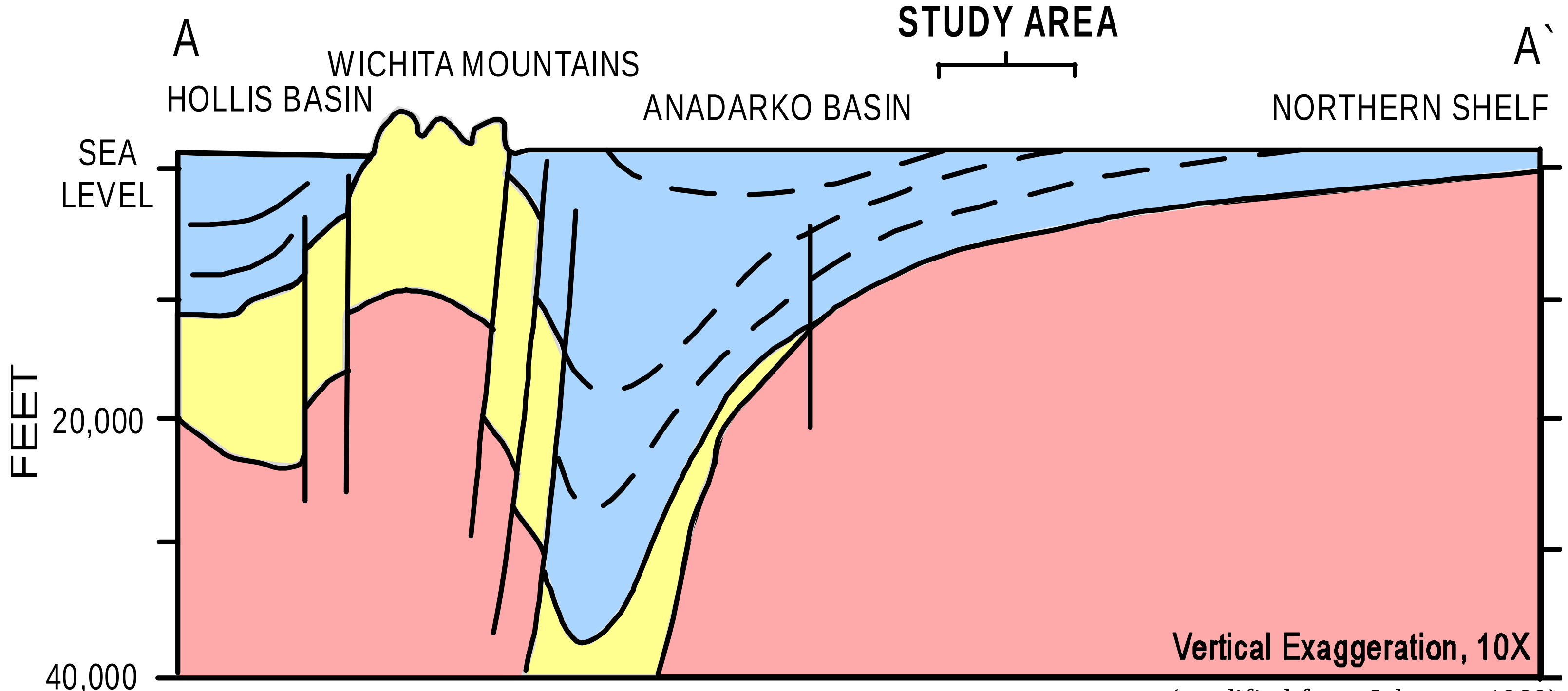
Determine the development potential within the Pennsylvanian Big Lime and Oswego Limestone of Dewey County, Oklahoma.

KEY QUESTIONS

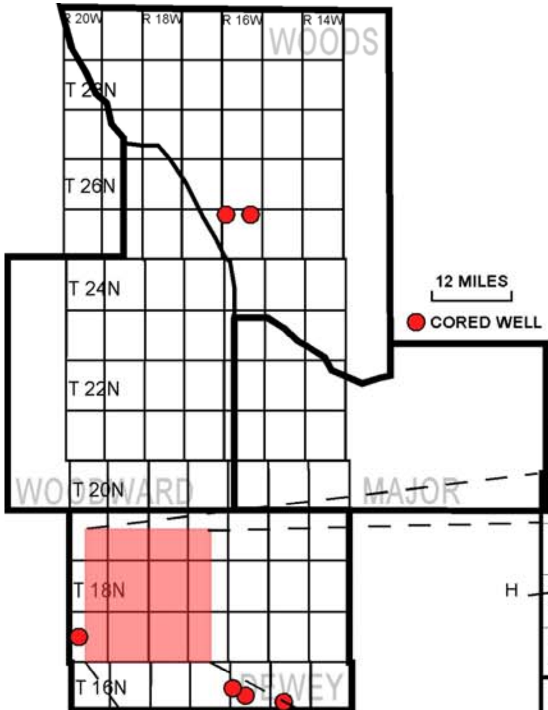
- What is the depositional model and controls on reservoir quality?
- How are reservoir quality facies distributed within a three-dimensional framework?
- What are the most favorable geographic location(s) for future development potential?

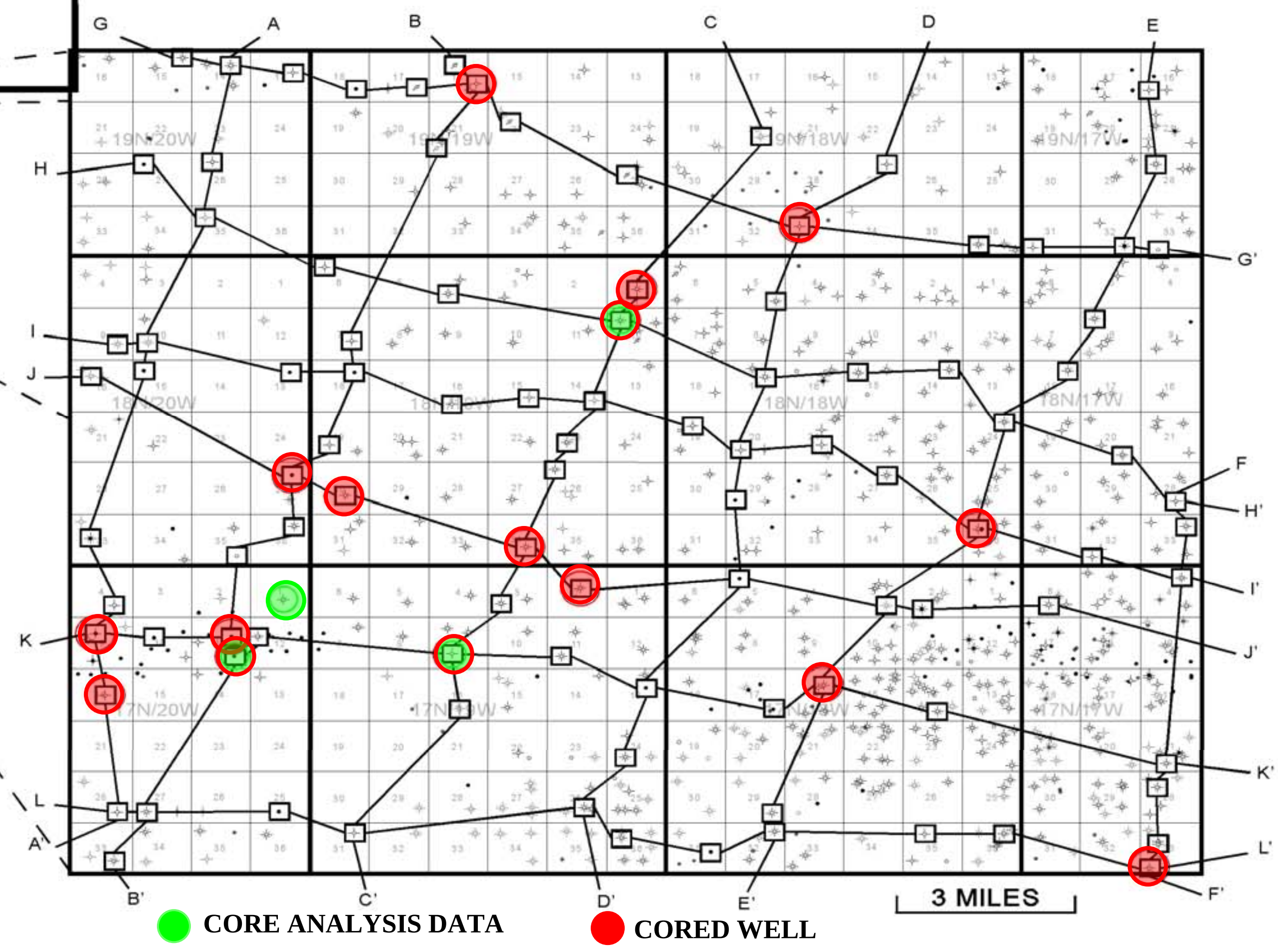


(after Michlik, 1984)

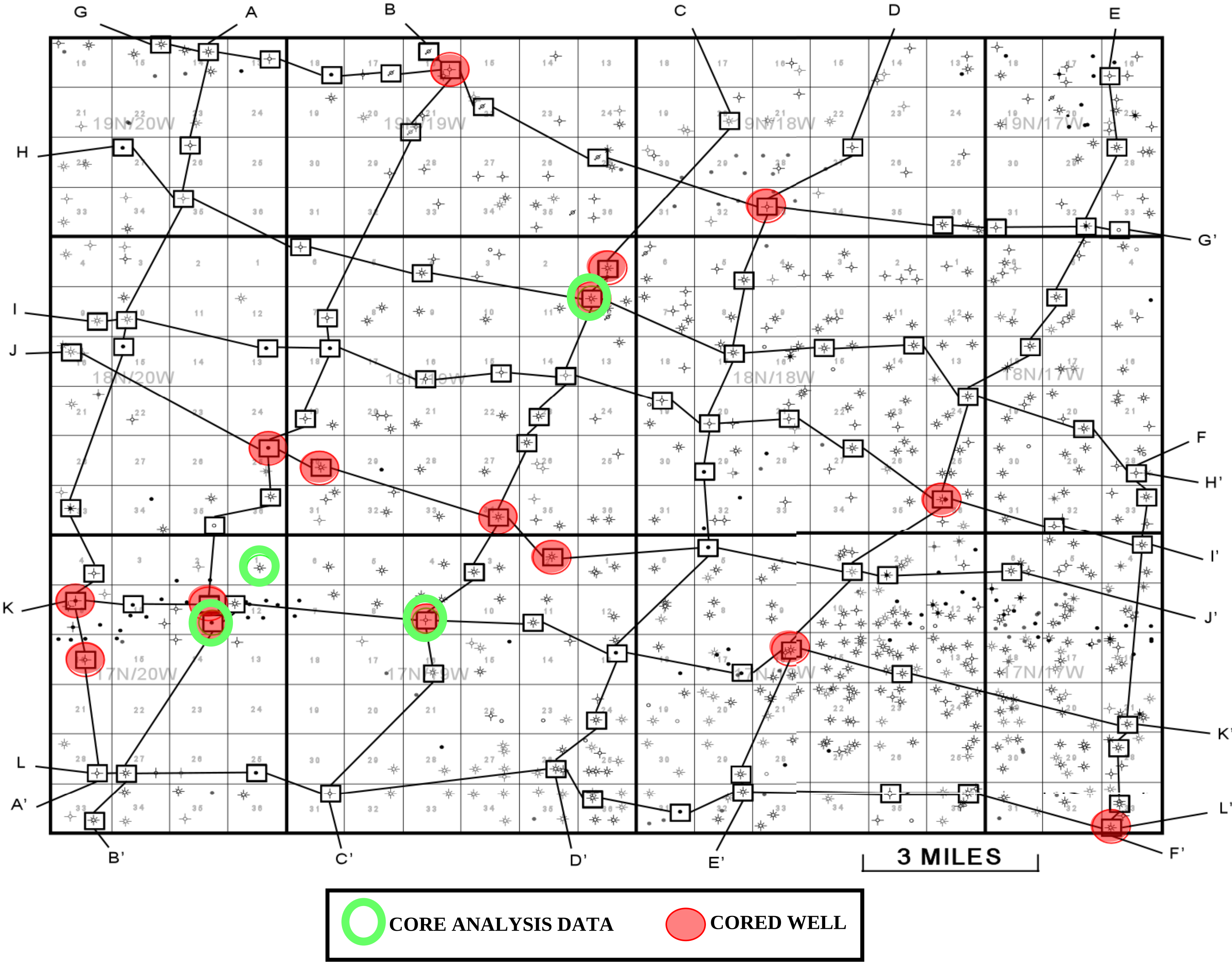


(modified from Johnson, 1989)





