Spaghetti with Marinara: Tertiary Oil Recovery in a Cretaceous Redbed Succession, Citronelle Field, Alabama*

Jack C. Pashin[1]

Search and Discovery Article #20207 (2013)**
Posted August 30, 2013

*Adapted from presentation at Tulsa Geological Society dinner meeting, May 7, 2013.
Please refer to related article, entitled "Modeling Reservoir Rock and Formation Fluid Geochemical Interactions: Implications for CO_2 Sequestration from Citronelle Oil Field, Alabama," Search and Discovery Article #20206 (2013).

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Abstract

Citronelle Field is a major Gulf Coast oil reservoir that has produced 170 MMbbl of 42-46° API gravity oil from the Donovan Sand (Lower Cretaceous). Original oil-in-place is estimated to be 537 MMbbl, and CO_2-enhanced oil recovery has potential for incremental recovery of 40 to 80 MMbbl. Producing from 43 sandstone bodies of fluvial and estuarine origin, the Donovan Sand is quite heterogeneous. Reservoir geometry was determined by a combination of primary depositional processes and the pedogenic processes associated with redbed formation. Feldspar dissolution and bioturbation are the principal determinants of reservoir quality and are thus important considerations for the design and implementation of tertiary recovery operations. A pilot CO_2 injection program has been completed in the Donovan Sand, and a CO_2 capture plant and pipeline system have been built to provide CO_2 from a coal-fired power facility to the field for further experiments.

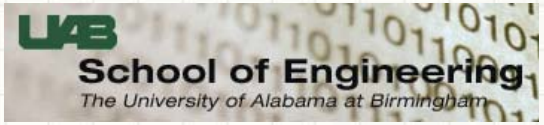
References Cited

Blakey, R.C., 2013, North American Paleographic Maps; Early Cretaceoous (115 Ma): Website accessed August 22, 2013. http://www2.nau.edu/rcb7/namK115.jpg

Eaves, E., 1976, Citronelle oil field, Mobile County, Alabama, *in* J. Braunstein (ed.), North American Oil and Gas Fields: AAPG Memoir 24, p. 259-275.

SPAGHETTI WITH MARINARA: CO_2 EOR IN A CRETACEOUS REDBED SUCCESSION, CITRONELLE FIELD, AL

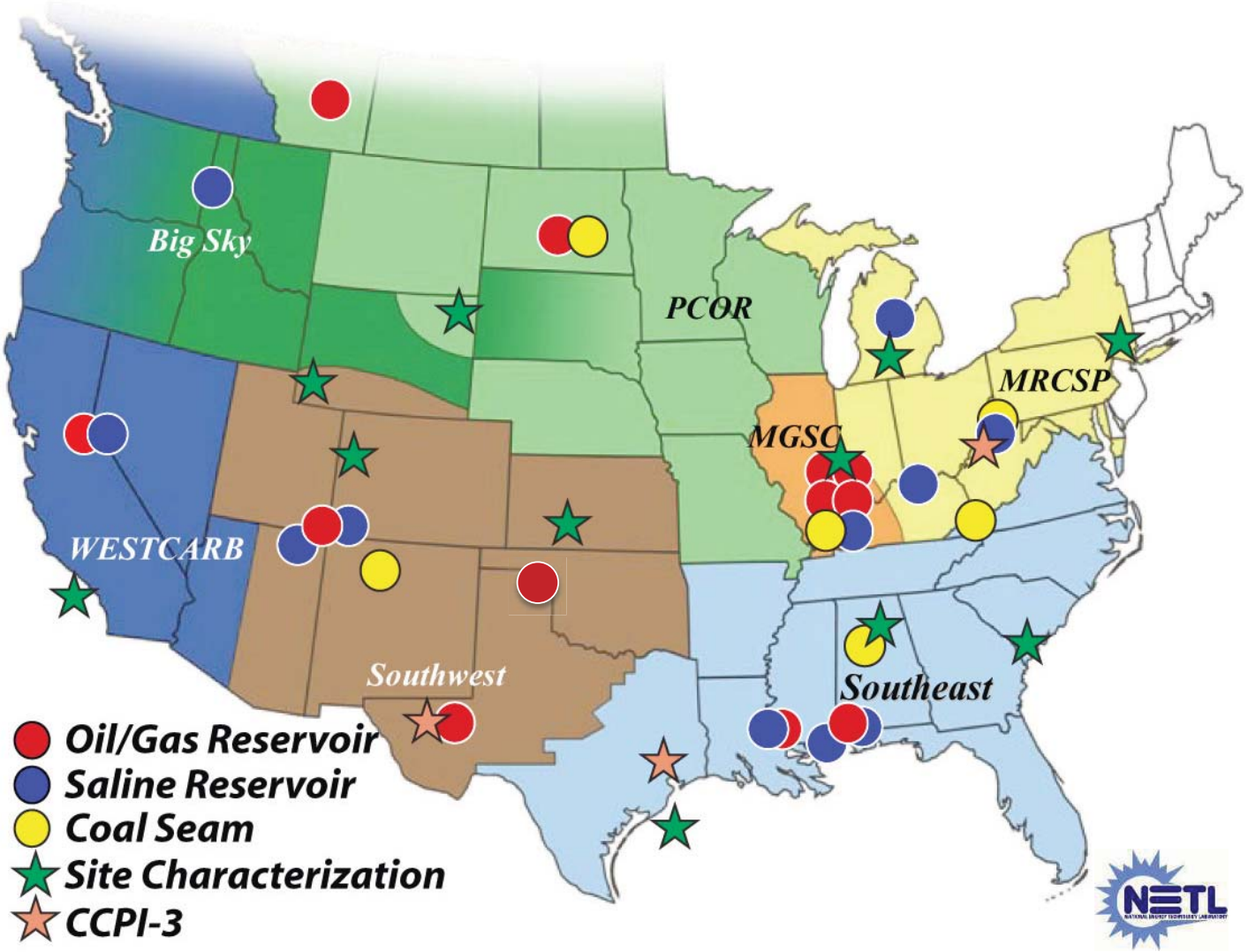
Jack C. Pashin, Oklahoma State University



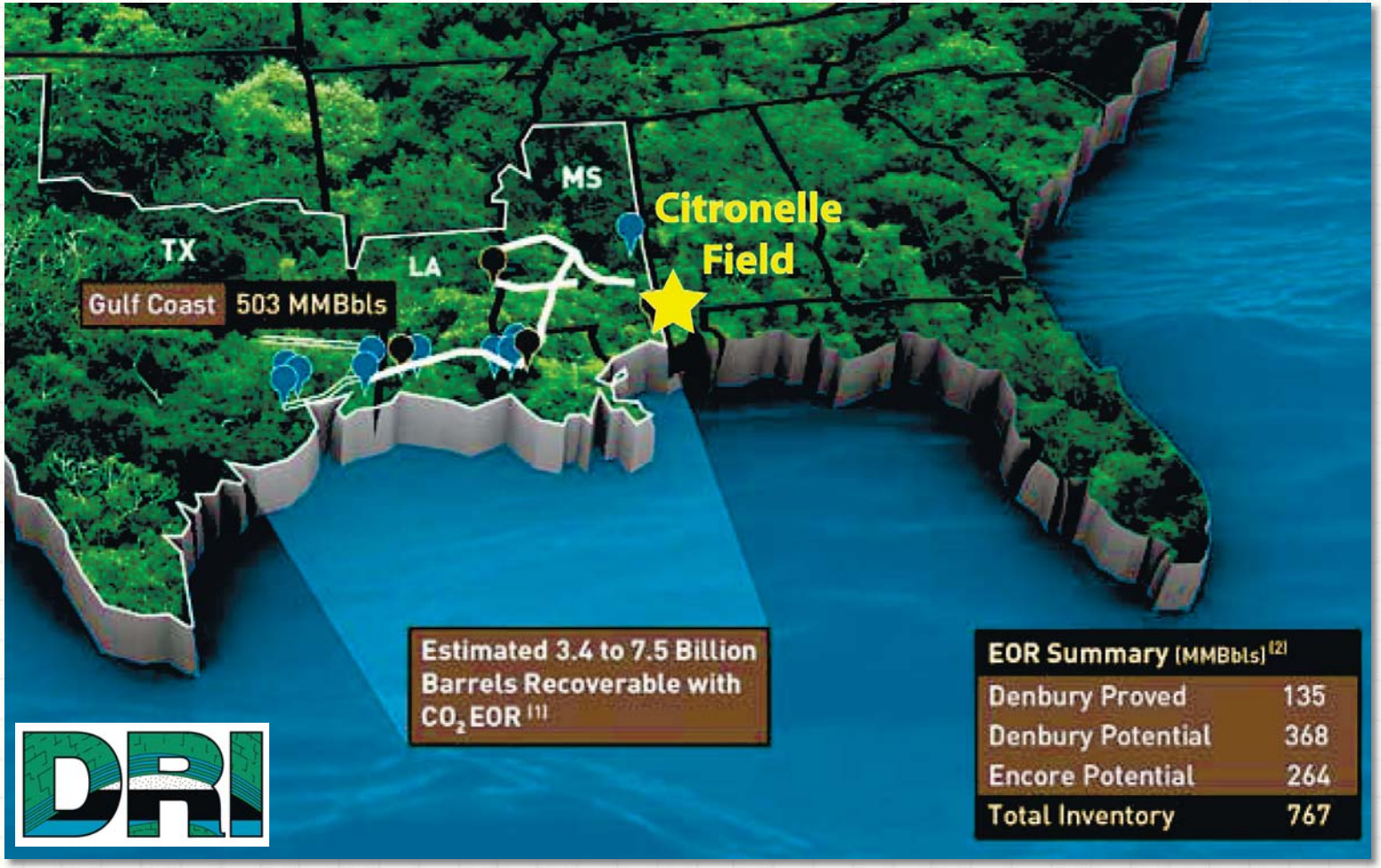
OUTLINE

- ✓ DOE-sponsored CO_2 injection programs (EOR, CCUS)
- ✓ Denbury Resources CO_2 EOR
- ✓ Citronelle Field overview
- ✓ Donovan Sand reservoir geology
- ✓ Tertiary recovery experiments and performance
- ✓ Future plans: CO_2 supply and injection programs

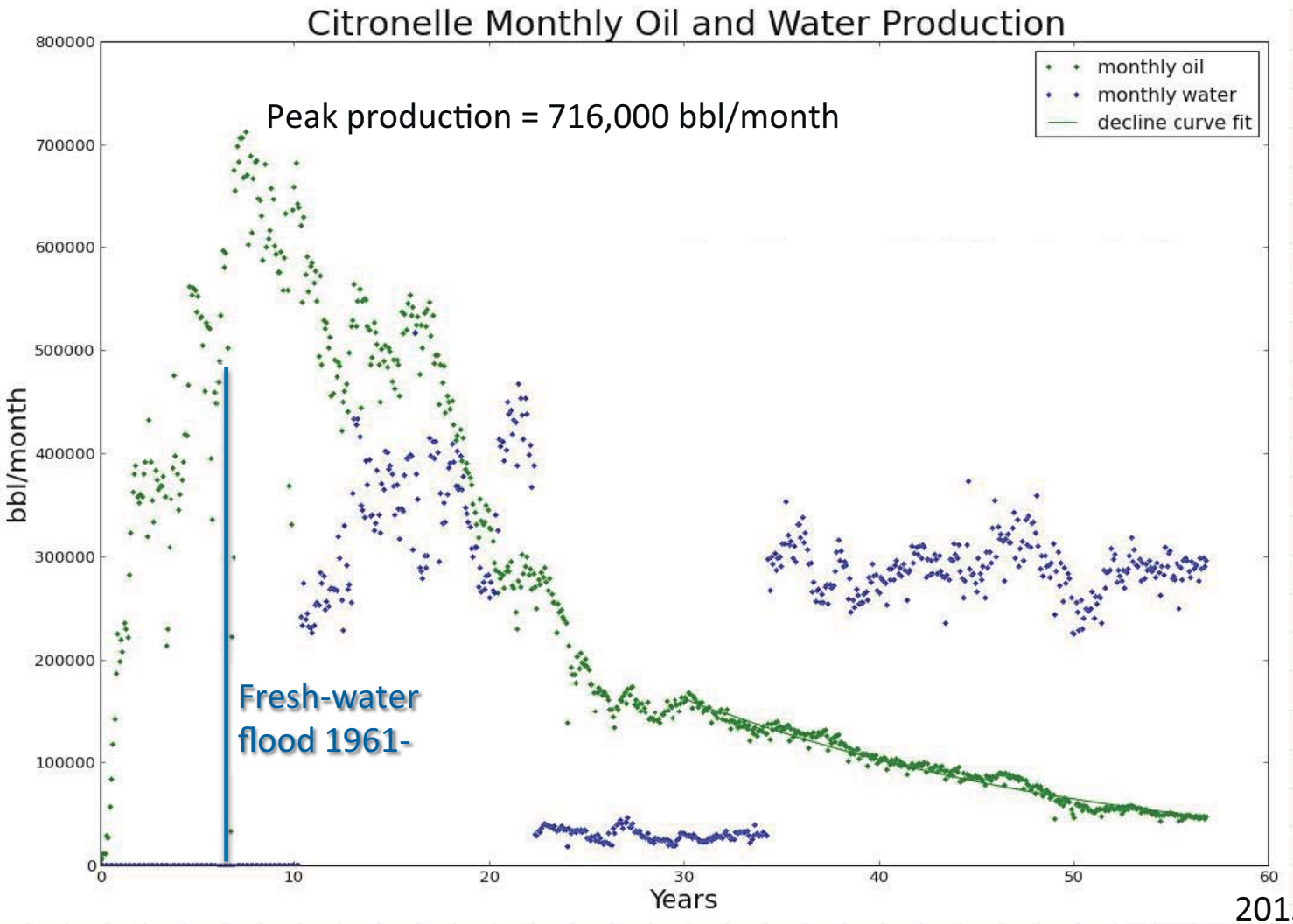
DOE REGIONAL PARTNERSHIPS



DENBURY RESOURCES CO_2-EOR



CITRONELLE PRODUCTION HISTORY



2015

CITRONELLE FIELD

Discovery - 1955

Depth - ~11,000 ft (3,350 m)

API Gravity - 42-46°

Available wells – 416

Formation - Donovan Sand (L. Cret.)