- 1523 feet of core from 22 wells
- Analyzed 100 wells



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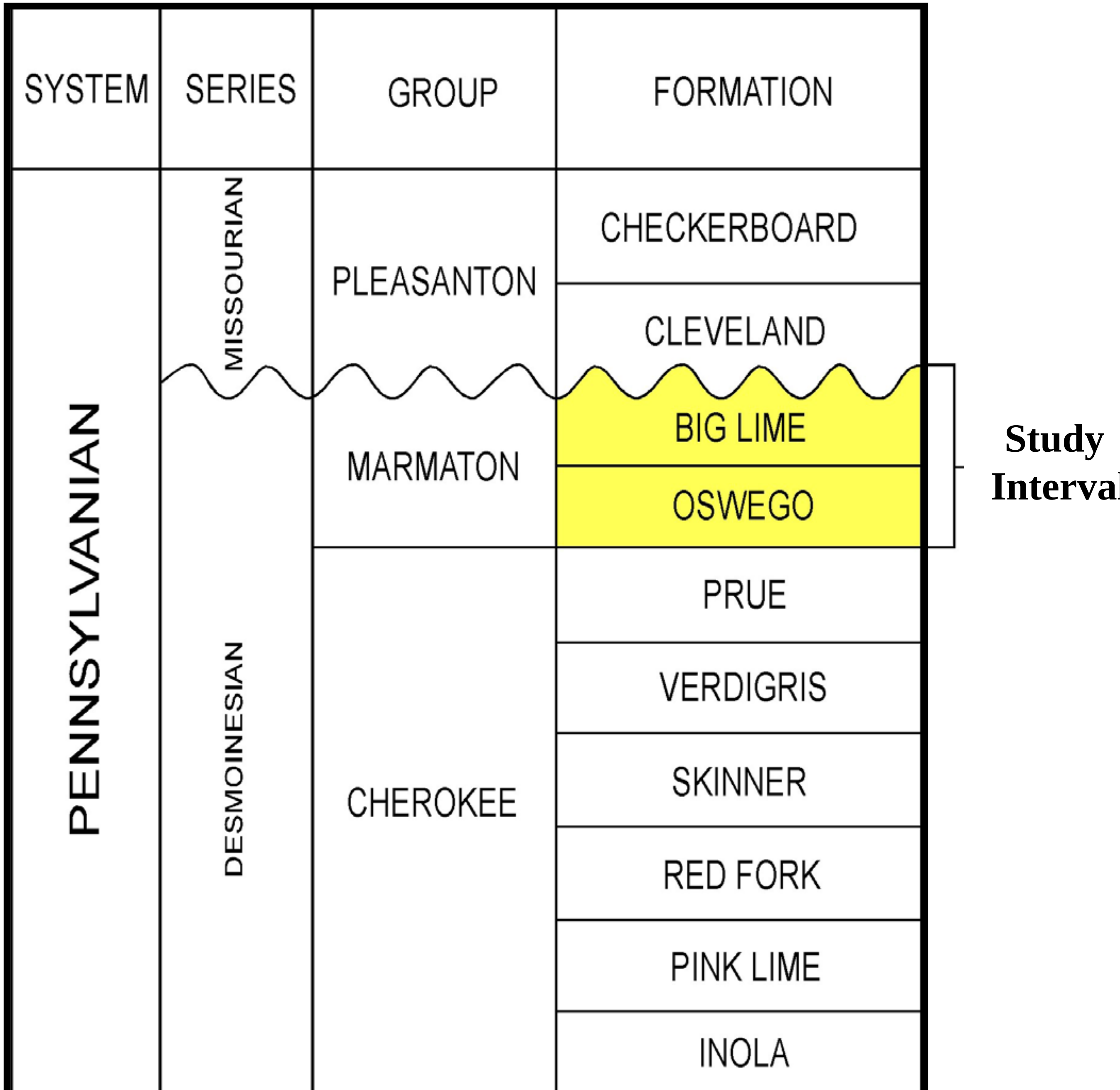
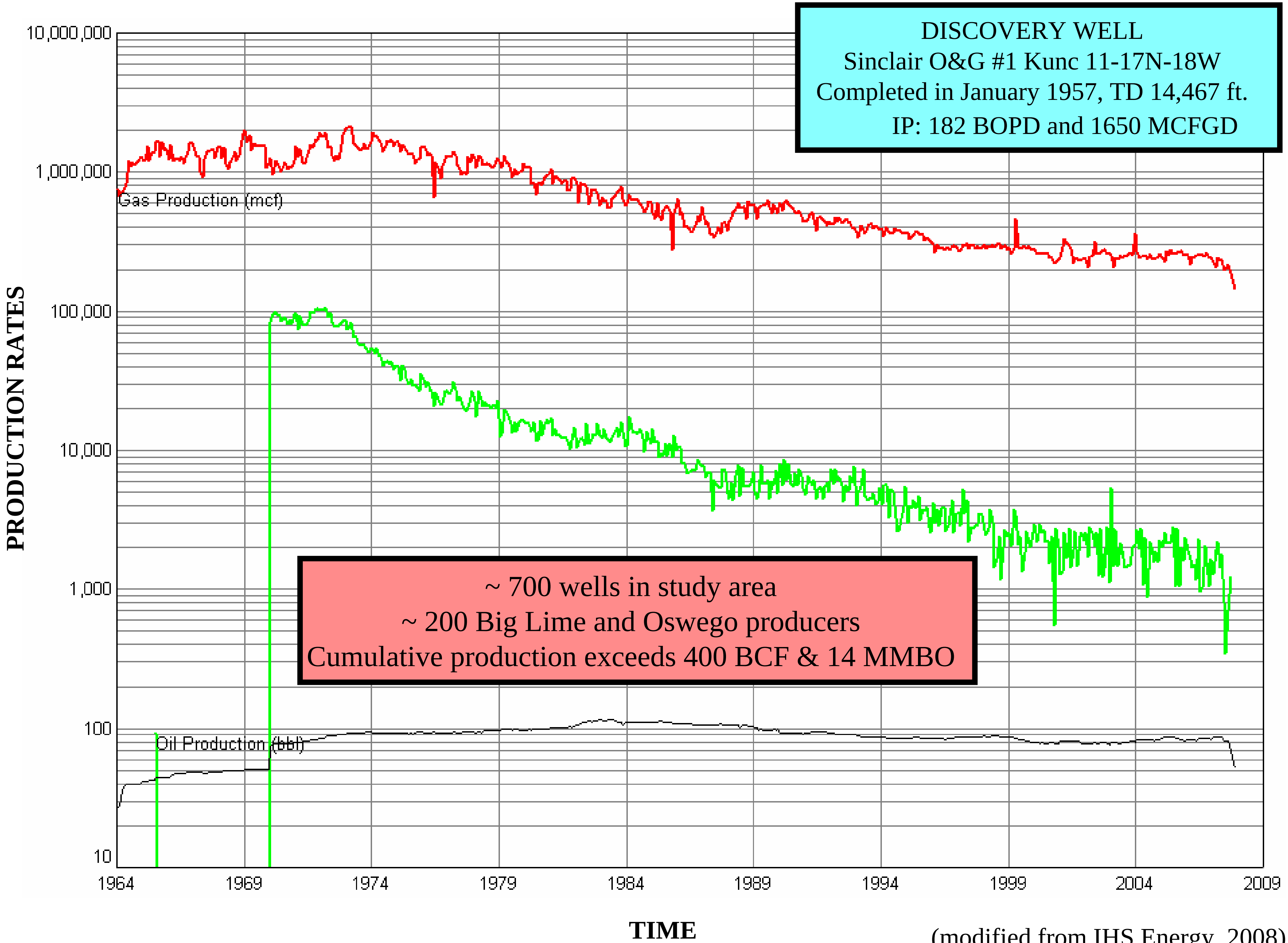
17N/18W
17N/17W
3 MILES
CORE ANALYSIS DATA
CORED WELL



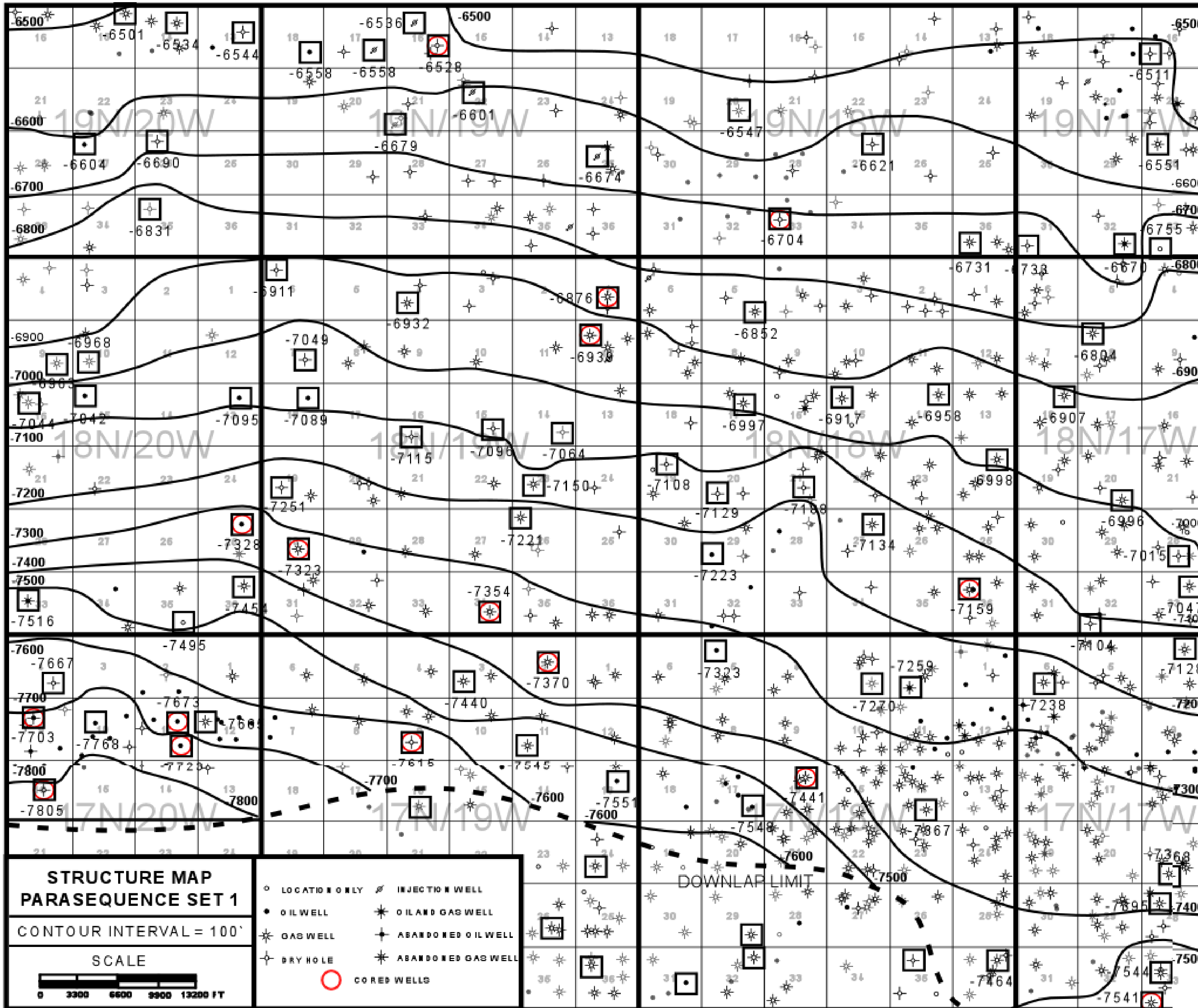
(modified from Derstine, 1989)



(modified from IHS Energy, 2008)

Discovery Information	Parameters	Reservoir Characteristics	Parameters	Production Information	Parameters
Year discovered	1957	Depth to reservoir	8120-9926 feet	Study area	201600 acres, 315 mi^2
Initial producer	1650 MCFD, 182 BOD	Average gross interval	123 feet	Estimated well count	700
Average elevation	1901 feet	Average porosity range	1-10%	Formation value factor	1.697
Oil gravity	43°	Average permeability range	0.01-10 mD	Recovery factor (gas)	0.88
Gas gravity	0.7	Average S_w	30%	Expansion factor	0.0038
Drive mechanism	Gravity			Cumulative production (as of 5/02)	
Reservoir Pressure	4500 psi			Big Lime	239 MBO, 12 Bcf
				Oswego	13MMBO, 395 Bcf
Reservoir Temperature	160 °F				
Trap	Stratigraphic				

(Brown, 1963; Swanson, 1967;Zagaar, 1965; and IHS Energy)


STRUCTURE MAP
PARASEQUENCE SET 1
CONTOUR INTERVAL = 100`
SCALE
0 3300 6600 9900 13200 FT
LOCATION ONLY
OIL WELL
GAS WELL
DRY HOLE
INJECTION WELL
OIL AND GAS WELL
ABANDONED OIL WELL
ABANDONED GAS WELL
CORED WELLS
19N/20W
19N/19W
19N/18W
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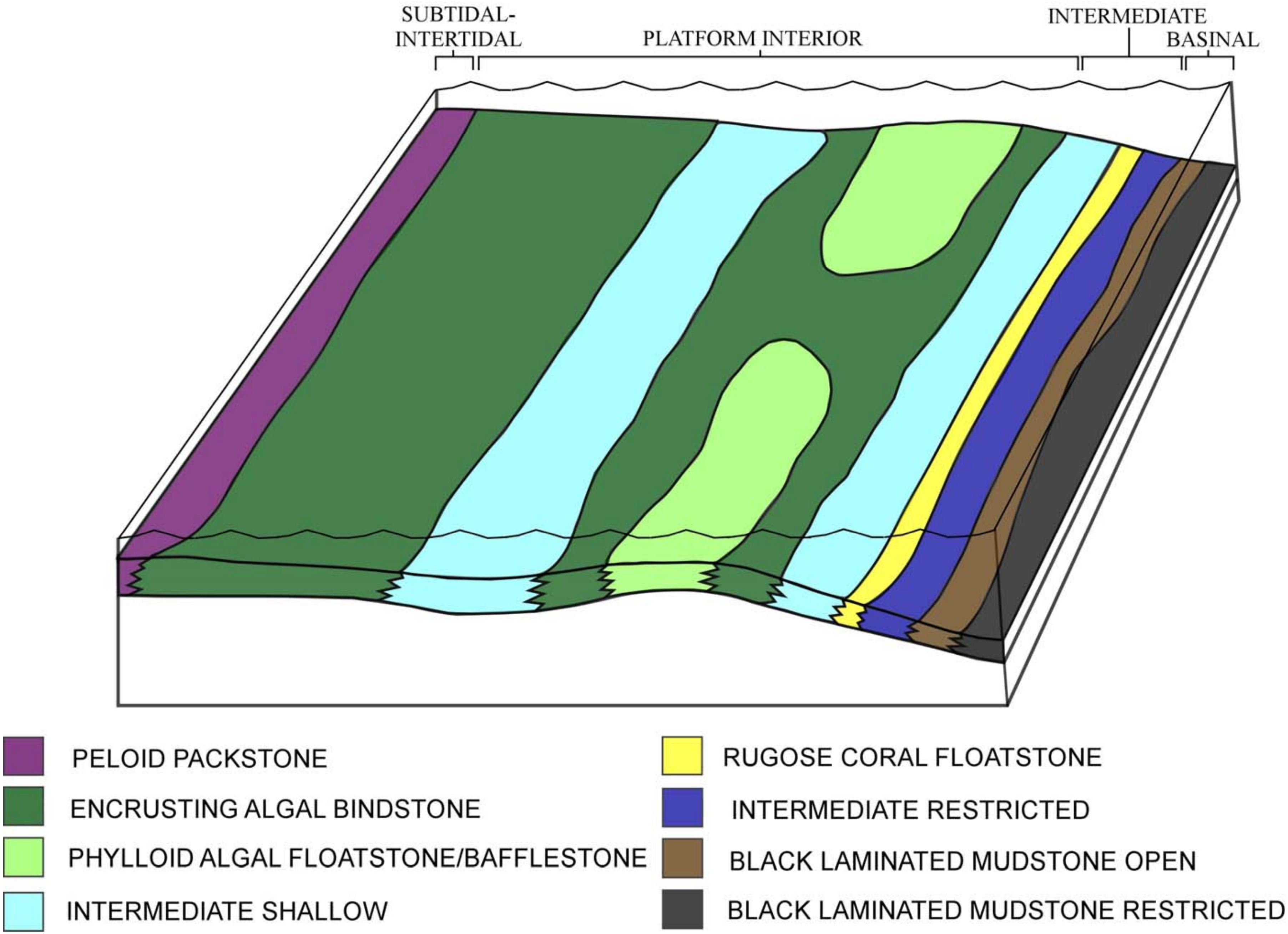
17N/19W
17N/18W
17N/17W
DOWNLAP LIMIT
-6500
-6600
-6700
-6800
-6900
-7000
-7100
-7200
-7300
-7400
-7500
-7600
-7700
-7800

KEY QUESTIONS

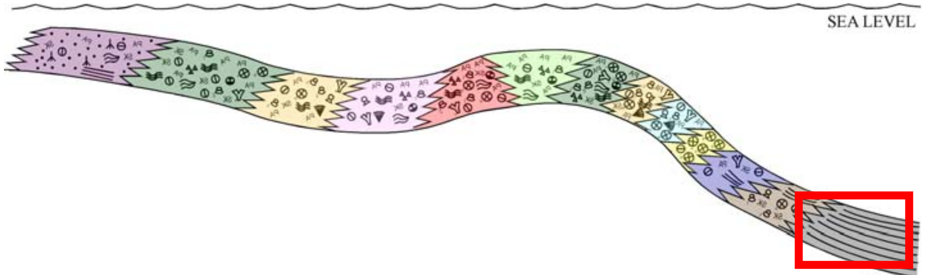
- **What is the depositional model and controls on reservoir quality?**
- How are reservoir quality facies distributed within a three-dimensional framework?
- What are the most favorable geographic location(s) for future development potential?