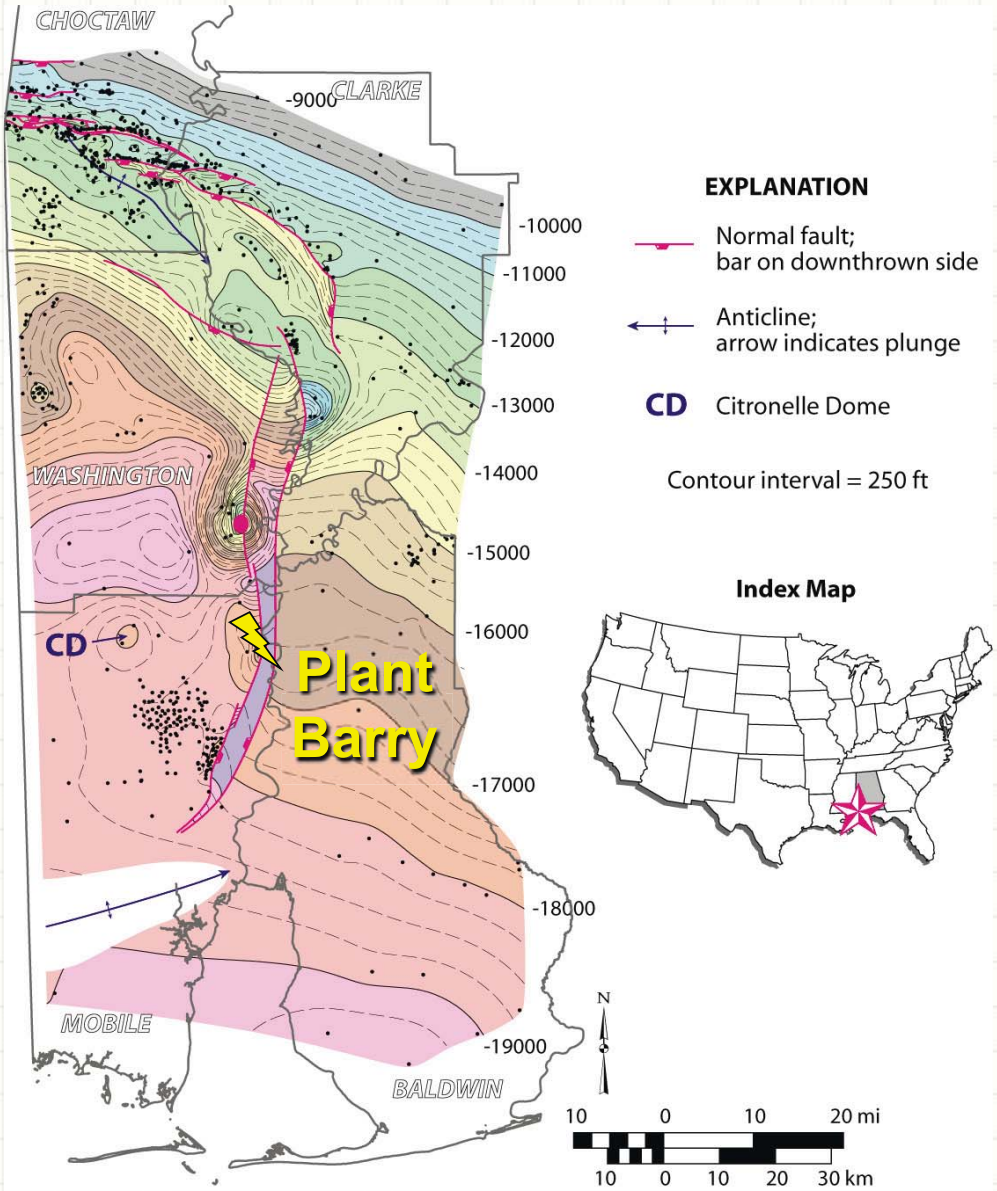
Facies - Aggradational sandstone

OOIP - 537 MMbbl

Cum. Oil production - 170 MMbbl

Waterflood - Since 1961

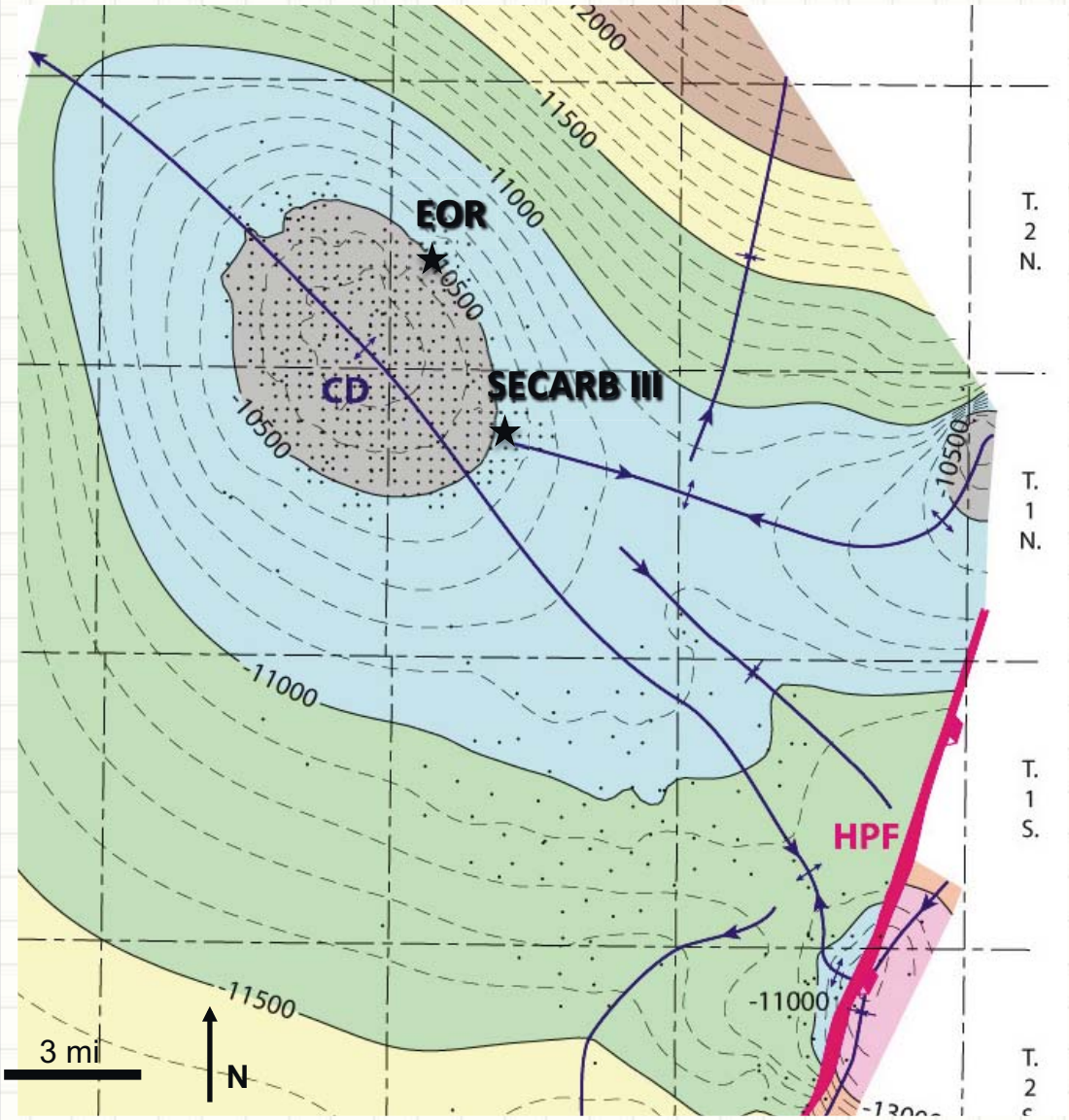
CO_2 experiments - 1981-1984, 2010



REGIONAL STRUCTURE

Top Smackover Limestone

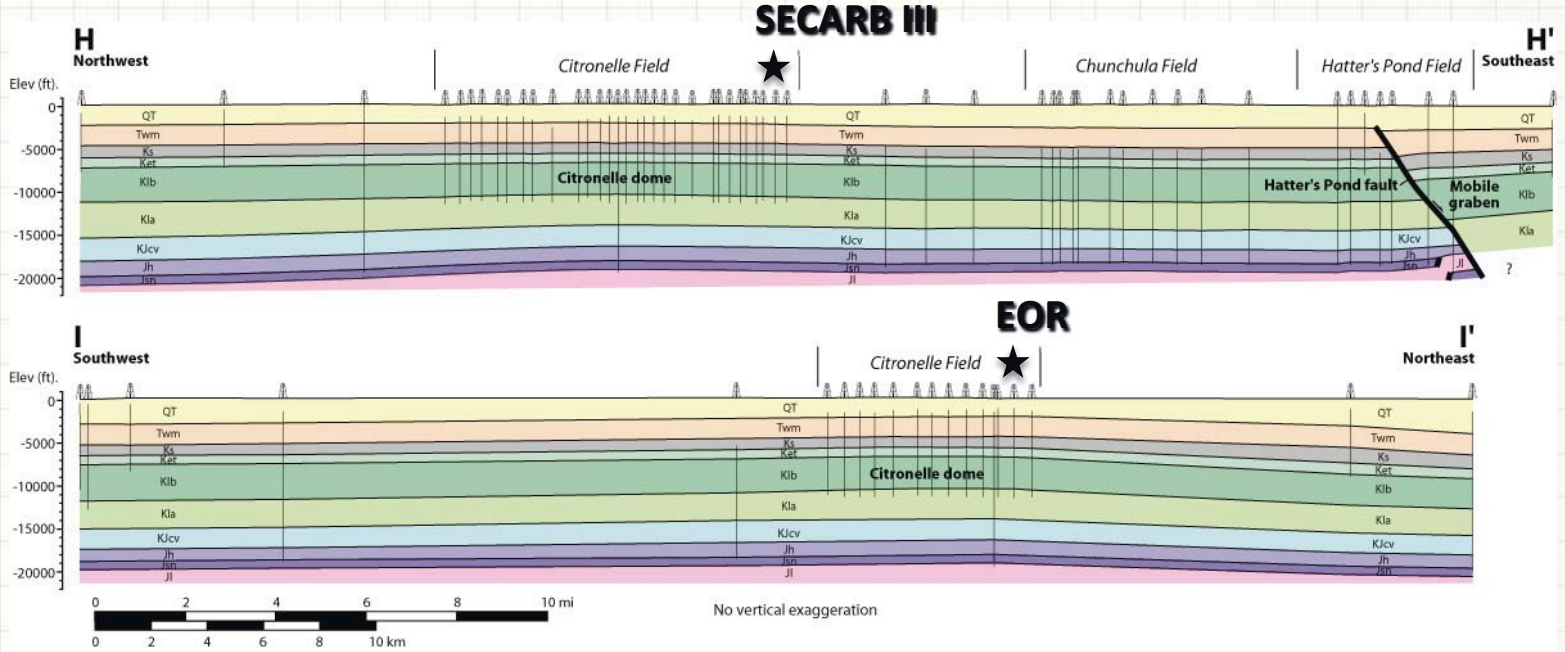
Mississippi Interior Salt Basin



CITRONELLE DOME STRUCTURE

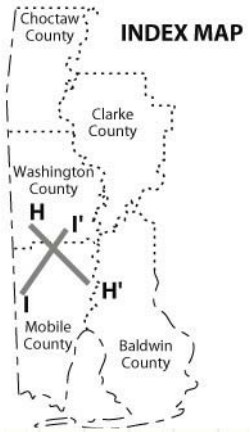
Top Donovan Sand

STRUCTURAL CROSS SECTIONS



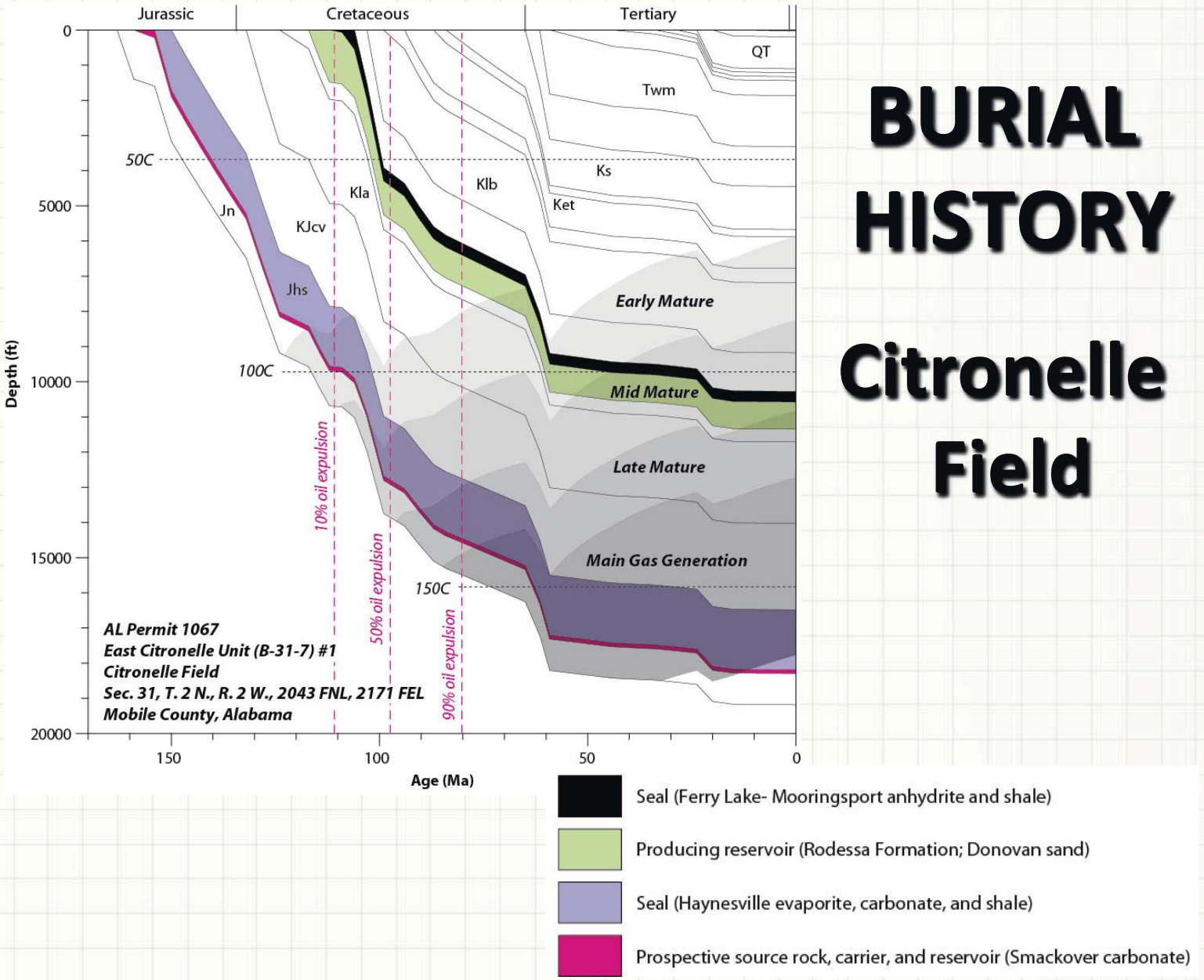
STRATIGRAPHY

QT	Quaternary and Tertiary undifferentiated
Twm	Wilcox and Midway Groups
Ks	Selma Group
Ket	Eutaw Formation and upper Tuscaloosa Group
Klb	Upper Tuscaloosa Group and Lower Cretaceous B
Kla	Lower Cretaceous A
KJcv	Cotton Valley Group
Jh	Haynesville Formation
Jsn	Smackover and Norphlet Formations
Jl	Louann Salt