(modified from Derstine, 1989)

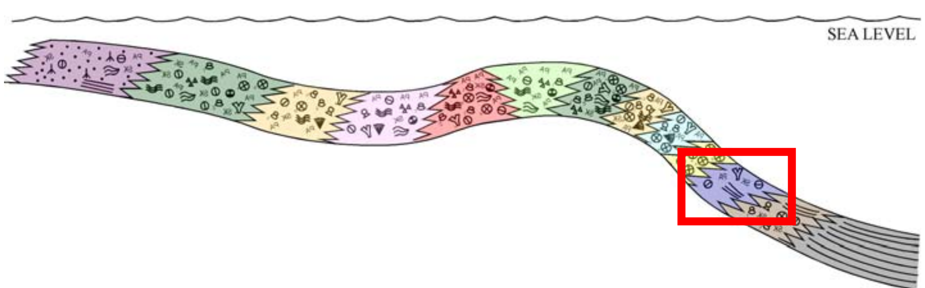
BLACK LAMINATED MUDSTONE OPEN/RESTRICTED

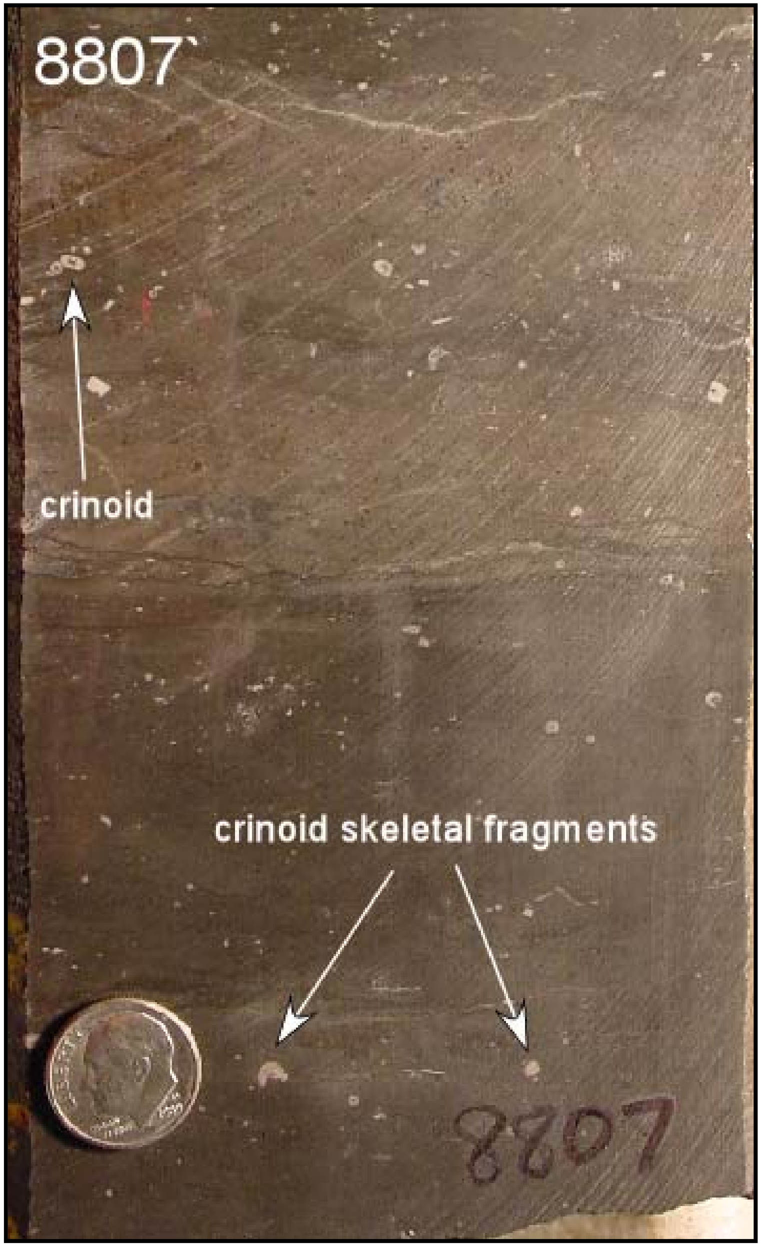
- Dark gray to black laminated mudstone
- Open to restricted basinal environment, low energy
- “Poker chip”



INTERMEDIATE DEEP

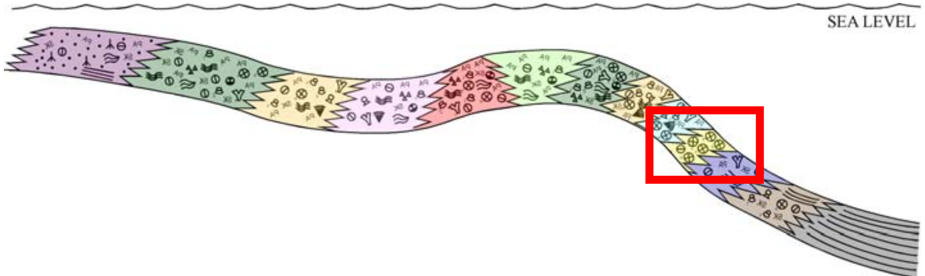
- Gray to black wackestone to mudstone
- Low energy, open marine environment
- Minor amounts of:
  - Phylloid algae
  - Crinoid fragments
  - Rugose coral
  - Skeletal fragments

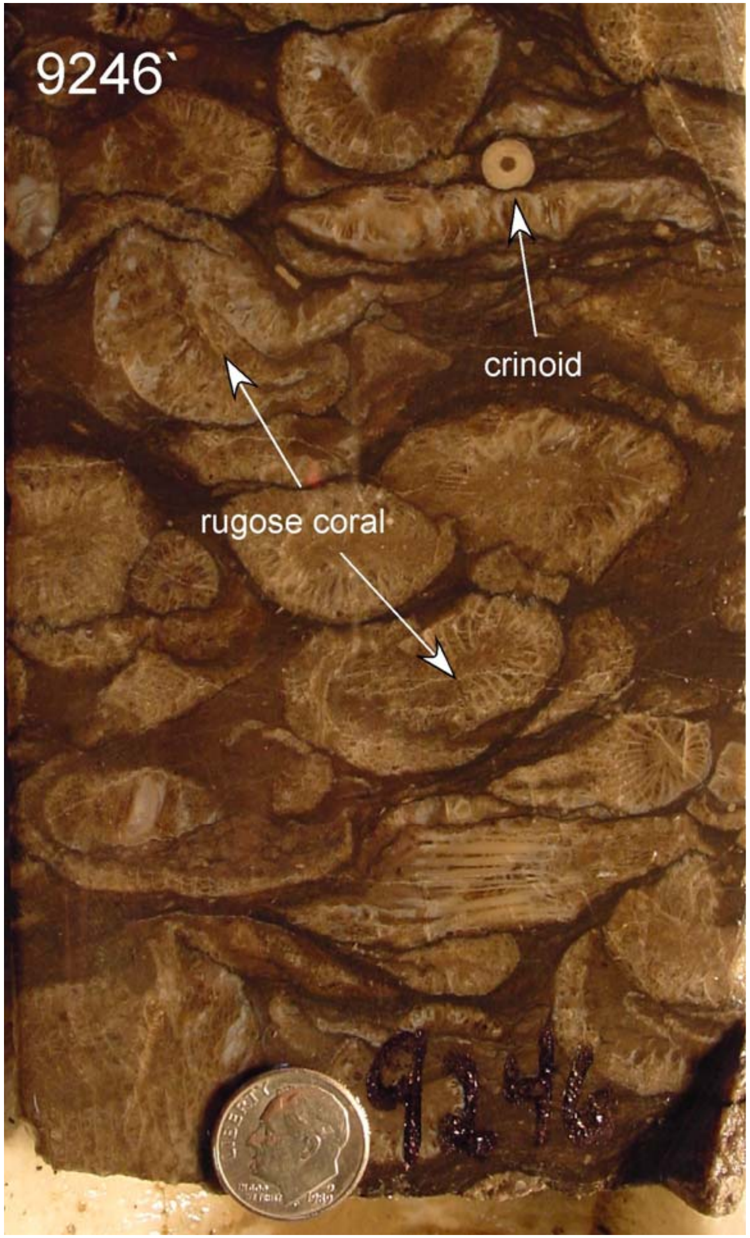




RUGOSE CORAL FLOATSTONE

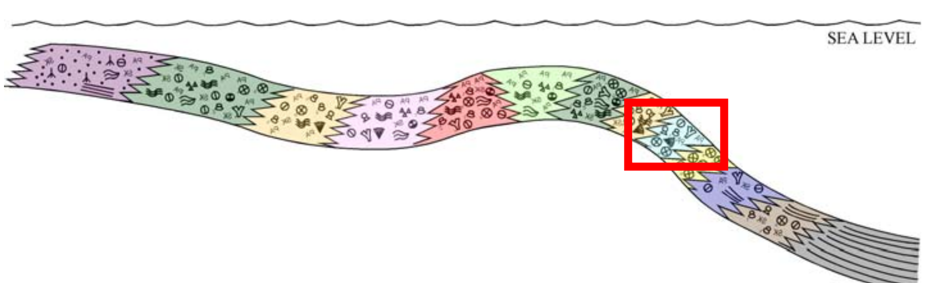
- Dark gray to black rugose coral floatstone
- Associated within intermediate facies
- Low energy, open marine environment
- Crinoid fragments

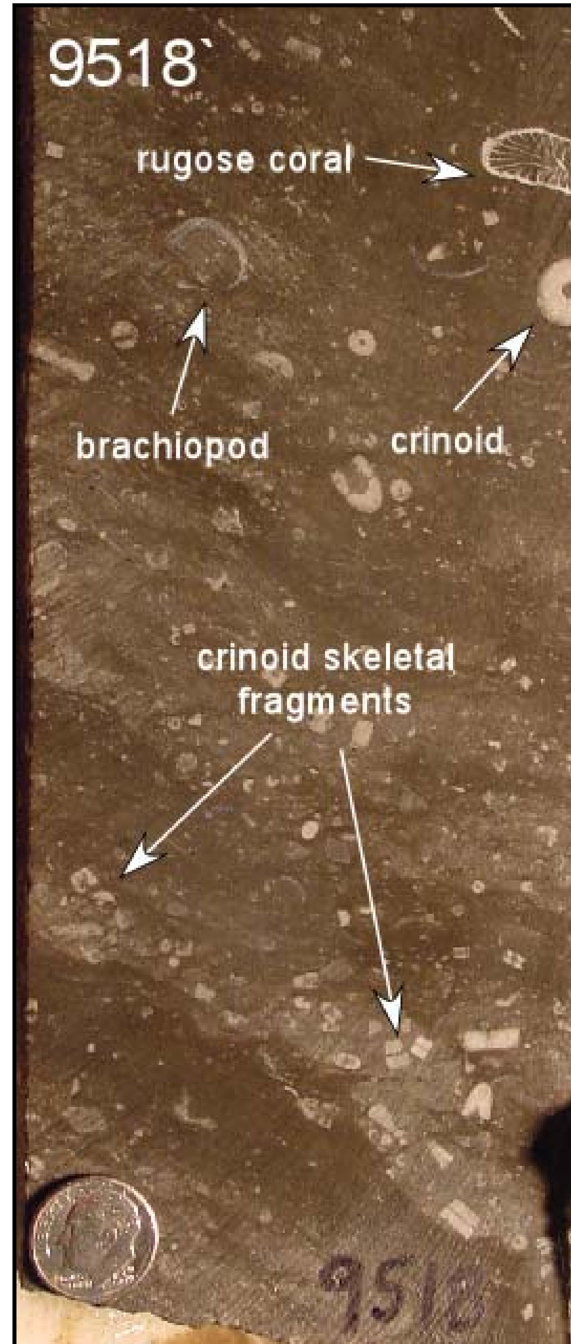




INTERMEDIATE SHALLOW

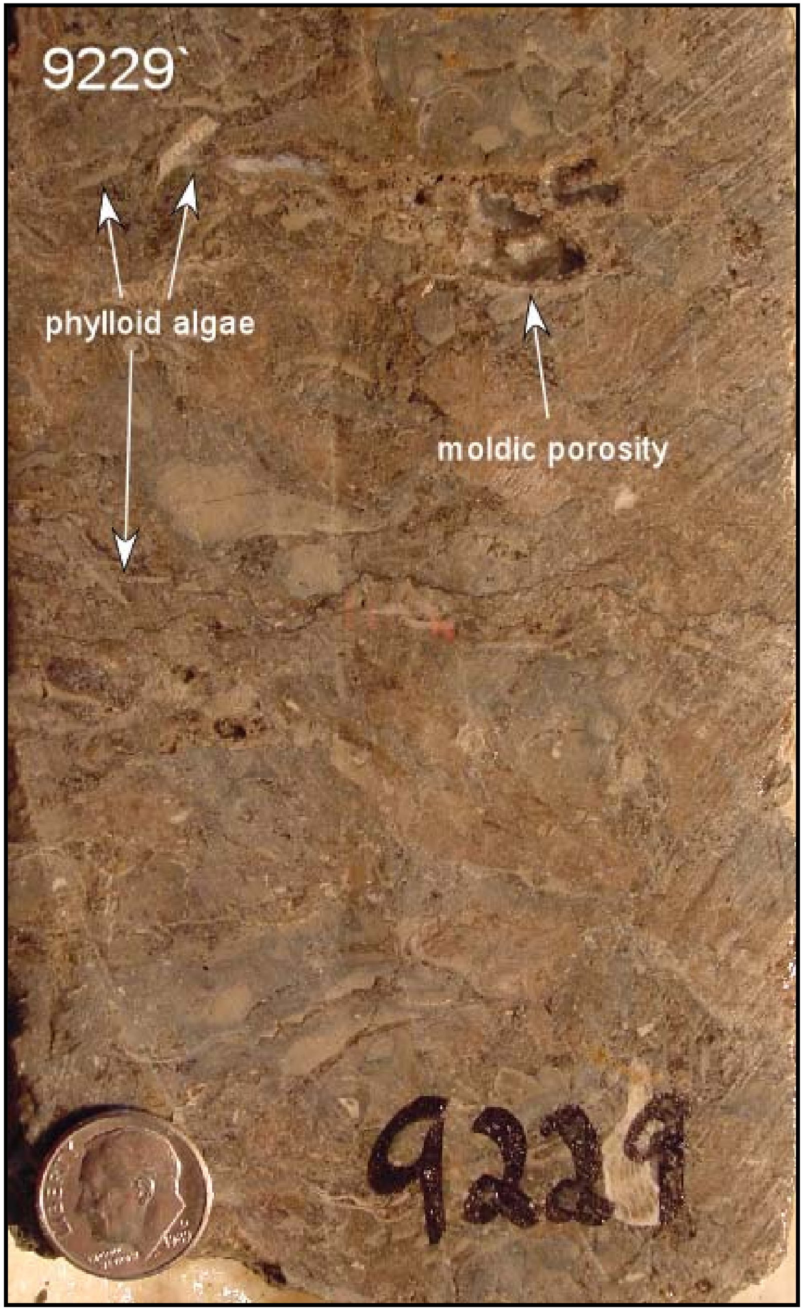
- Light to dark gray wackestone to packstone
- Low to moderate energy open-marine platform
- Moldic and fracture pore types
- Structures include:
  - Organic binding
  - Stylolites