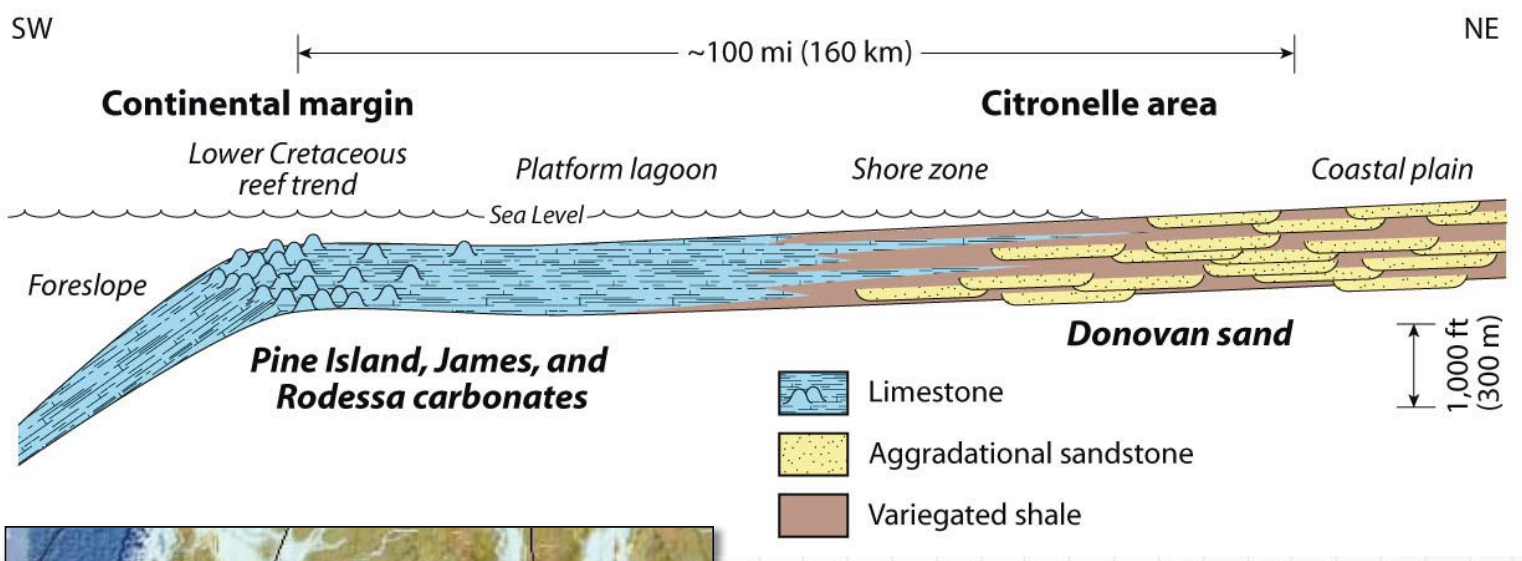


BURIAL HISTORY

Citronelle Field



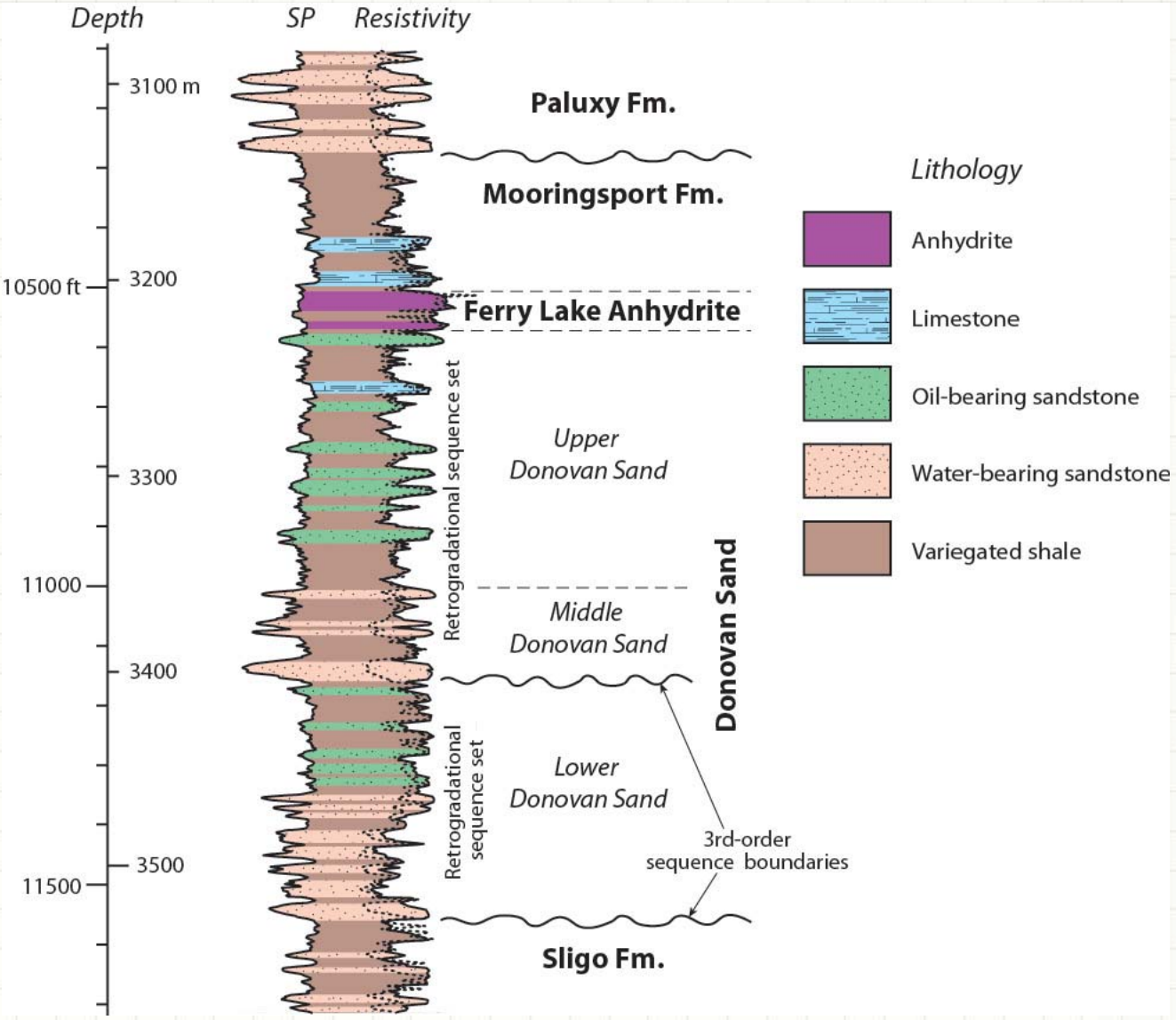
REGIONAL FACIES TREND



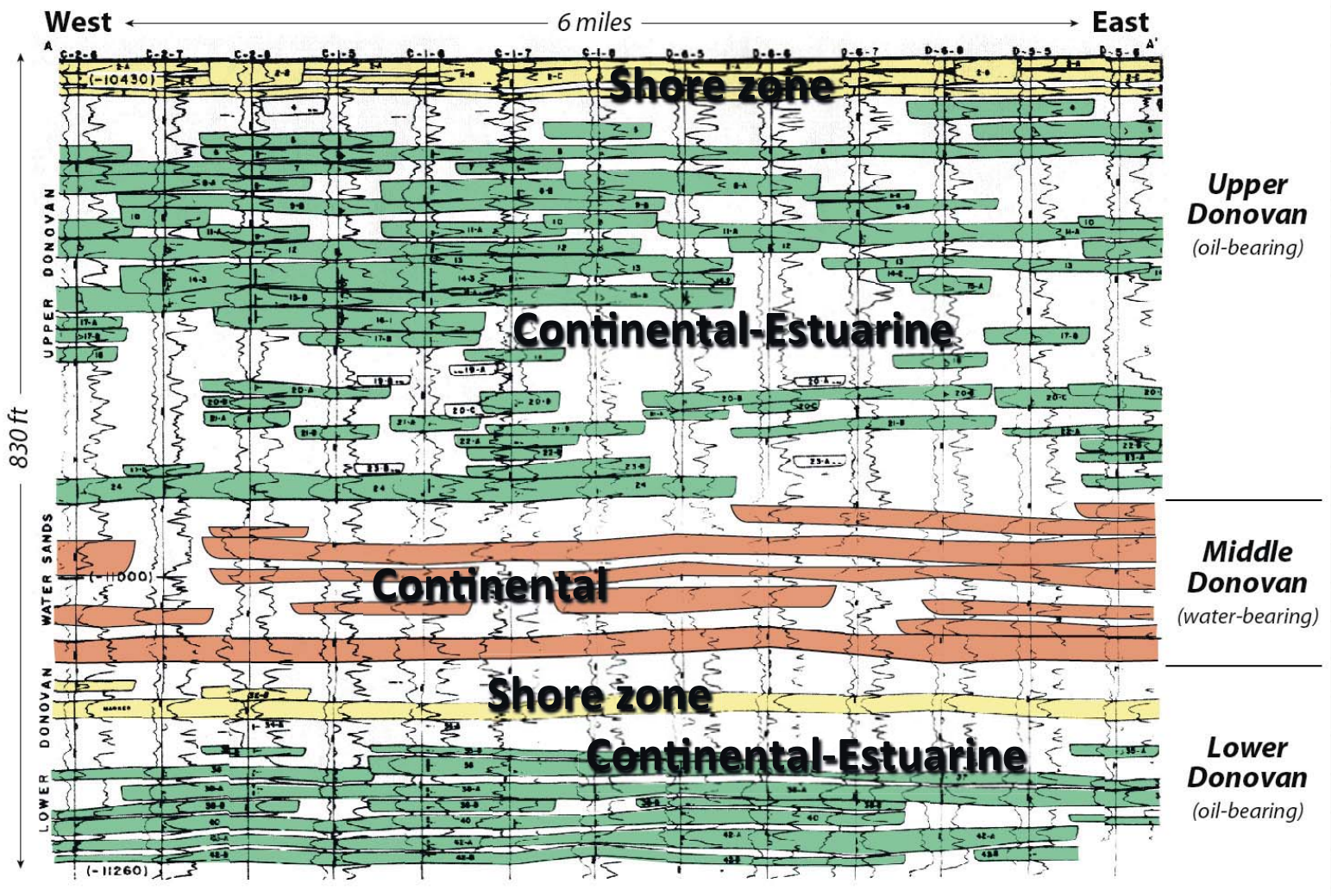
Regional Paleogeography 115Ma

Reconstruction by R. C. Blakey

DONOVAN STRATIGRAPHY



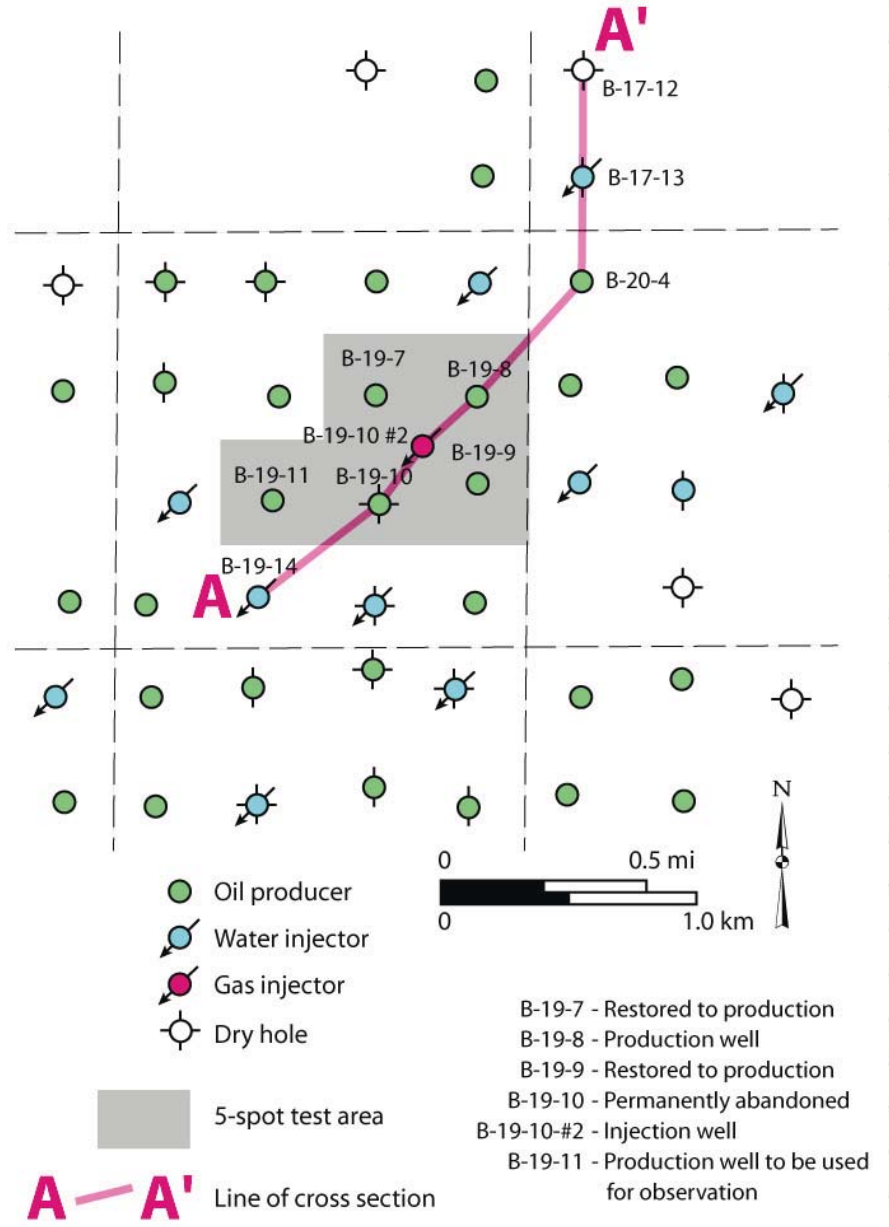
DONOVAN HETEROGENEITY



Eaves (1976)