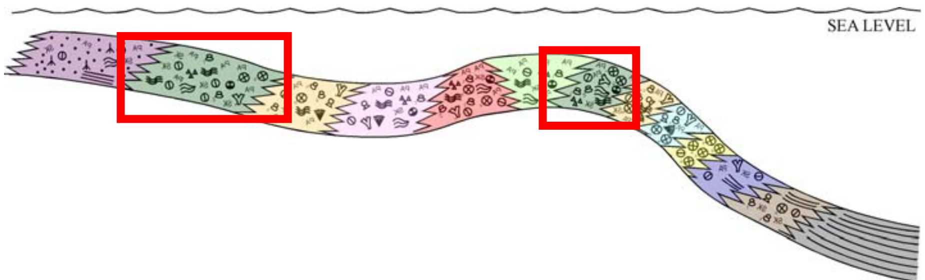




ENCRUSTING ALGAL BINDSTONE

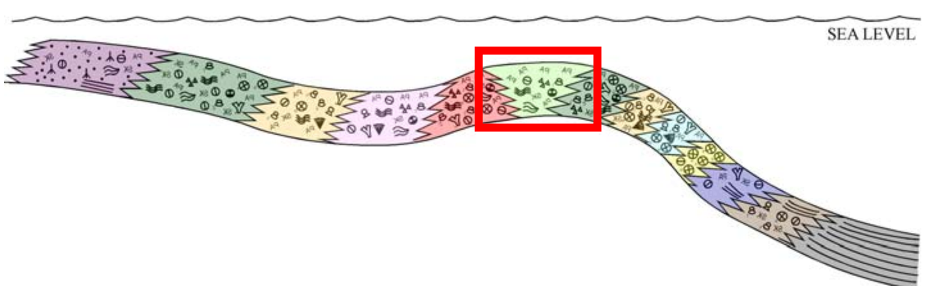
- Moderate energy, open-marine platform
- Structures include:
  - Stylolites
  - Geopetals
  - Organic sediment binding
- Moldic and fracture pore types

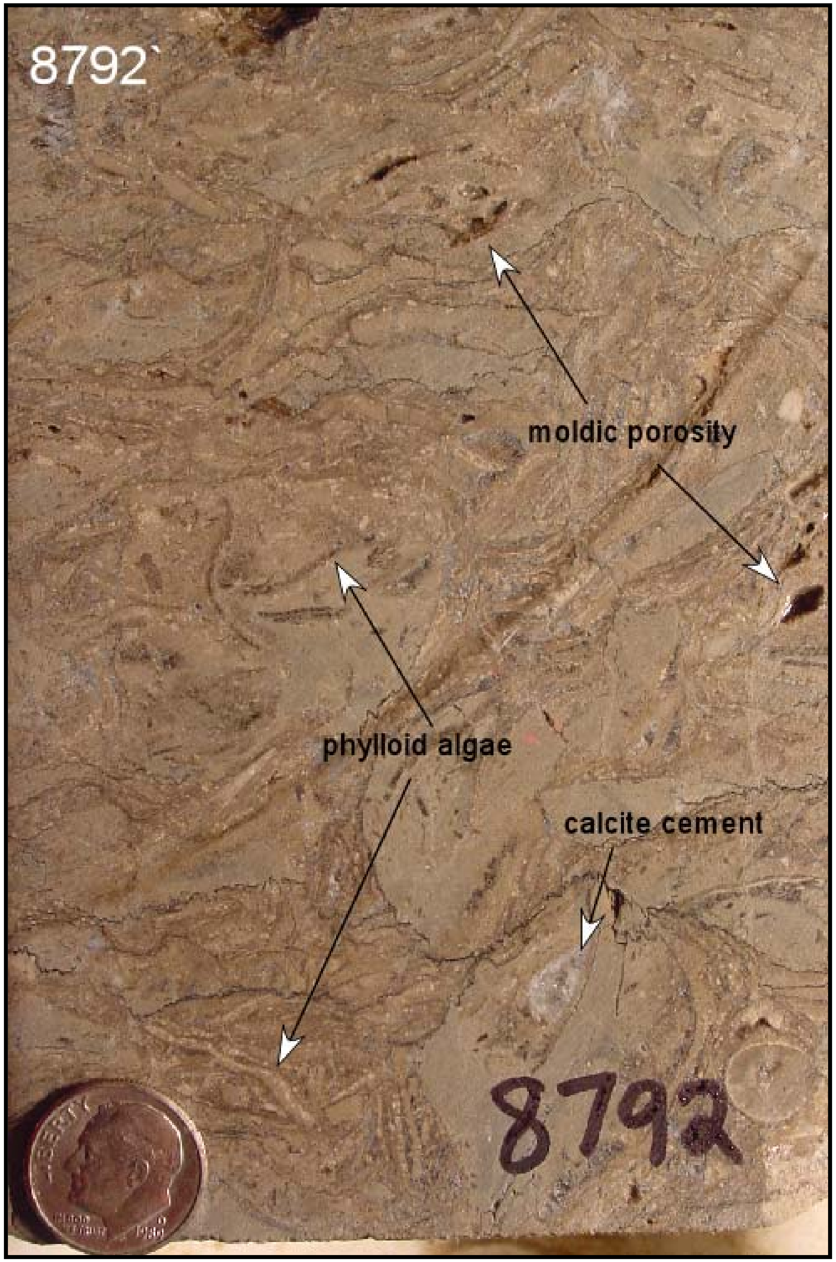




PHYLLOID ALGAL FLOATSTONE / BAFFLESTONE

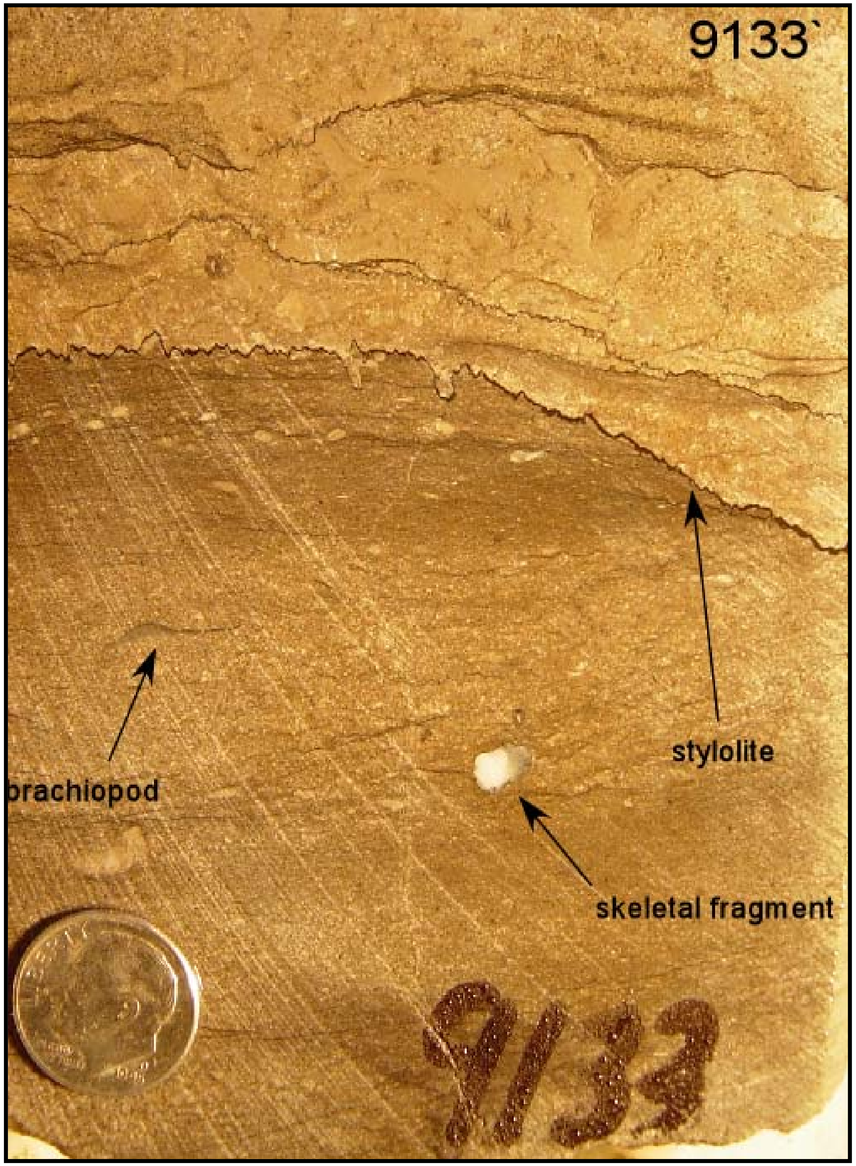
- Moderate energy, open-marine platform mound
- Structures include:
  - Organic sediment binding
  - Geopetals
  - Stylolites
- Moldic and fracture pore types

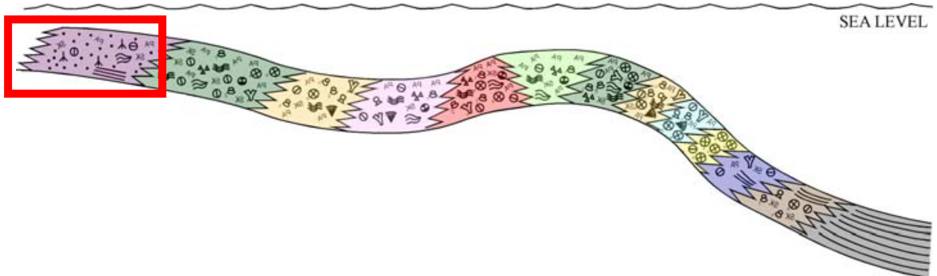


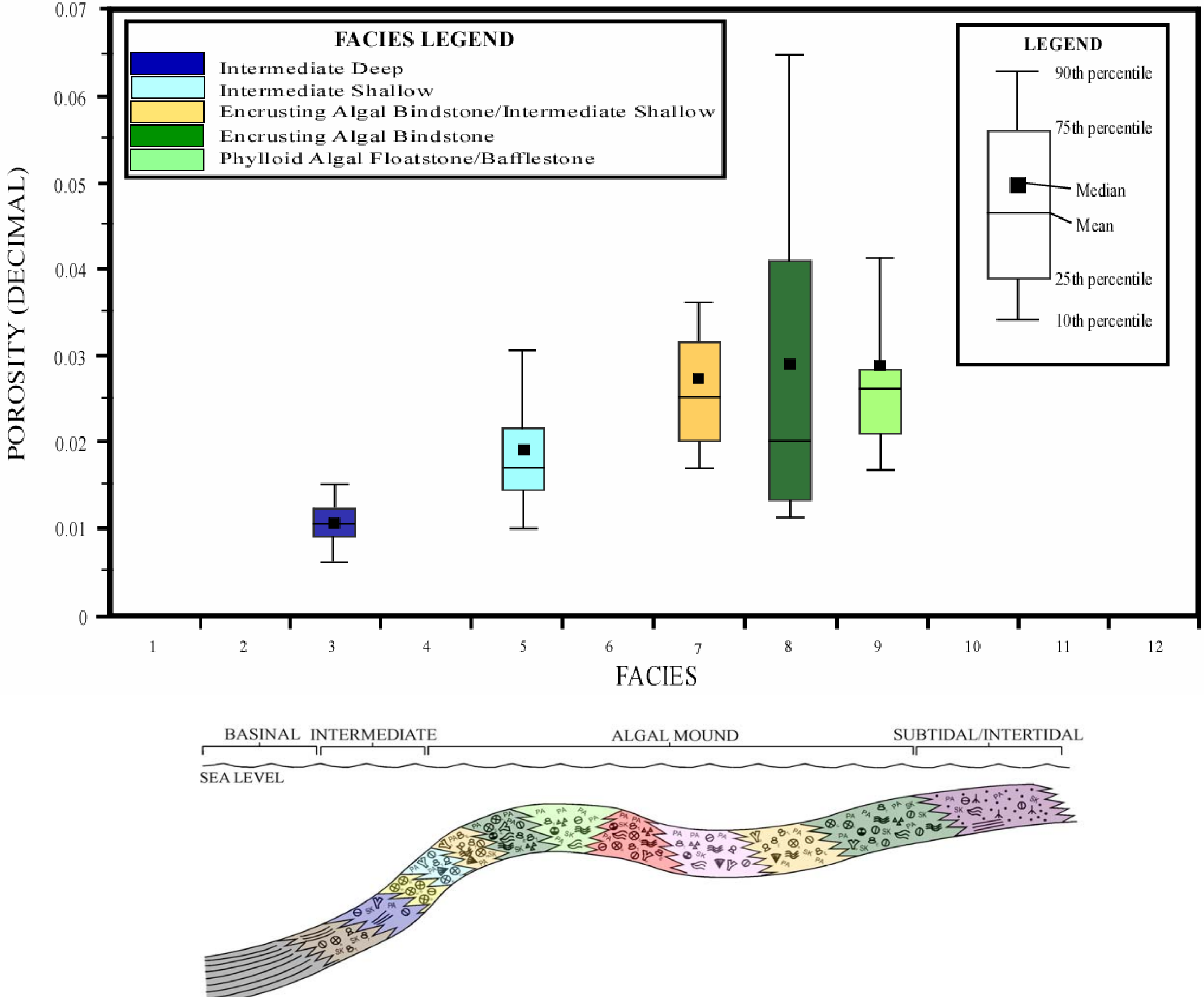


PELOID PACKSTONE

- Low to moderate energy, shallow subtidal to intertidal environment
- Fracture porosity
- Structures include:
  - Stylolites
  - Root traces
  - Laminae






FACIES LEGEND
Intermediate Deep
Intermediate Shallow
Encrusting Algal Bindstone/Intermediate Shallow
Encrusting Algal Bindstone
Phylloid Algal Floatstone/Bafflestone
LEGEND
90th percentile
75th percentile
Median
Mean
25th percentile
10th percentile
POROSITY (DECIMAL)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
1
2
3
4
5
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11
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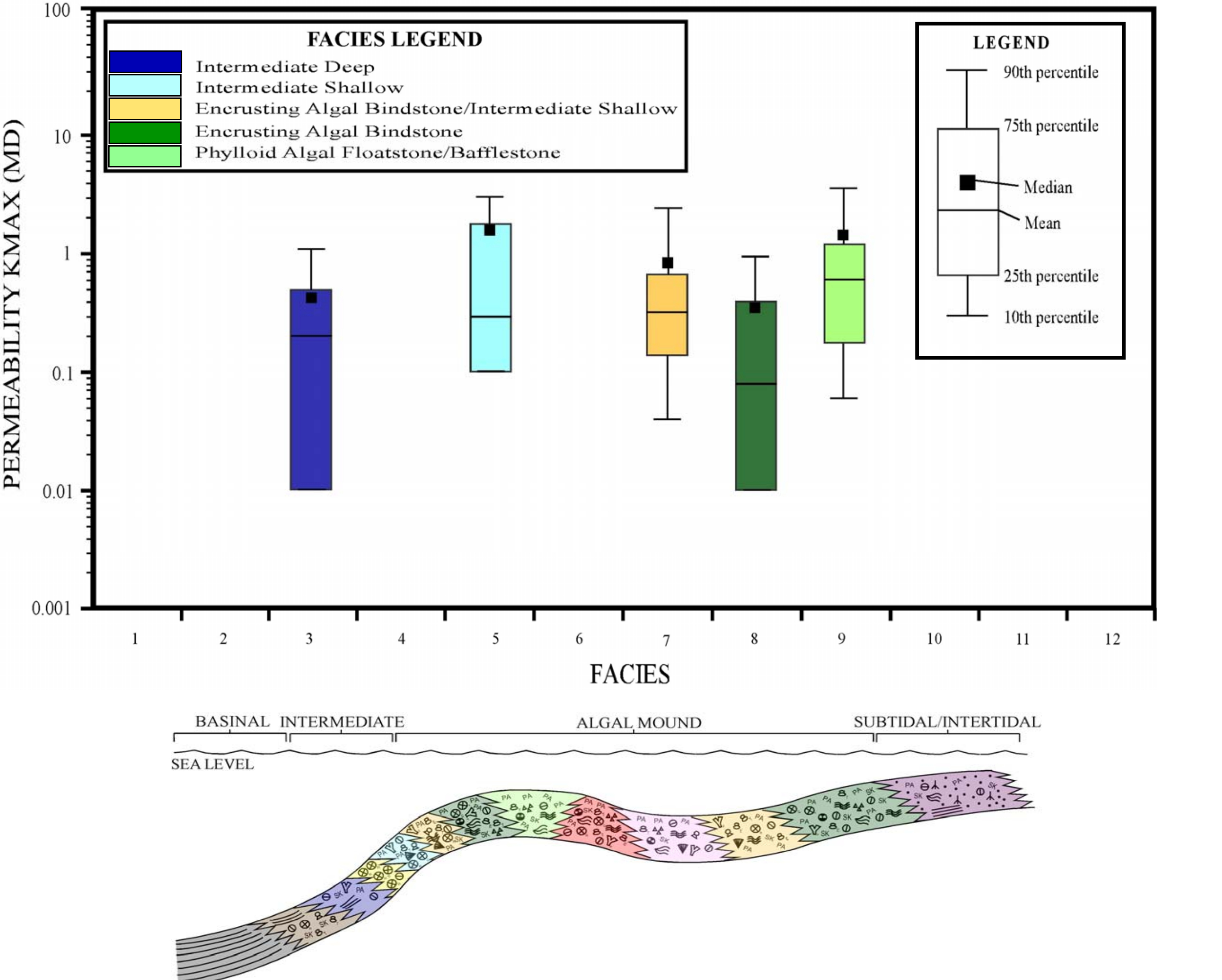
FACIES
BASINAL
INTERMEDIATE
ALGAL MOUND
SUBTIDAL/INTERTIDAL
SEA LEVEL