BASELINE RESERVOIR MODEL

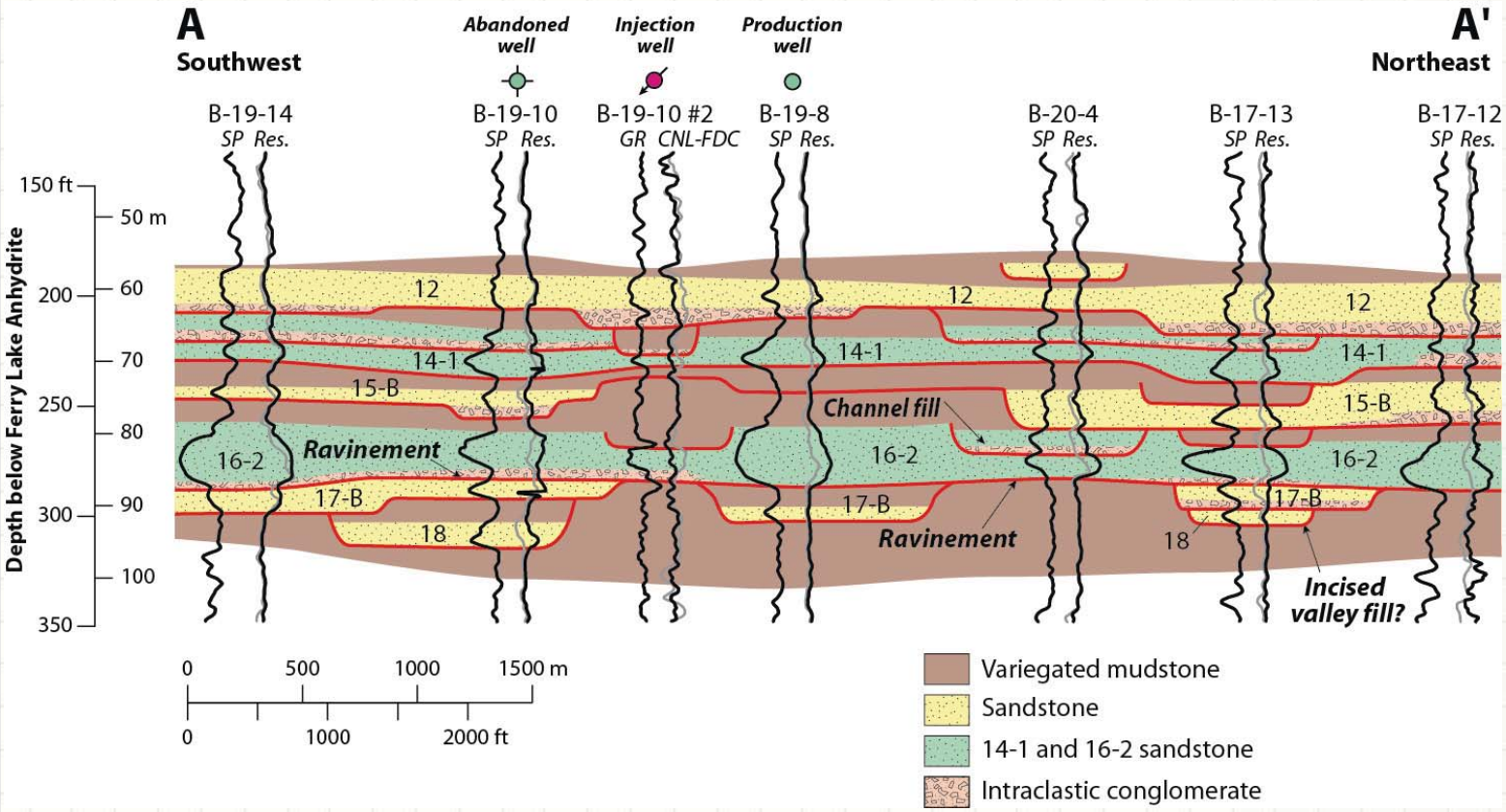
http://thenourishinggourmet.com/



EOR TEST AREA

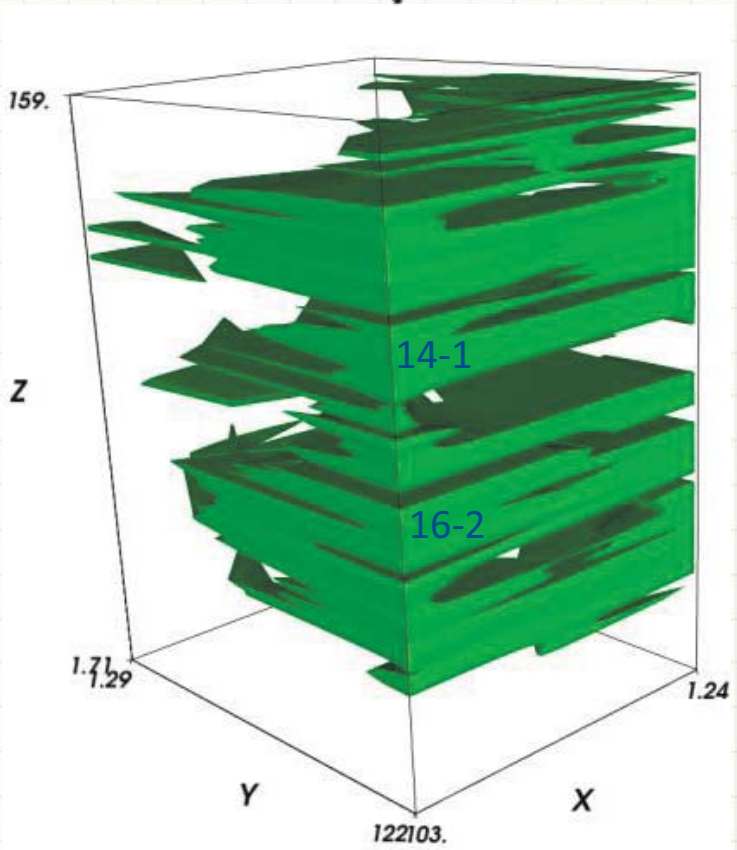
Citronelle Field

STRATIGRAPHIC CROSS SECTION

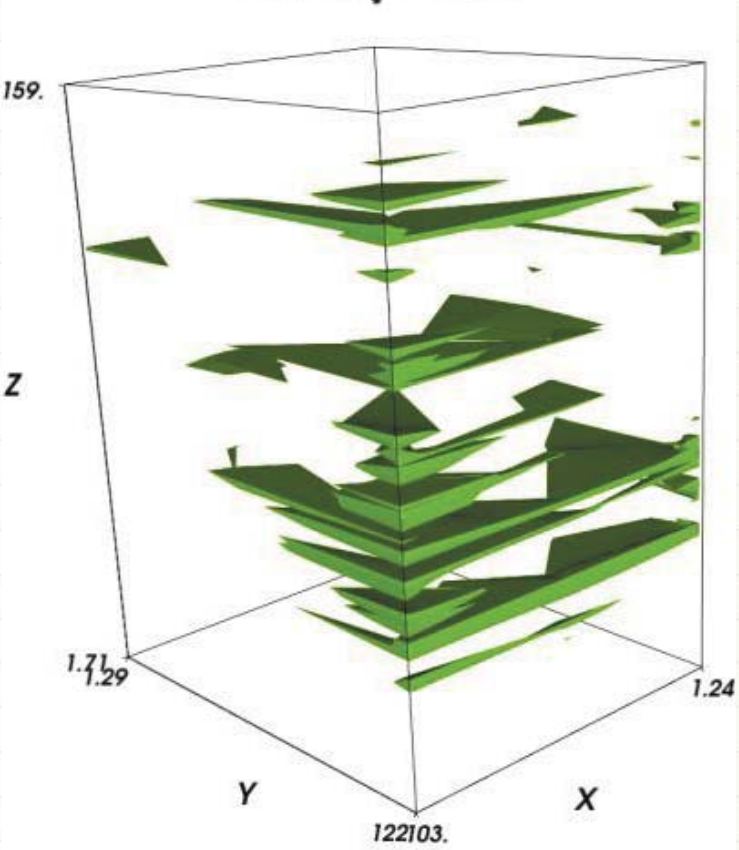


POROSITY MODELS

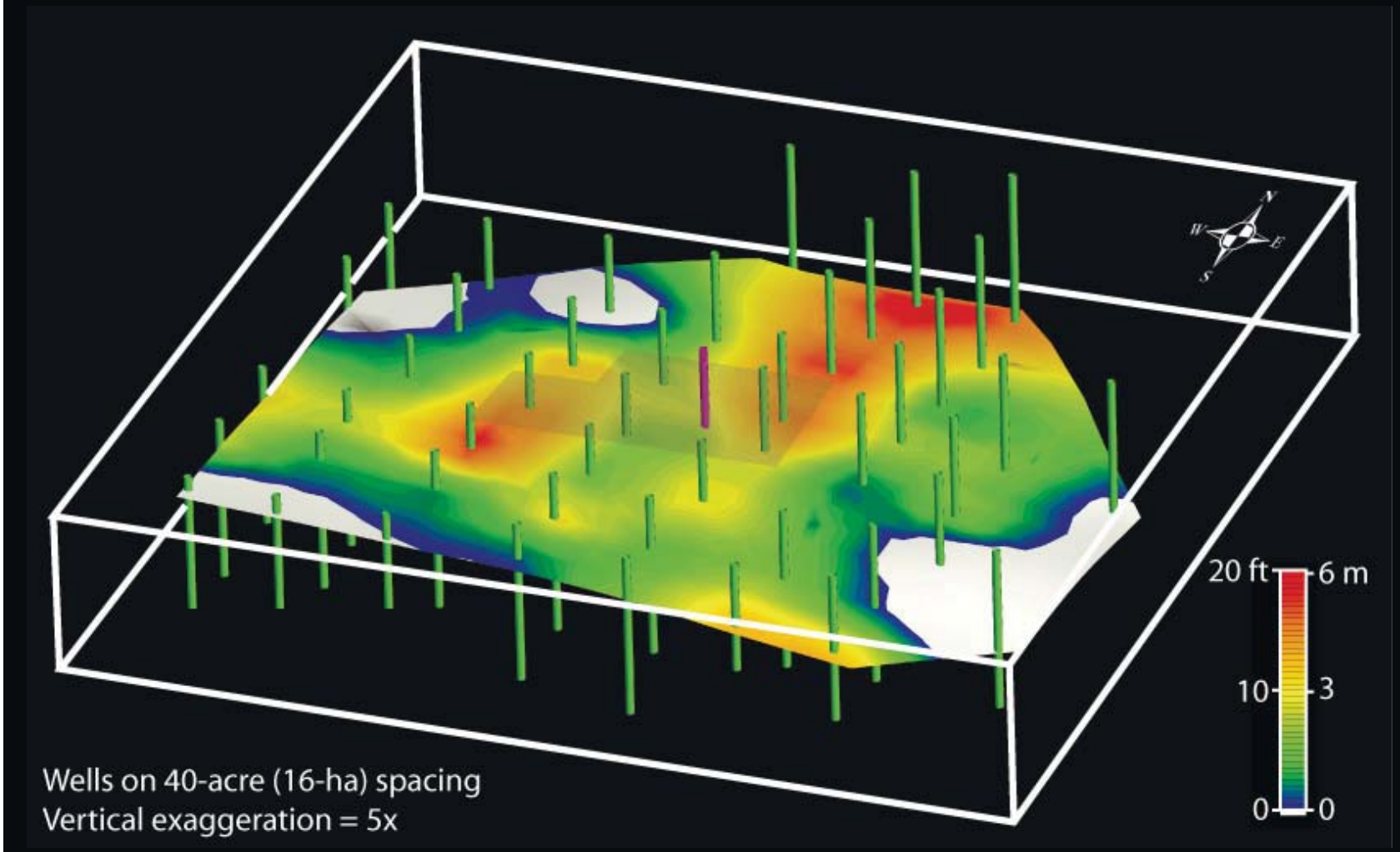
Porosity > 8%



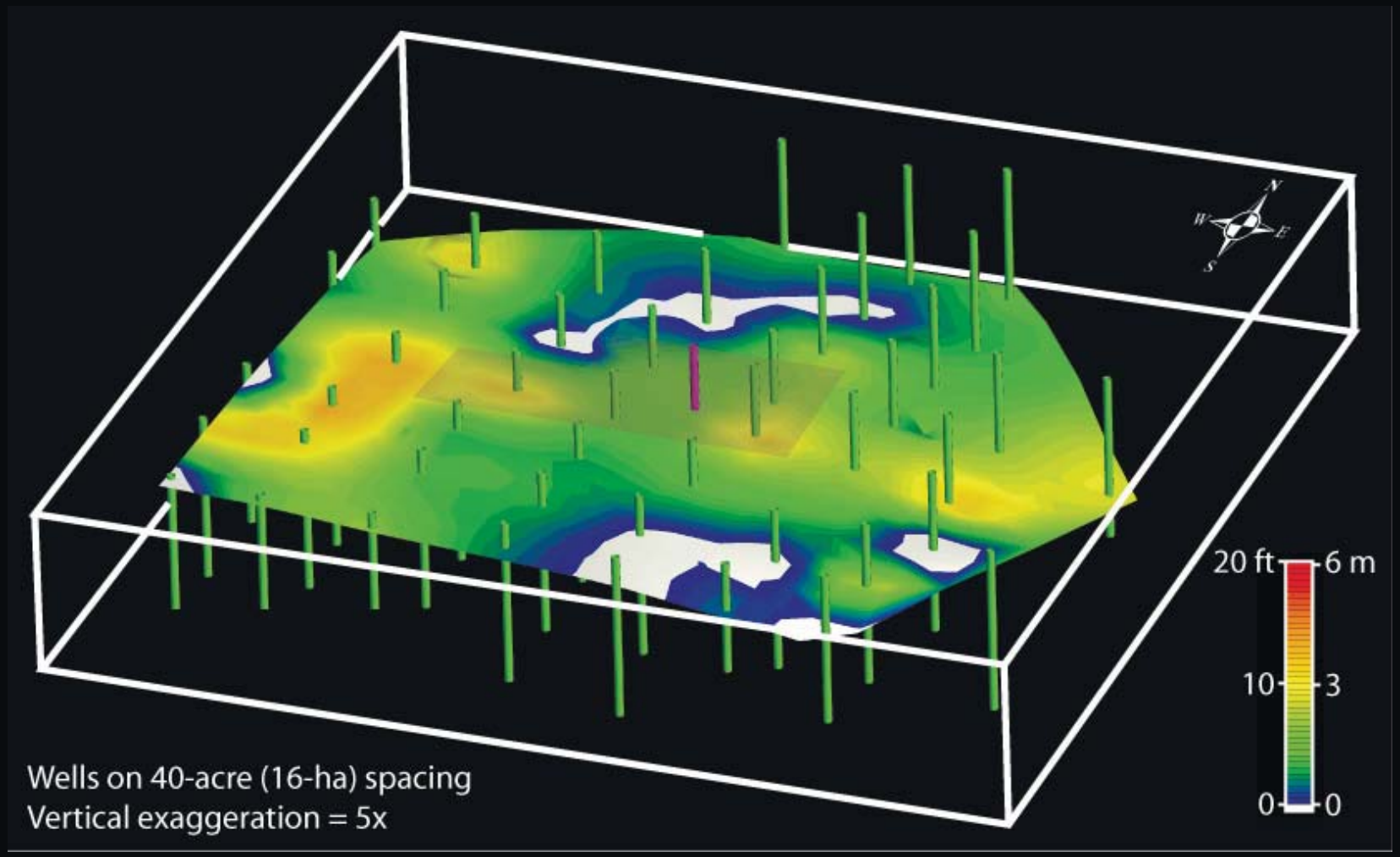
Porosity > 12%



3D MODEL, 16-2 NET PAY



3D MODEL, 14-1 NET PAY



CONGLOMERATIC ROCKS

Dolomitic mudstone

Core width = 10 cm

Oysters

Coalified plants

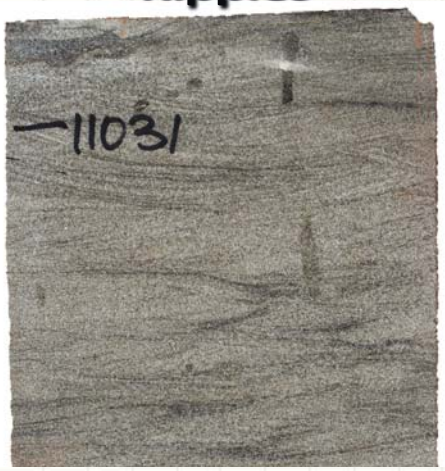
SANDSTONE

Cross-strata

Core width = 10 cm

Horizontal laminae

Ripples

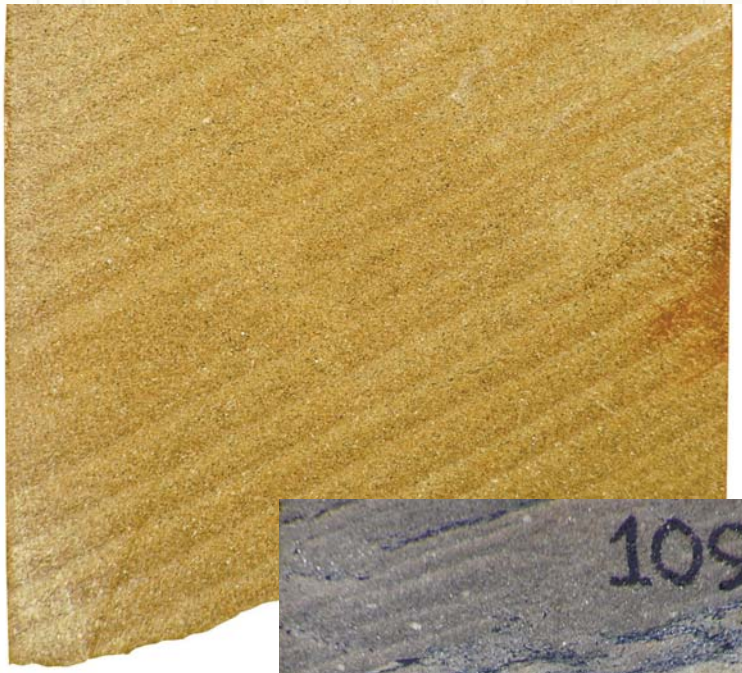


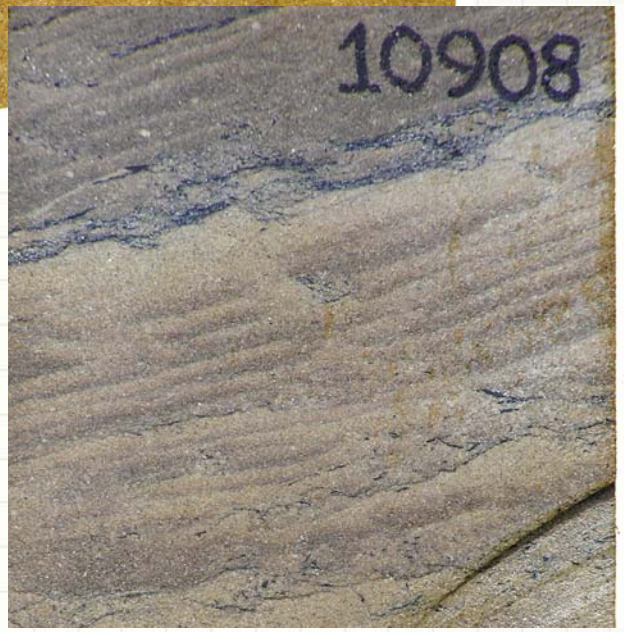
Mud drapes

Anhydrite nodules

SANDSTONE

Root tubules





Graded (grainfall?) laminae

Core width = 10 cm

MENISCATE BURROWS

HETEROLITHIC STRATA

Oysters

Teichichnus?

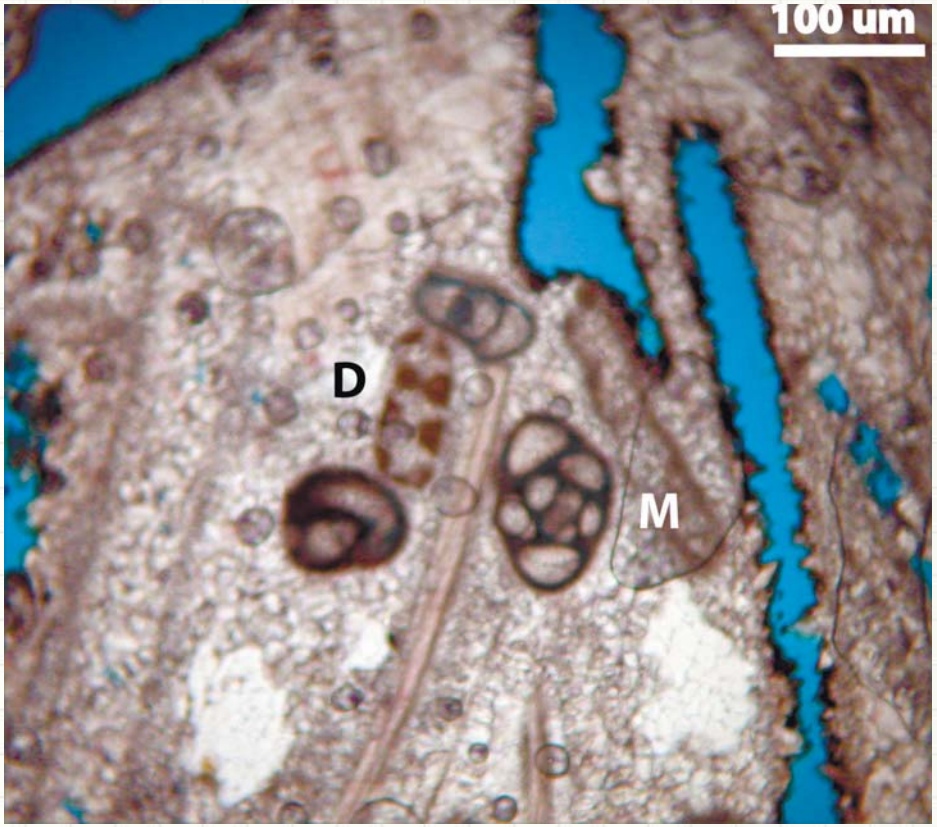
Rhizocorallium

Core width = 10 cm

LIMESTONE

Grainstone

Moldic pores, forams



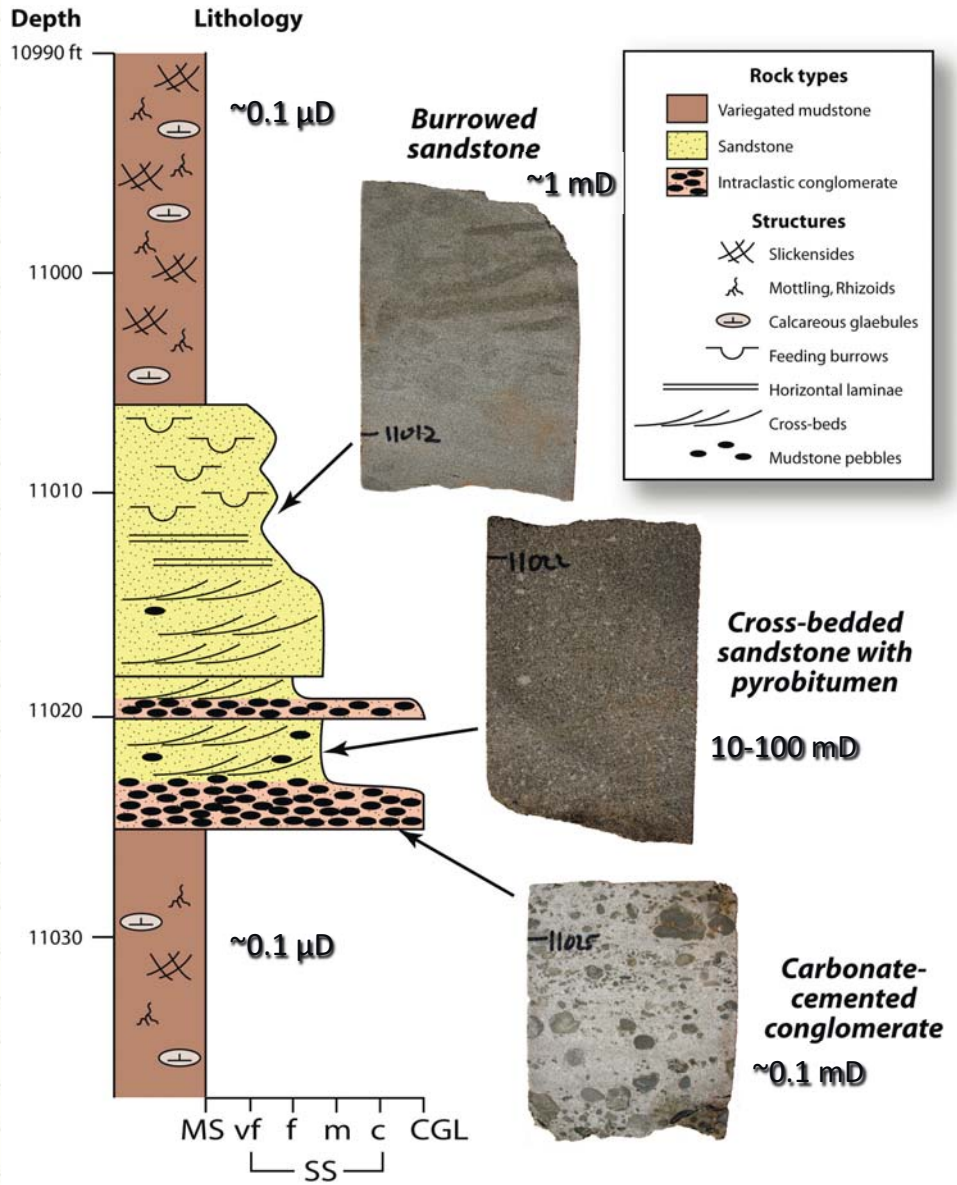
MUD ROCKS

Mud crack

Dolomitic nodules

Pedogenic slickensides

Core width = 4 in

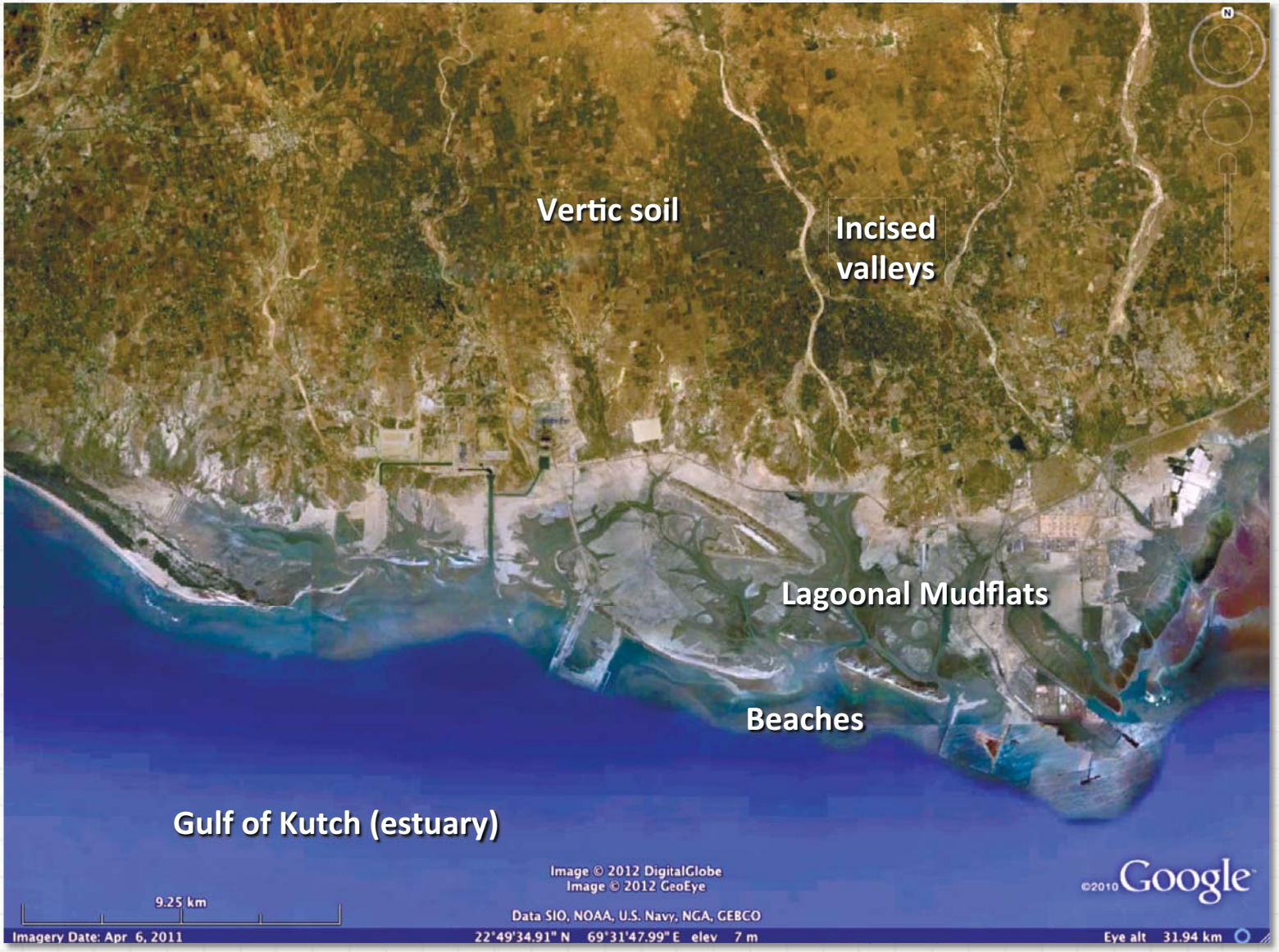


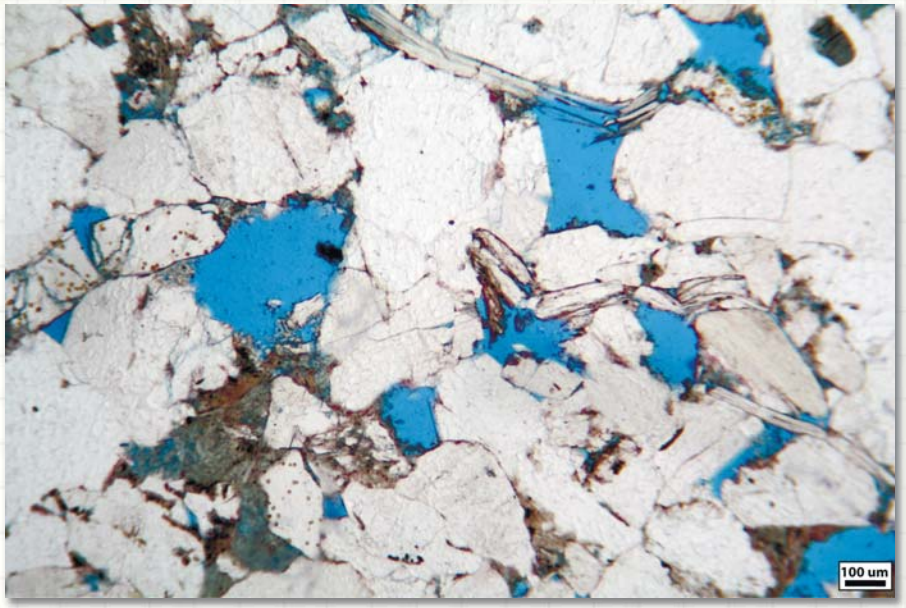
CORE LOG

16-2 Sand Citronelle Field

Well B-19-10 #2

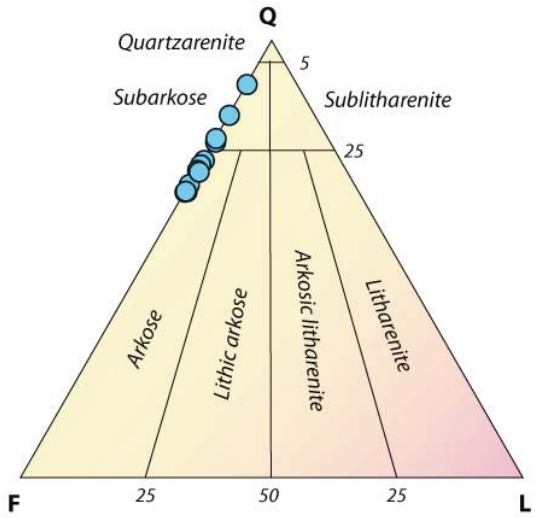
GULF OF KUTCH, INDIA



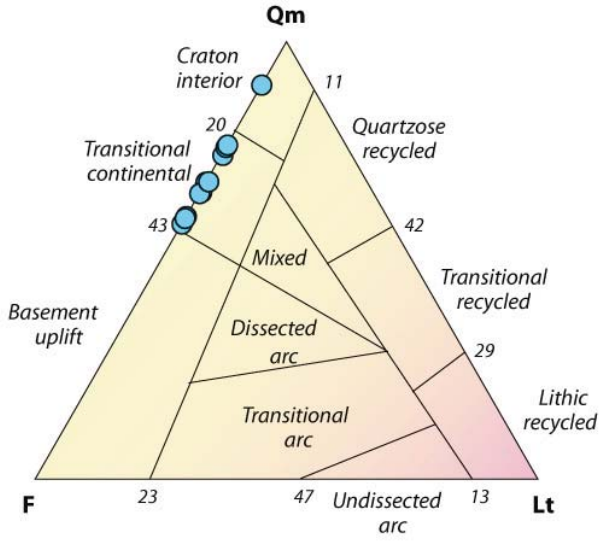


ARKOSIC SANDSTONE

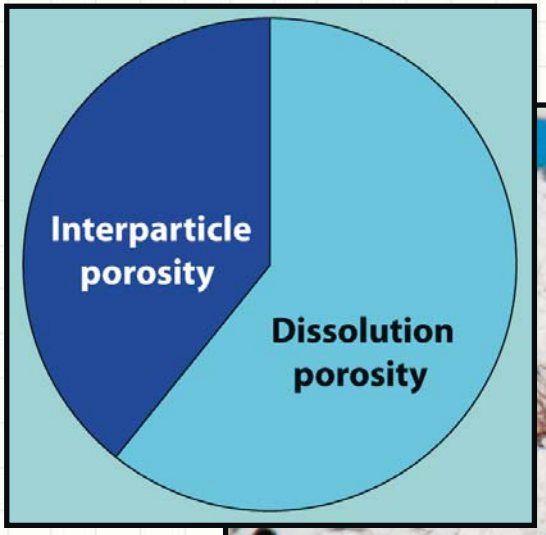