FACIES LEGEND
Intermediate Deep
Intermediate Shallow
Encrusting Algal Bindstone/Intermediate Shallow
Encrusting Algal Bindstone
Phylloid Algal Floatstone/Bafflestone
LEGEND
90th percentile
75th percentile
Median
Mean
25th percentile
10th percentile
PERMEABILITY KMAX (MD)
100
10
1
0.1
0.01
0.001
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6
7
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11
12
FACIES
BASINAL
INTERMEDIATE
ALGAL MOUND
SUBTIDAL/INTERTIDAL
SEA LEVEL

KEY QUESTIONS

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- **How are reservoir quality facies distributed within a three-dimensional framework?**
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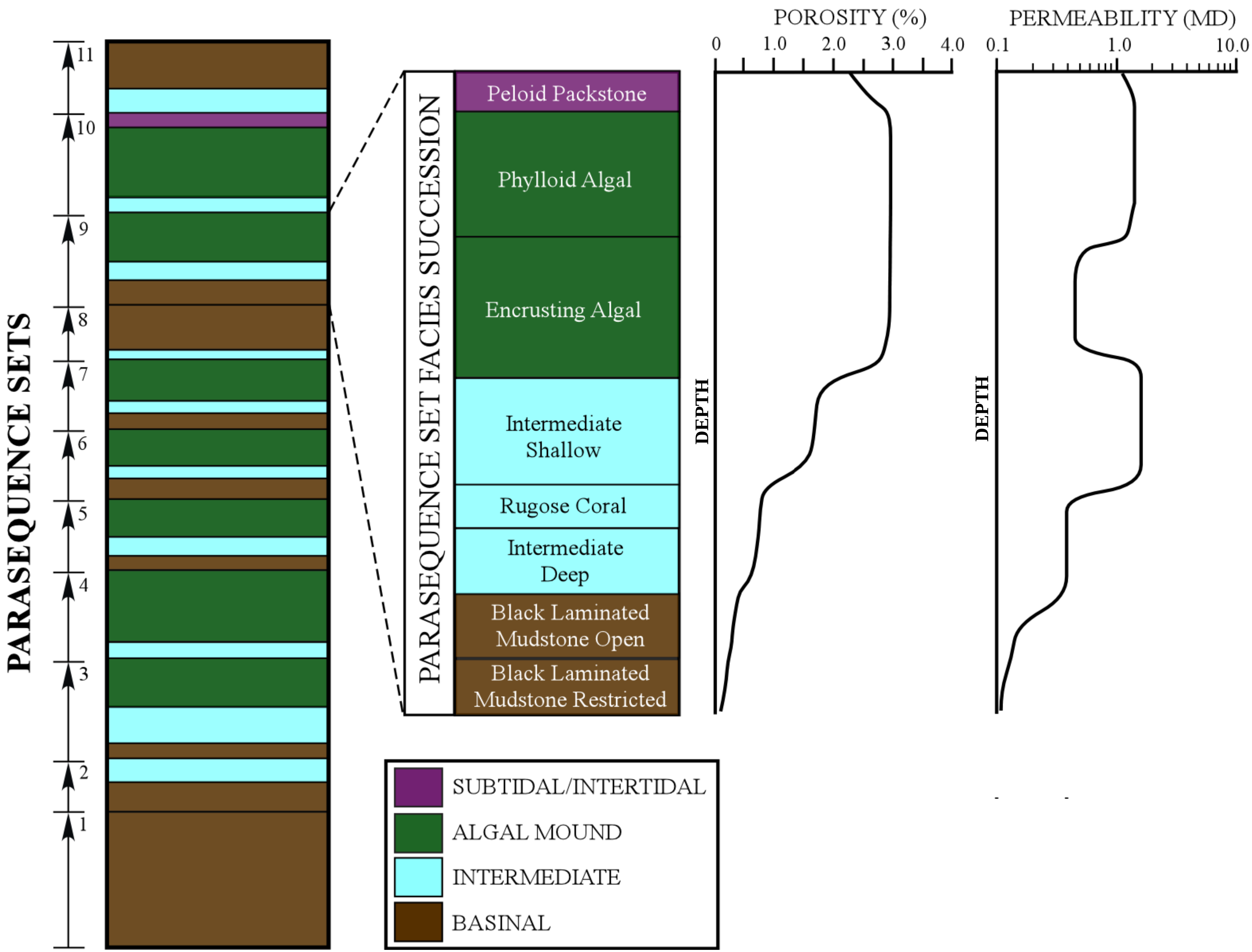
PARASEQUENCE SETS
11
10
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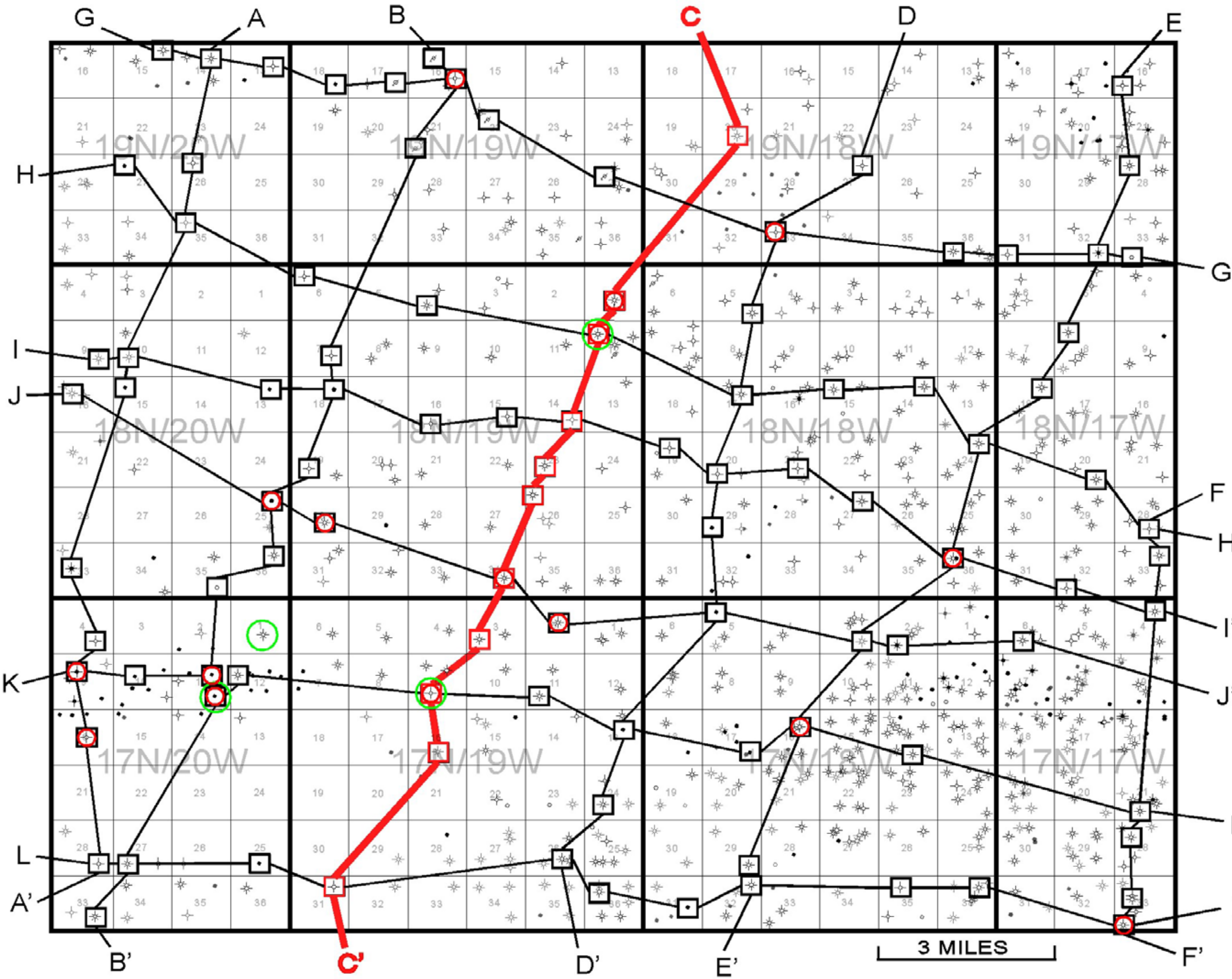
1
PARASEQUENCE SET FACIES SUCCESSION
Peloid Packstone
Phylloid Algal
Encrusting Algal
Intermediate Shallow
Rugose Coral
Intermediate Deep
Black Laminated Mudstone Open
Black Laminated Mudstone Restricted
POROSITY (%)
0
1.0
2.0
3.0
4.0
DEPTH
PERMEABILITY (MD)
0.1
1.0
10.0
DEPTH
SUBTIDAL/INTERTIDAL
ALGAL MOUND
INTERMEDIATE
BASINAL



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3 MILES

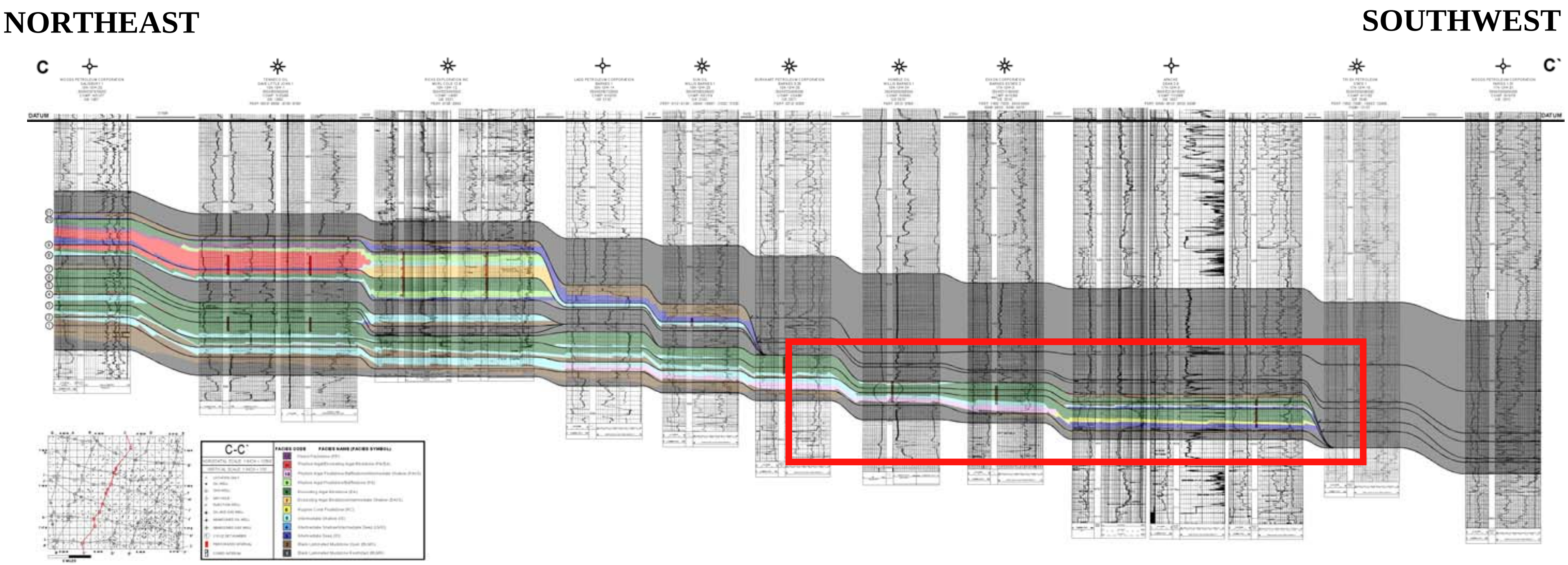
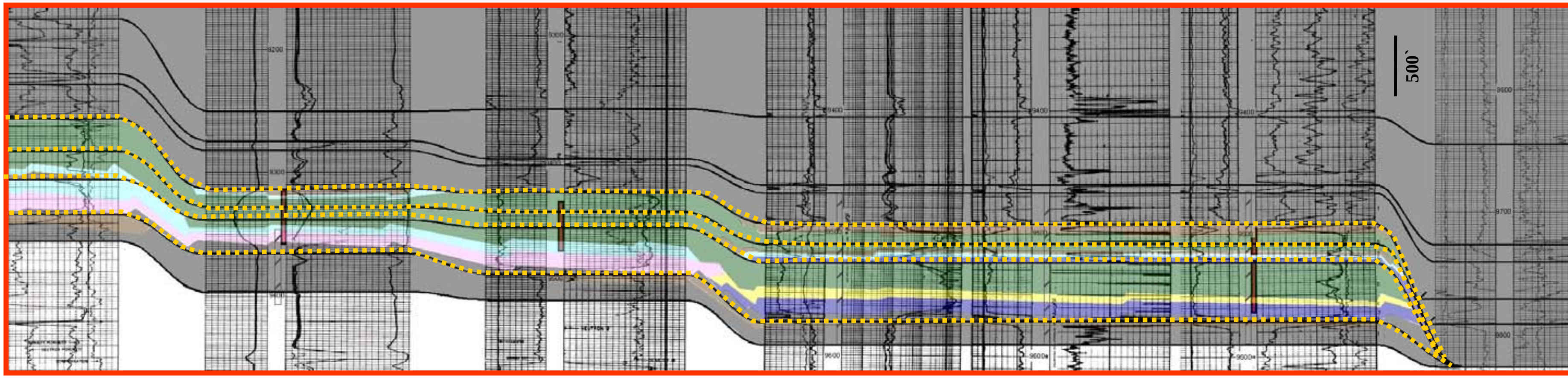


PLATE 3: CROSS SECTION C - C`

- **PELOID PACKSTONE**
- ***PHYLLOID ALGAL/ENCRUSTING ALGAL BINDSTONE***
- ***PHYLLOID ALGAL FLOATSTONE-BAFFLESTONE/INTERMEDIATE SHALLOW***
- **PHYLLOID ALGAL FLOATSTONE-BAFFLESTONE**
- **ENCRUSTING ALGAL BINDSTONE**
- ***ENCRUSTING ALGAL BINDSTONE/INTERMEDIATE SHALLOW***
- **RUGOSE CORAL FLOATSTONE**
- **INTERMEDIATE SHALLOW**
- **INTERMEDIATE DEEP**
- **BLACK LAMINATED MUDSTONE OPEN**
- **BLACK LAMINATED MUDSTONE OPEN**



Progradational stacking of parasequence sets is characteristic of the platform adjacent the basin axis, and reflects subsidence rates exceeded by sedimentation

- PELOID PACKSTONE
- *PHYLLOID ALGAL/ENCRUSTING ALGAL BINDSTONE*
- *PHYLLOID ALGAL FLOATSTONE-BAFFLESTONE/INTERMEDIATE SHALLOW*
- PHYLLOID ALGAL FLOATSTONE-BAFFLESTONE
- ENCRUSTING ALGAL BINDSTONE
- *ENCRUSTING ALGAL BINDSTONE/INTERMEDIATE SHALLOW*
- RUGOSE CORAL FLOATSTONE
- INTERMEDIATE SHALLOW
- INTERMEDIATE DEEP
- BLACK LAMINATED MUDSTONE OPEN
- BLACK LAMINATED MUDSTONE OPEN

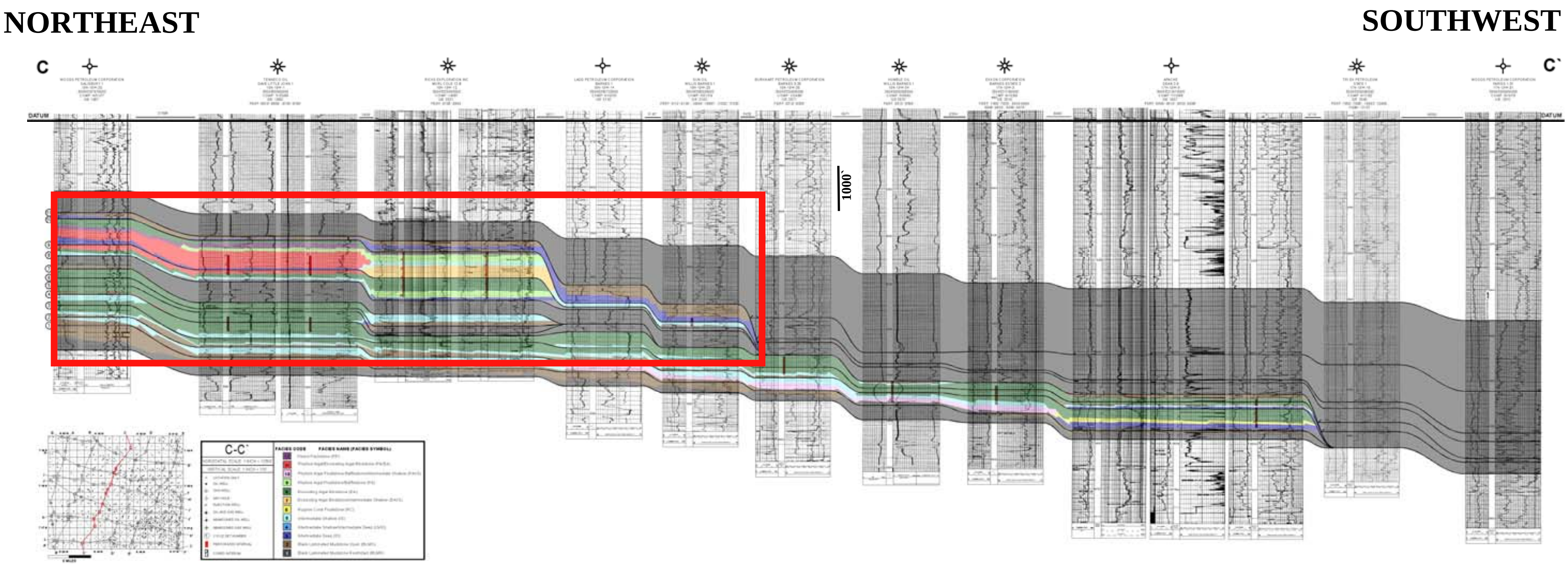


PLATE 3: CROSS SECTION C - C`

- PELOID PACKSTONE
- *PHYLLOID ALGAL/ENCRUSTING ALGAL BINDSTONE*
- *PHYLLOID ALGAL FLOATSTONE-BAFFLESTONE/INTERMEDIATE SHALLOW*
- PHYLLOID ALGAL FLOATSTONE-BAFFLESTONE
- ENCRUSTING ALGAL BINDSTONE
- *ENCRUSTING ALGAL BINDSTONE/INTERMEDIATE SHALLOW*
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- INTERMEDIATE SHALLOW
- INTERMEDIATE DEEP
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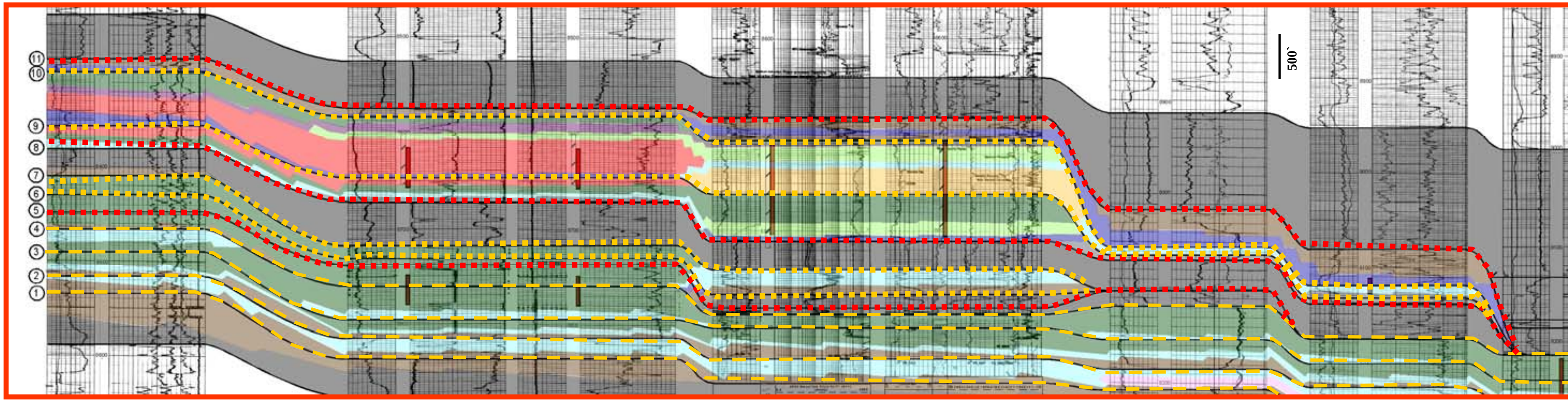
- BLACK LAMINATED MUDSTONE OPEN



Retrogradational stacking patterns common toward the basin axis and reflect subsidence rates exceeding sedimentation

- **PELOID PACKSTONE**
- ***PHYLLOID ALGAL/ENCRUSTING ALGAL BINDSTONE***
- ***PHYLLOID ALGAL FLOATSTONE-BAFFLESTONE/INTERMEDIATE SHALLOW***
- **PHYLLOID ALGAL FLOATSTONE-BAFFLESTONE**
- **ENCRUSTING ALGAL BINDSTONE**
- ***ENCRUSTING ALGAL BINDSTONE/INTERMEDIATE SHALLOW***
- **RUGOSE CORAL FLOATSTONE**
- **INTERMEDIATE SHALLOW**
- **INTERMEDIATE DEEP**
- **BLACK LAMINATED MUDSTONE OPEN**
- **BLACK LAMINATED MUDSTONE OPEN**

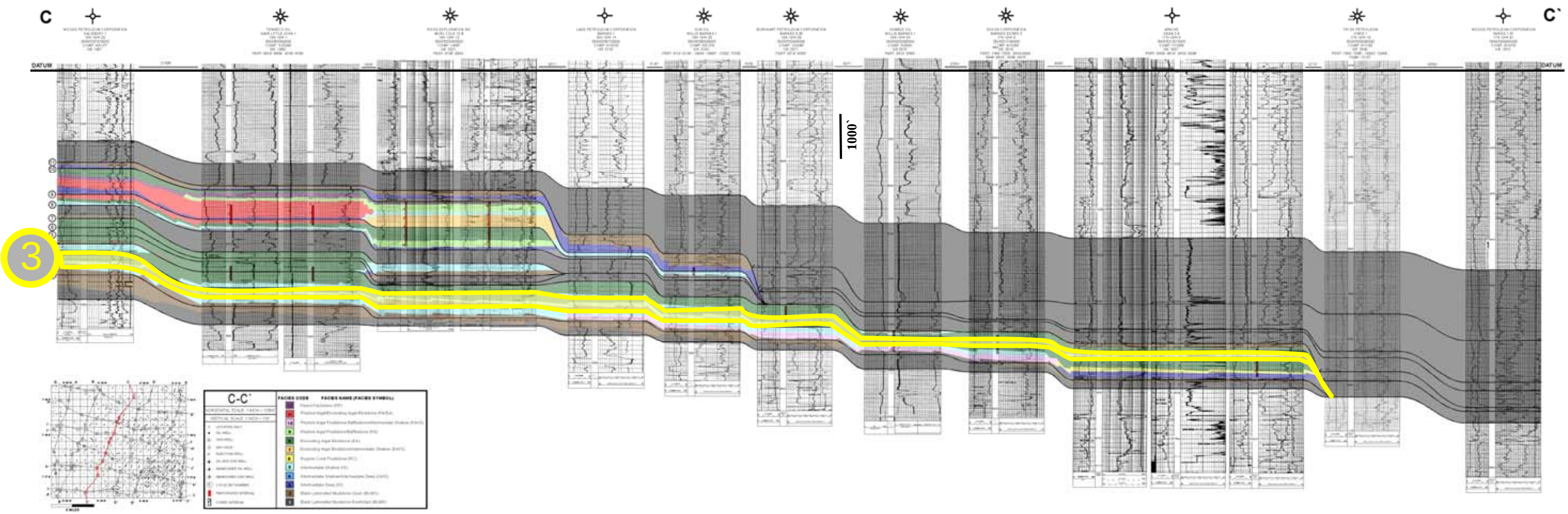


PLATE 3: CROSS SECTION C - C`

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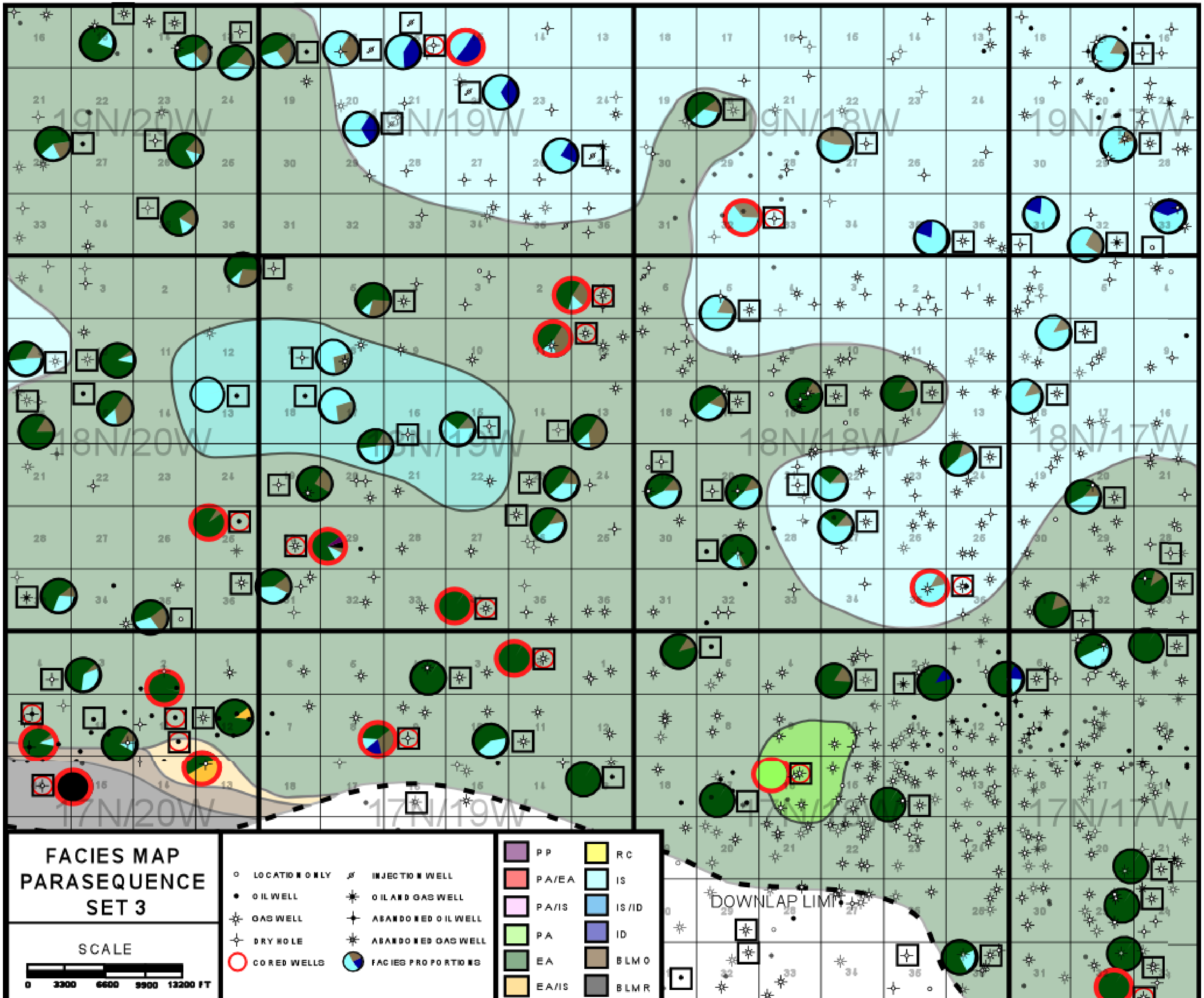
- *PHYLLOID ALGAL FLOATSTONE-BAFFLESTONE/INTERMEDIATE SHALLOW*
- PHYLLOID ALGAL FLOATSTONE-BAFFLESTONE
- ENCRUSTING ALGAL BINDSTONE
- *ENCRUSTING ALGAL BINDSTONE/INTERMEDIATE SHALLOW*
- RUGOSE CORAL FLOATSTONE
- INTERMEDIATE SHALLOW
- INTERMEDIATE DEEP
- BLACK LAMINATED MUDSTONE OPEN
- BLACK LAMINATED MUDSTONE OPEN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19N/19W
19N/18W
19N/17W
18N/20W
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17N/20W
17N/19W
17N/18W
17N/17W
DOWNLAP LIMIT
FACIES MAP
PARASEQUENCE SET 3
SCALE
0 3300 6600 9900 13200 FT
LOCATION ONLY
OIL WELL
GAS WELL
DRY HOLE
CORED WELLS
INJECTION WELL
OIL AND GAS WELL
ABANDONED OIL WELL
ABANDONED GAS WELL
FACIES PROPORTIONS
PP
PA/EA
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EA/IS
RC
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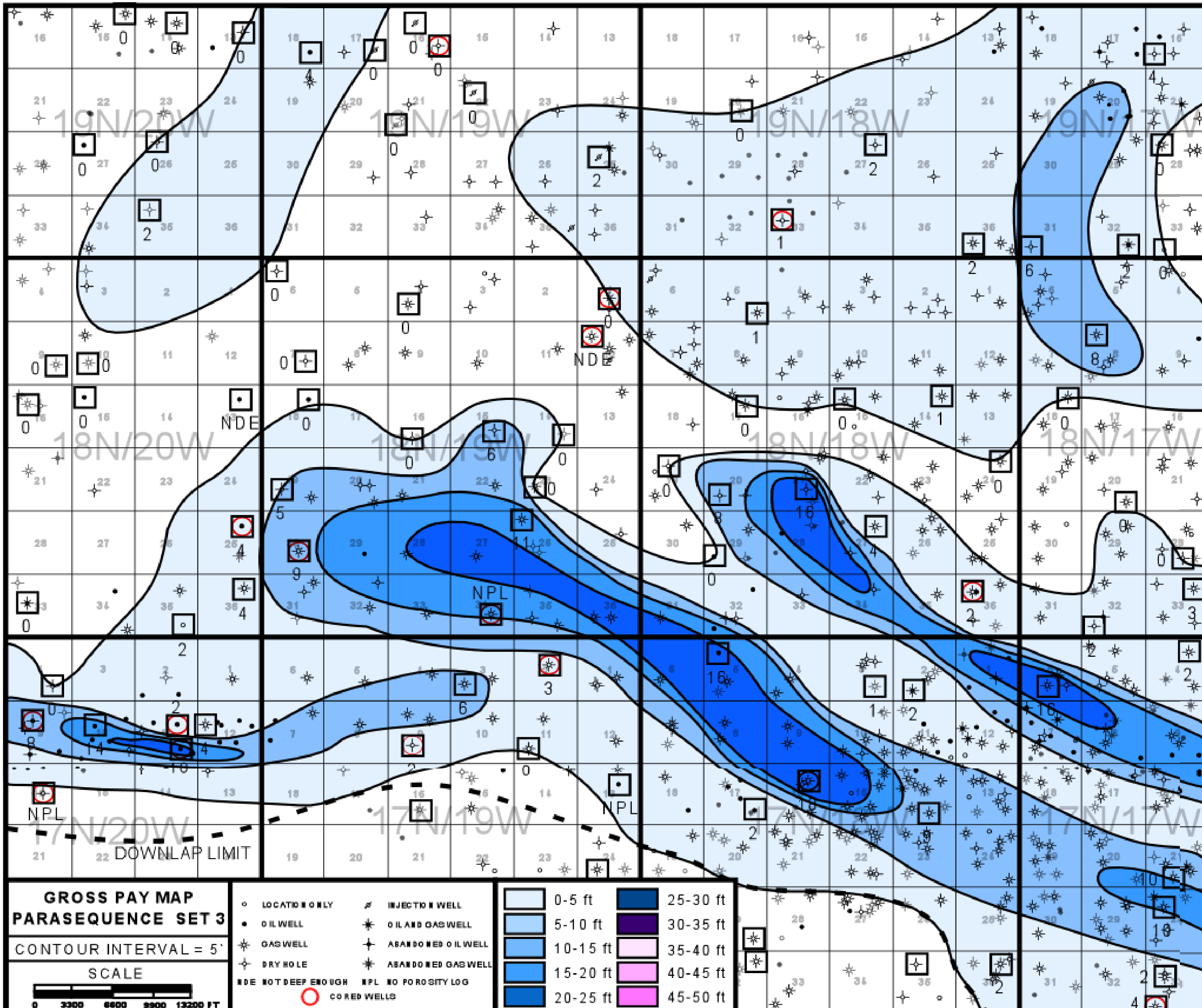
IS/ID
ID
BLMO
BLMR