CLASSIFICATION



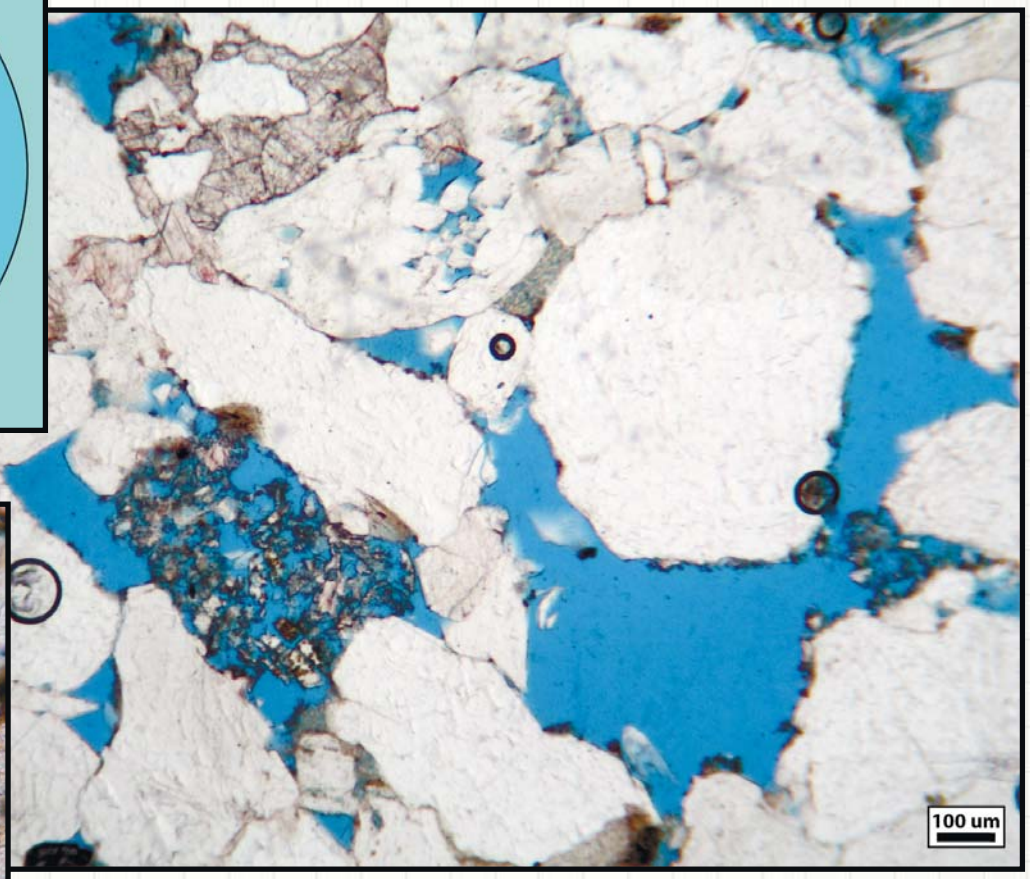
PROVENANCE

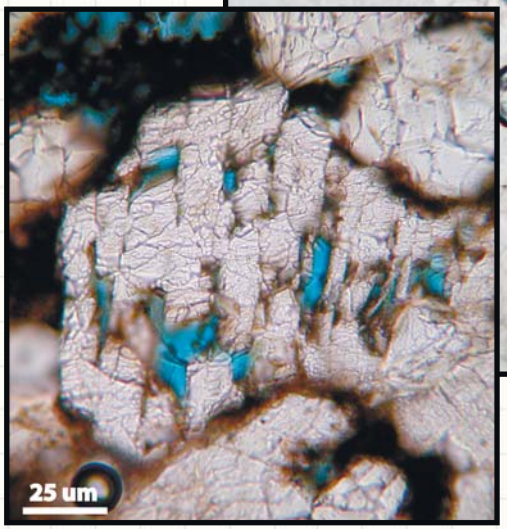


FELDSPAR DISSOLUTION



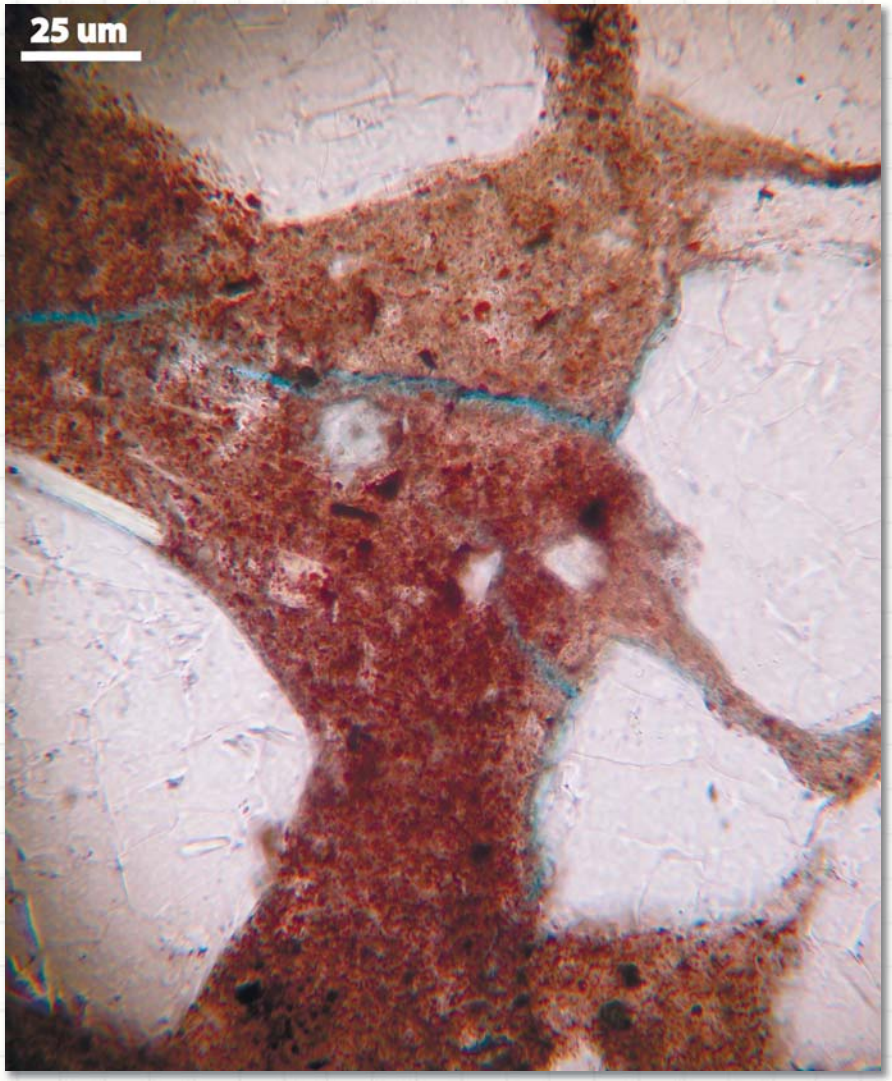
Donovan sandstone,
Gulf of Mexico basin





Close association with red paleosols suggests vadose dissolution and flushing

ILLUVIAL CLAY



Flushed clay derived from mineral dissolution may accumulate deeper in the soil profile in a process called illuviation.

In this case, illuvial clay plugged porosity, thus destroying reservoir quality.