19N/20W
19N/19W
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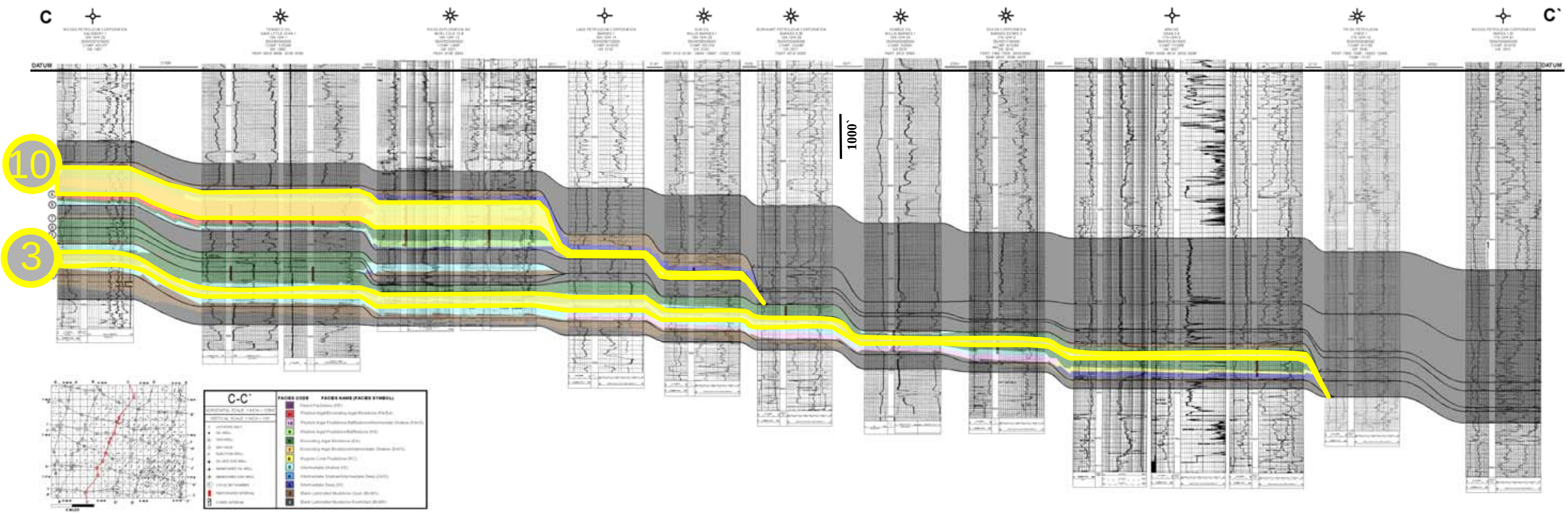
17N/20W
17N/19W
17N/18W
17N/17W
DOWNLAP LIMIT
NDE
NPL
GROSS PAY MAP
PARASEQUENCE SET 3
CONTOUR INTERVAL = 5'
SCALE
0 3300 6600 9900 13200 FT
LOCATION ONLY
OIL WELL
GAS WELL
DRY HOLE
INJECTION WELL
OIL AND GAS WELL
ABANDONED OIL WELL
ABANDONED GAS WELL
NDE NOT DEEP ENOUGH
NPL NO POROSITY LOG
CORED WELLS
0-5 ft
5-10 ft
10-15 ft
15-20 ft
20-25 ft
25-30 ft
30-35 ft
35-40 ft
40-45 ft
45-50 ft



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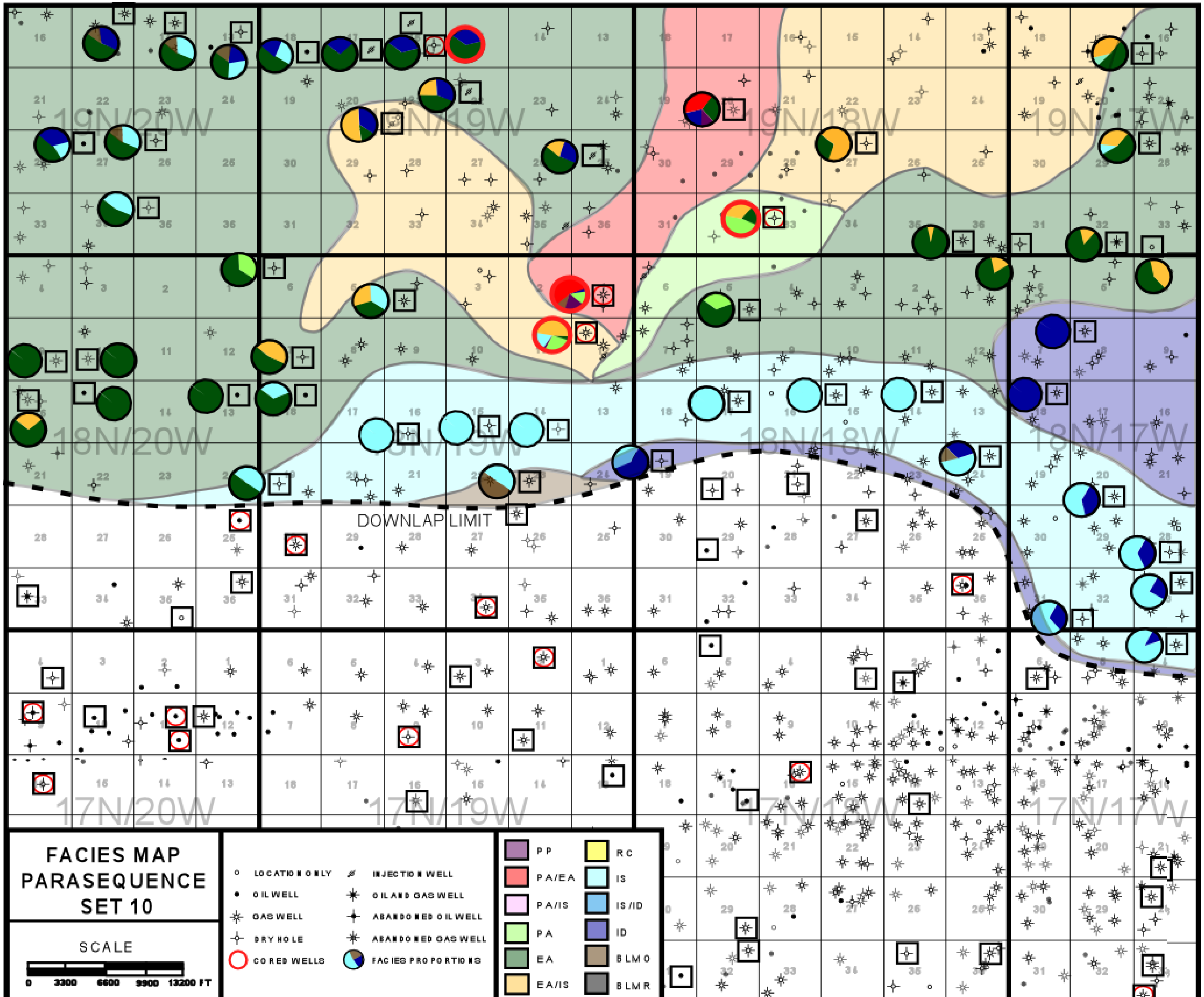
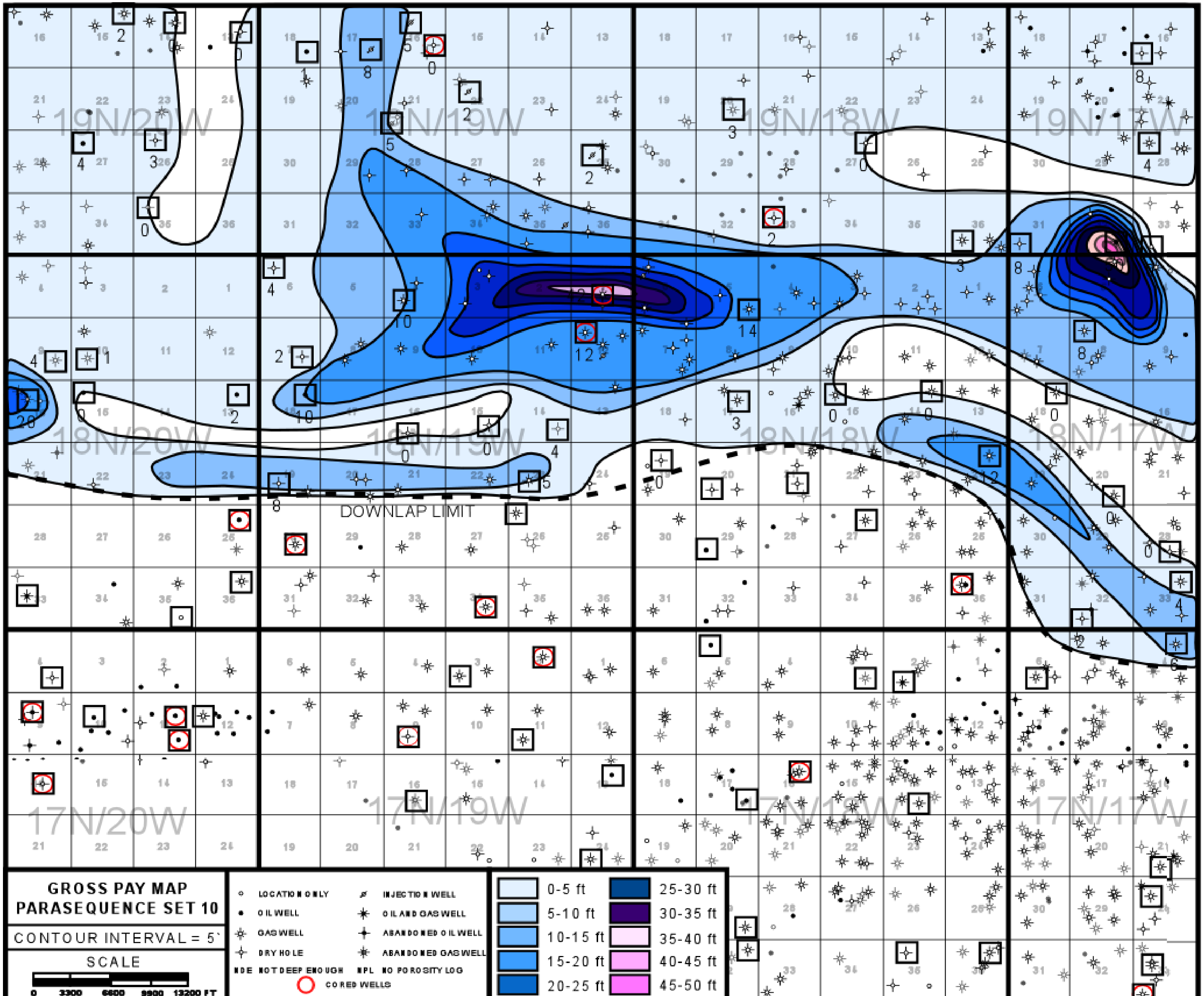
- ***PHYLLOID ALGAL/ENCRUSTING ALGAL BINDSTONE***
- ***PHYLLOID ALGAL FLOATSTONE-BAFFLESTONE/INTERMEDIATE SHALLOW***
- **PHYLLOID ALGAL FLOATSTONE-BAFFLESTONE**
- **ENCRUSTING ALGAL BINDSTONE**
- ***ENCRUSTING ALGAL BINDSTONE/INTERMEDIATE SHALLOW***
- **RUGOSE CORAL FLOATSTONE**
- **INTERMEDIATE SHALLOW**
- **INTERMEDIATE DEEP**
- **BLACK LAMINATED MUDSTONE OPEN**
- **BLACK LAMINATED MUDSTONE OPEN**