Donovan sandstone,
Gulf of Mexico basin

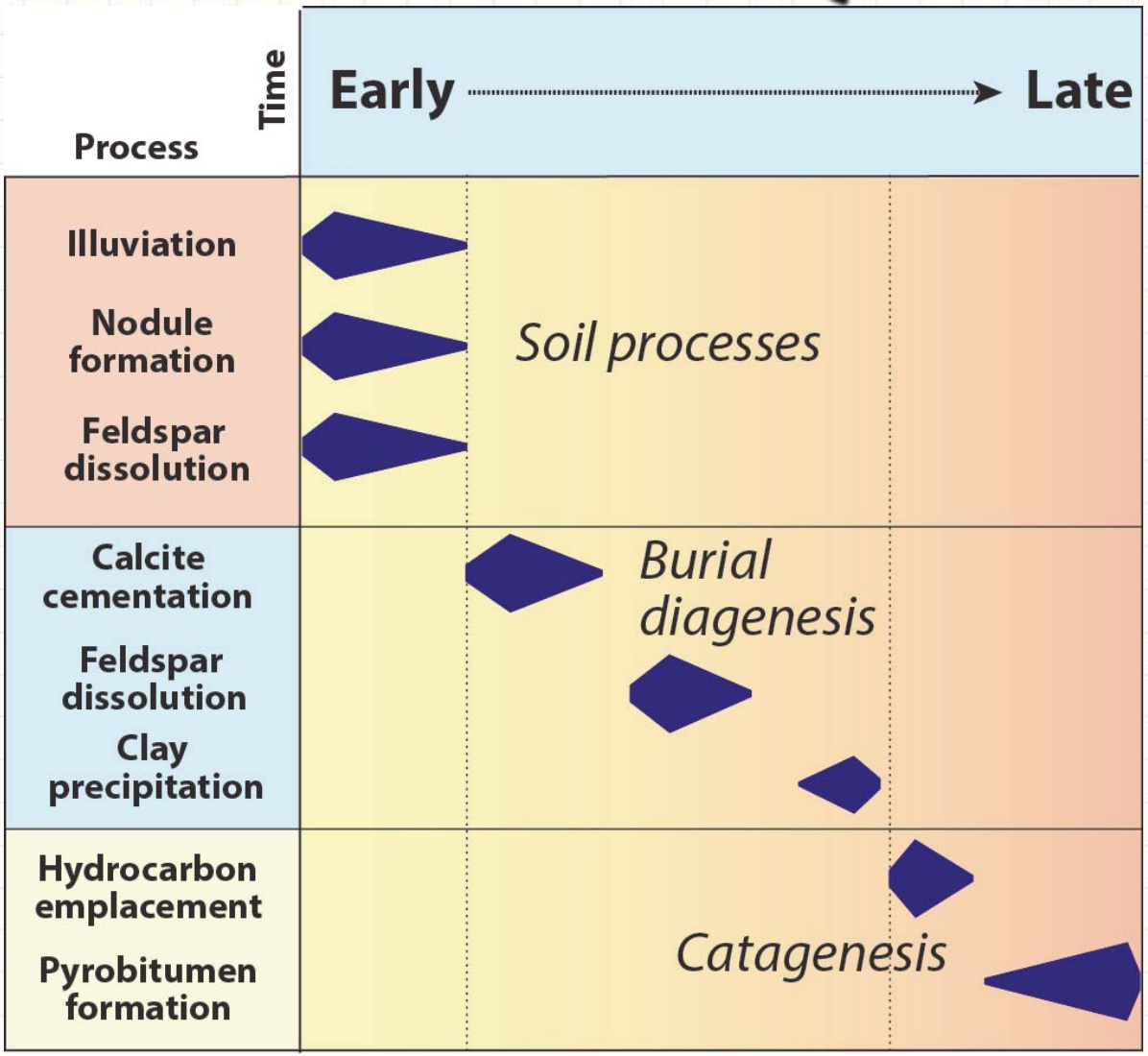
REDUCING FLUIDS

Oil-water contact, lower Donovan Sand

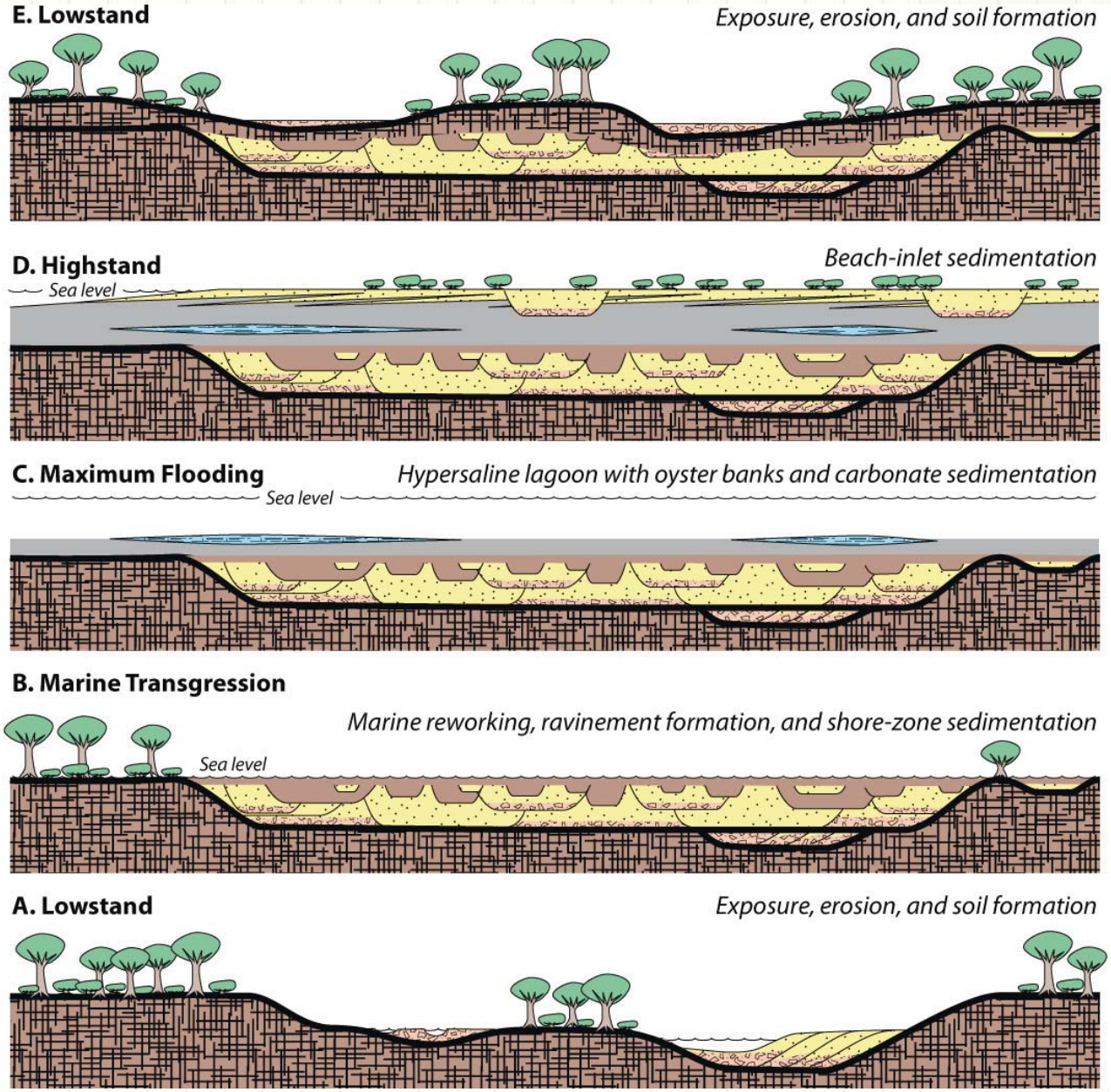
SECU D-9-8 #2

Core diameter = 10 cm

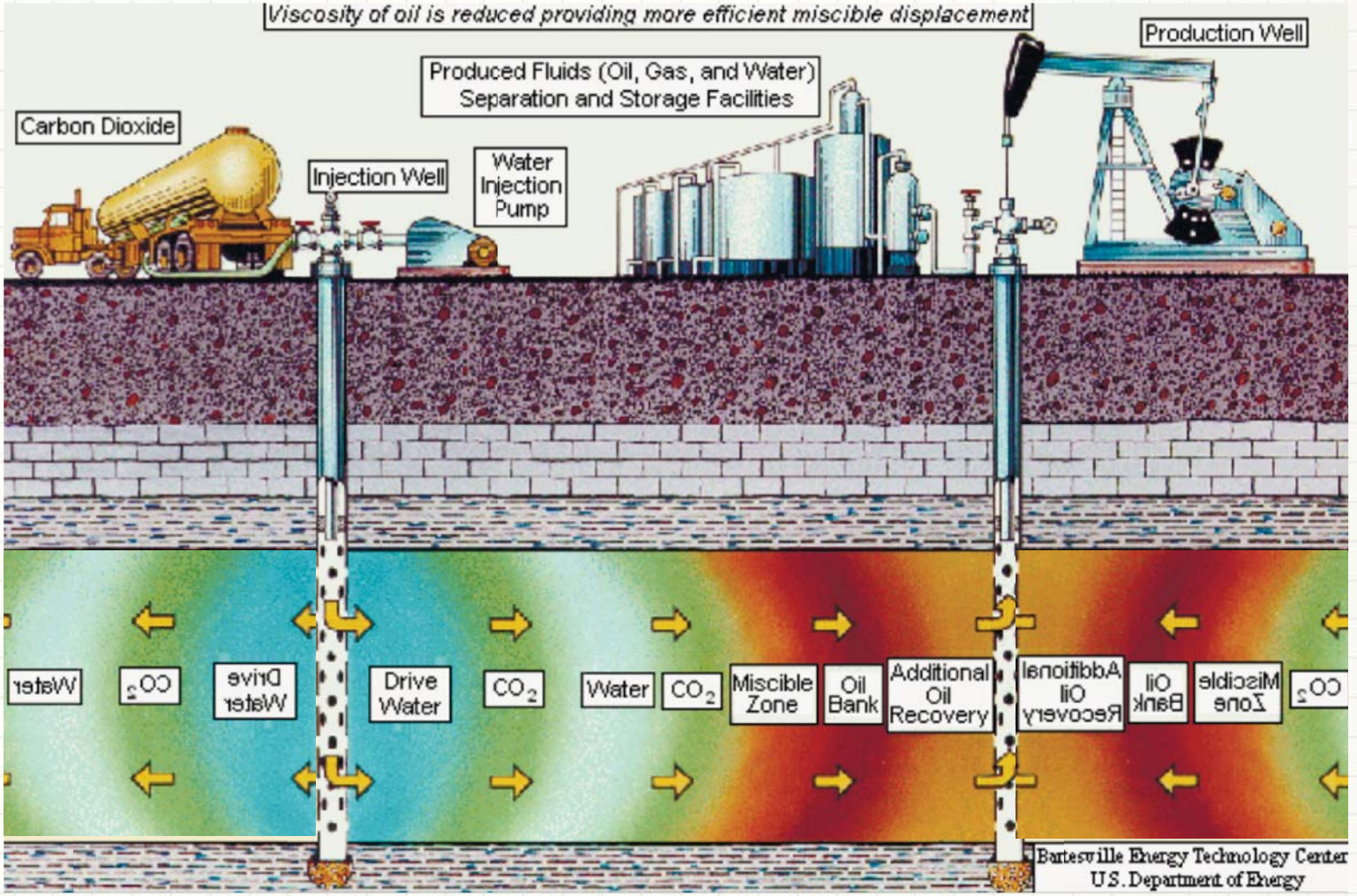
PARAGENETIC SEQUENCE



IDEALIZED 5th-ORDER DEPOSITIONAL SEQUENCE



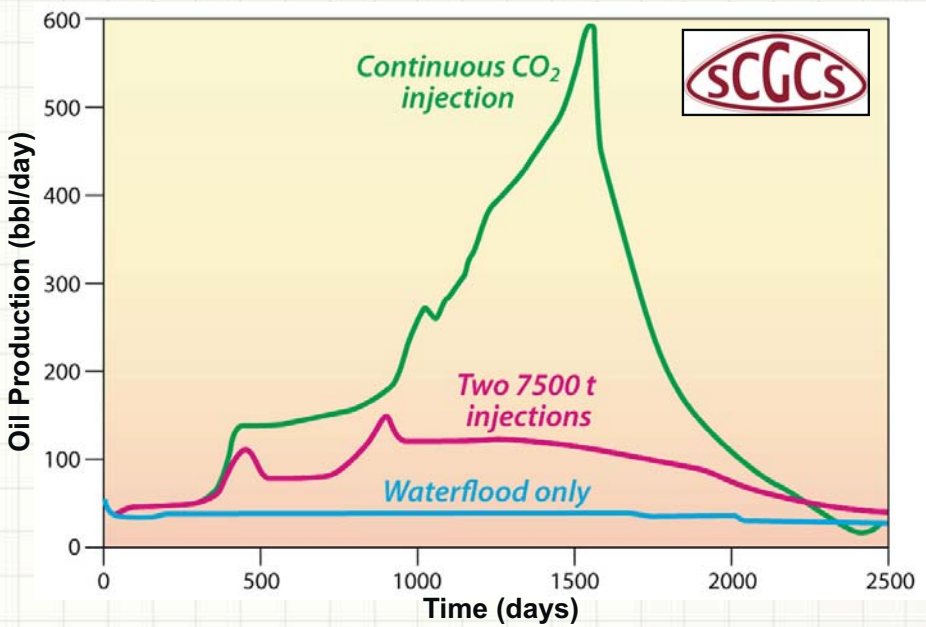