FACIES MAP
PARASEQUENCE SET 10
SCALE
0 3300 6600 9900 13200 FT
LOCATION ONLY
OIL WELL
GAS WELL
DRY HOLE
CORED WELLS
INJECTION WELL
OIL AND GAS WELL
ABANDONED OIL WELL
ABANDONED GAS WELL
FACIES PROPORTIONS
PP
PA/EA
PA/IS
PA
EA
EA/IS
RC
IS
IS/ID
ID
BLMO
BLMR
DOWNLAP LIMIT
19N/20W
19N/19W
19N/18W
19N/17W
18N/20W
18N/19W
18N/18W
18N/17W
17N/20W
17N/19W
17N/18W
17N/17W

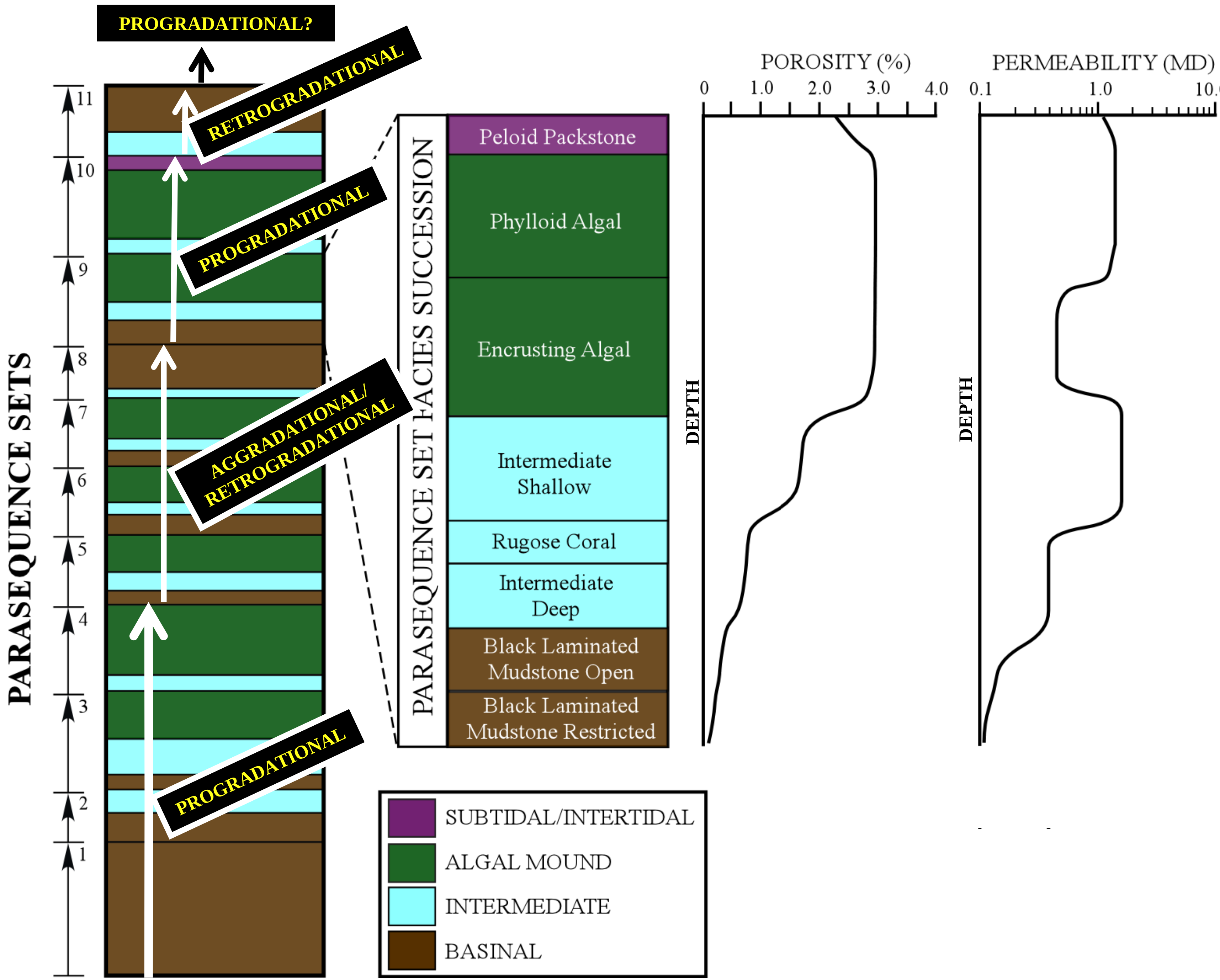

19N/20W
19N/19W
19N/18W
19N/17W
18N/20W
18N/19W
18N/18W
18N/17W
17N/20W
17N/19W
17N/18W
17N/17W
DOWNLAP LIMIT
GROSS PAY MAP
PARASEQUENCE SET 10
CONTOUR INTERVAL = 5`
SCALE
0 3300 6600 9900 13200 FT
LOCATION ONLY
OIL WELL
GAS WELL
DRY HOLE
INJECTION WELL
OIL AND GAS WELL
ABANDONED OIL WELL
ABANDONED GAS WELL
NDE NOT DEEP ENOUGH
NPL NO POROSITY LOG
CORED WELLS
0-5 ft
5-10 ft
10-15 ft
15-20 ft
20-25 ft
25-30 ft
30-35 ft
35-40 ft
40-45 ft
45-50 ft

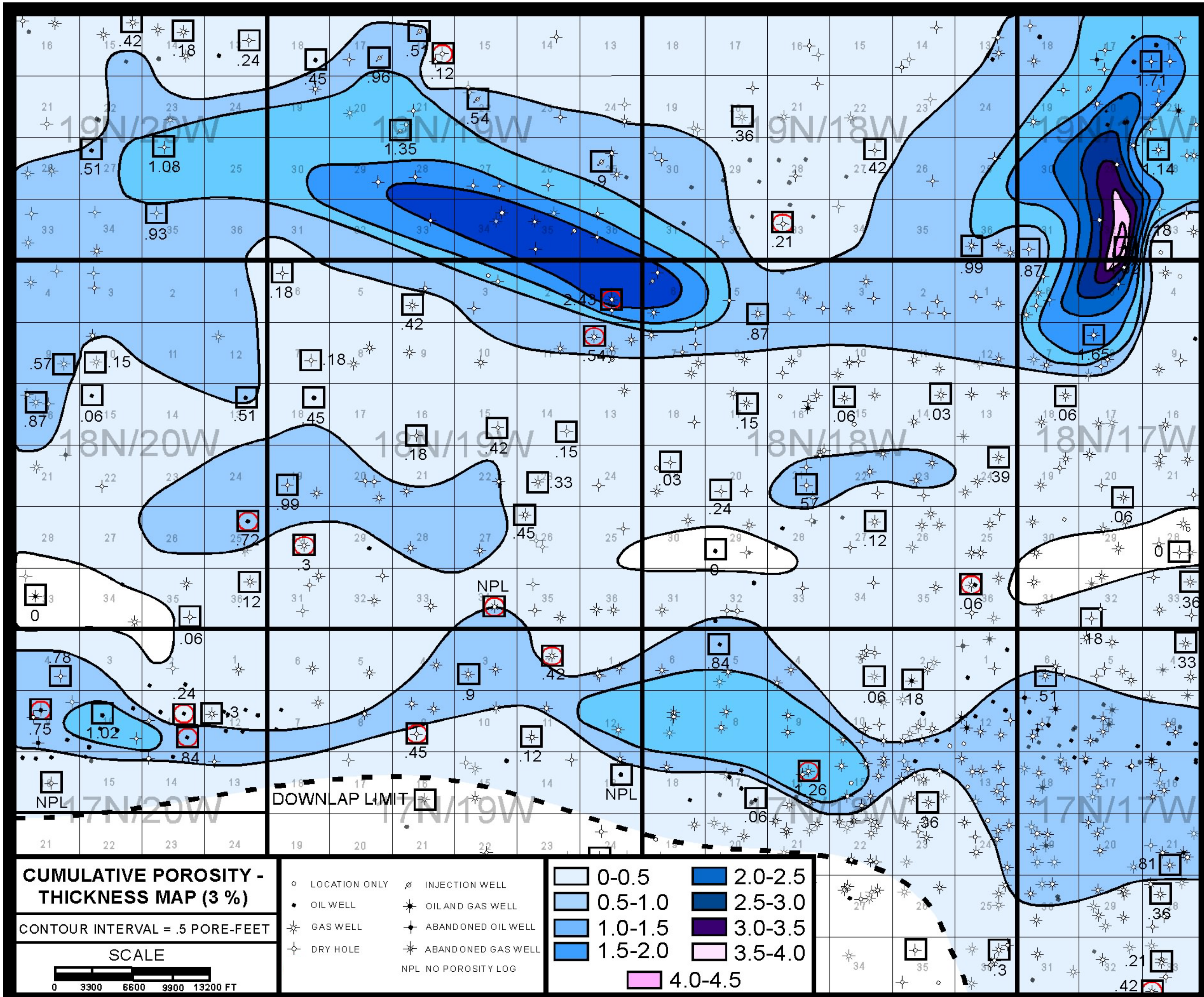
KEY QUESTIONS

- What is the depositional model and controls on reservoir quality?
- How are reservoir quality facies distributed within a three-dimensional framework?
- **What are the most favorable geographic location(s) for future development potential?**

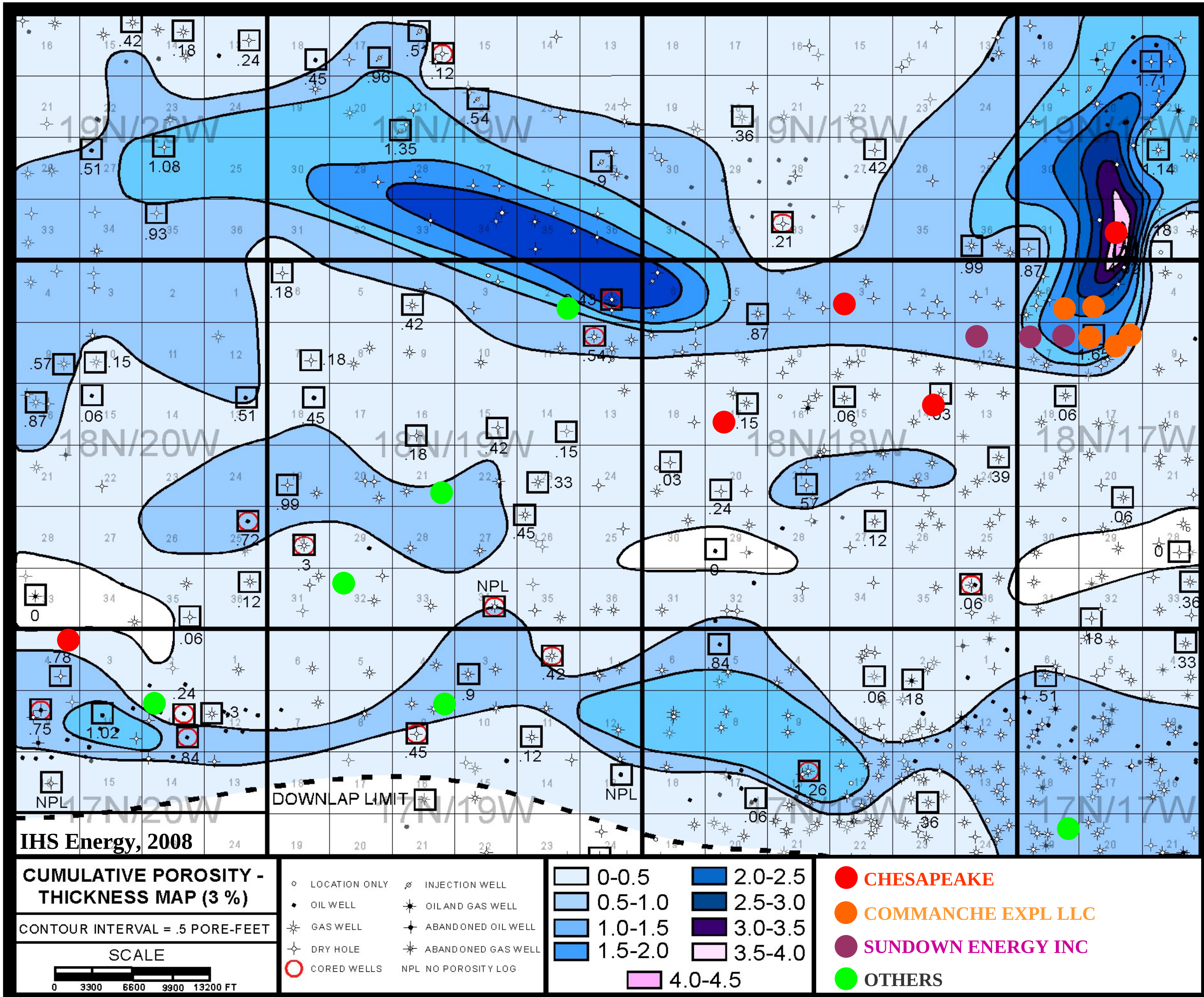
FUTURE EXPLORATION AND DEVELOPMENT

- The occurrence of reservoir-prone phylloid algal facies within a retrogradational succession across the study area does not exclude the possibility that undiscovered gas reserves may still exist updip of the Putnam trend.


PROGRADATIONAL?
RETROGRADATIONAL
PROGRADATIONAL
AGGRADATIONAL/
RETROGRADATIONAL
PROGRADATIONAL
PARASEQUENCE SETS
1
2
3
4
5
6
7
8
9
10
11
PARASEQUENCE SET FACIES SUCCESSION
Peloid Packstone
Phylloid Algal
Encrusting Algal
Intermediate
Shallow
Rugose Coral
Intermediate
Deep
Black Laminated
Mudstone Open
Black Laminated
Mudstone Restricted
POROSITY (%)
0
1.0
2.0
3.0
4.0
DEPTH
PERMEABILITY (MD)
0.1
1.0
10.0
DEPTH
SUBTIDAL/INTERTIDAL
ALGAL MOUND
INTERMEDIATE
BASINAL



CUMULATIVE POROSITY - THICKNESS MAP (3 %)


19N/20W
19N/19W
19N/18W
19N/17W
18N/20W
18N/19W
18N/18W
18N/17W
17N/20W
17N/19W
17N/18W
17N/17W
DOWNLAP LIMIT
NPL
IHS Energy, 2008
CUMULATIVE POROSITY - THICKNESS MAP (3 %)
CONTOUR INTERVAL = .5 PORE-FEET
SCALE
0 3300 6600 9900 13200 FT
LOCATION ONLY
OIL WELL
GAS WELL
DRY HOLE
CORED WELLS
INJECTION WELL
OIL AND GAS WELL
ABANDONED OIL WELL
ABANDONED GAS WELL
NPL NO POROSITY LOG
0-0.5
0.5-1.0
1.0-1.5
1.5-2.0
2.0-2.5
2.5-3.0
3.0-3.5
3.5-4.0
4.0-4.5
CHESAPEAKE
COMMANCHE EXPL LLC
SUNDOWN ENERGY INC
OTHERS

CONCLUSIONS

- Twelve depositional facies were recognized.
- Accumulated within basinal and platform interior environments (subtidal, intertidal and mound). Reservoir quality is preferentially associated within algal mound facies.

CONCLUSIONS

- Facies were partitioned within eleven parasequence sets. Parasequence set stacking controls the spatial distribution of reservoir facies and hydrocarbon distribution.