CO_2-ENHANCED OIL RECOVERY



CITRONELLE FIELD OPERATIONS

Well B-19-10 #2

Projected 5-spot performance SENSOR simulation

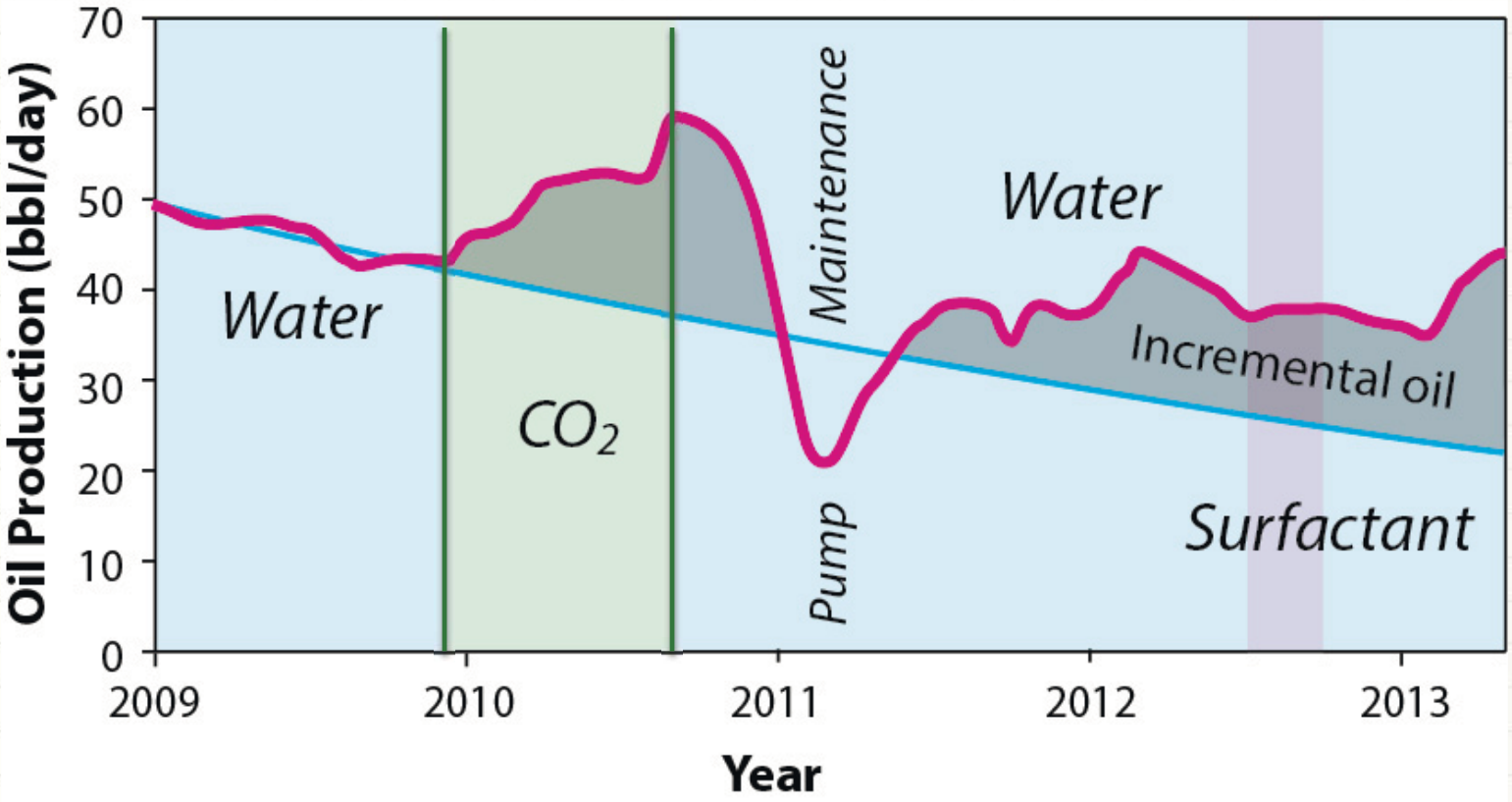


Simulation by E. Carlson, Univ. AL

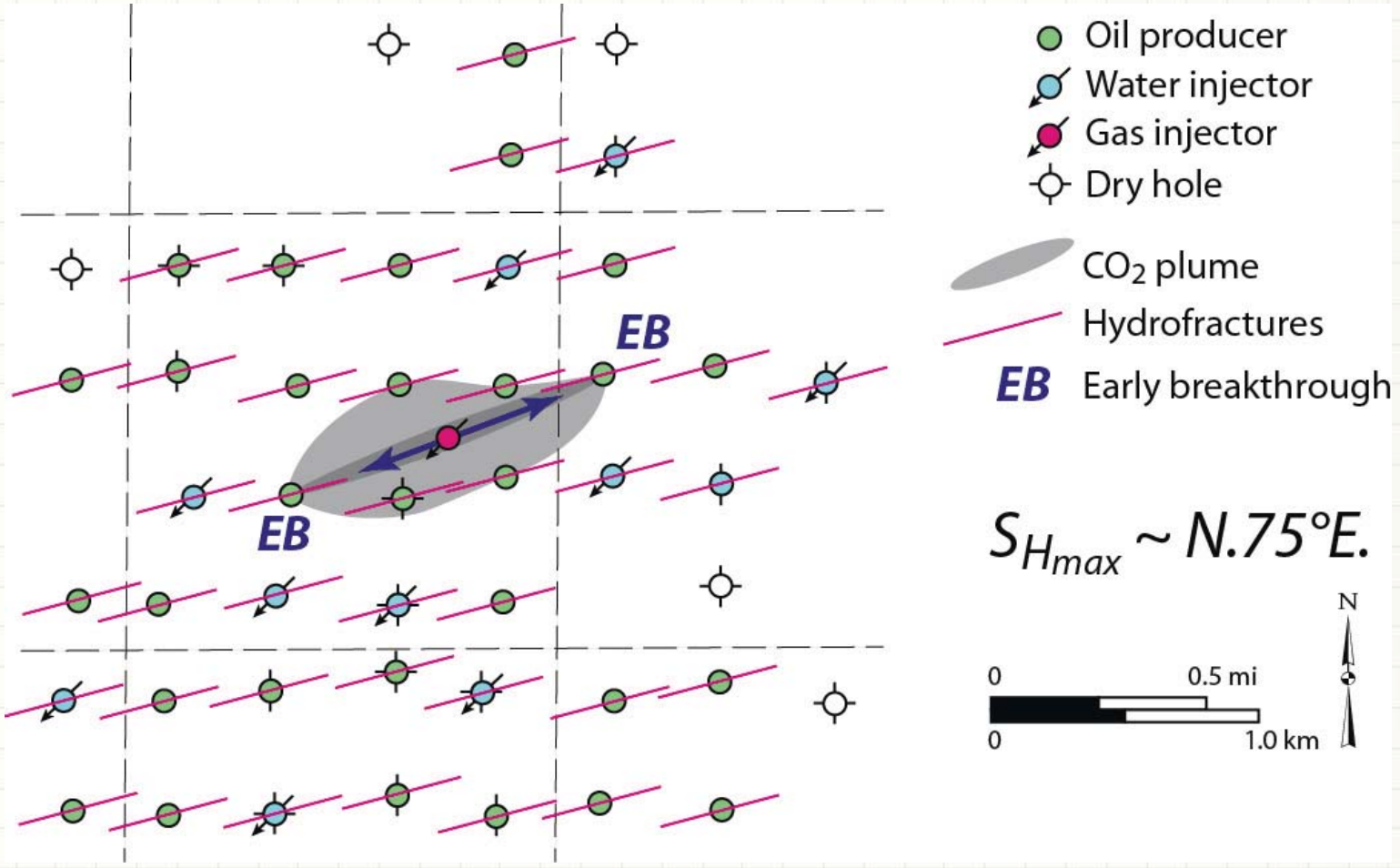
DRI

UAB School of Engineering
The University of Alabama at Birmingham

INCREMENTAL OIL RECOVERY



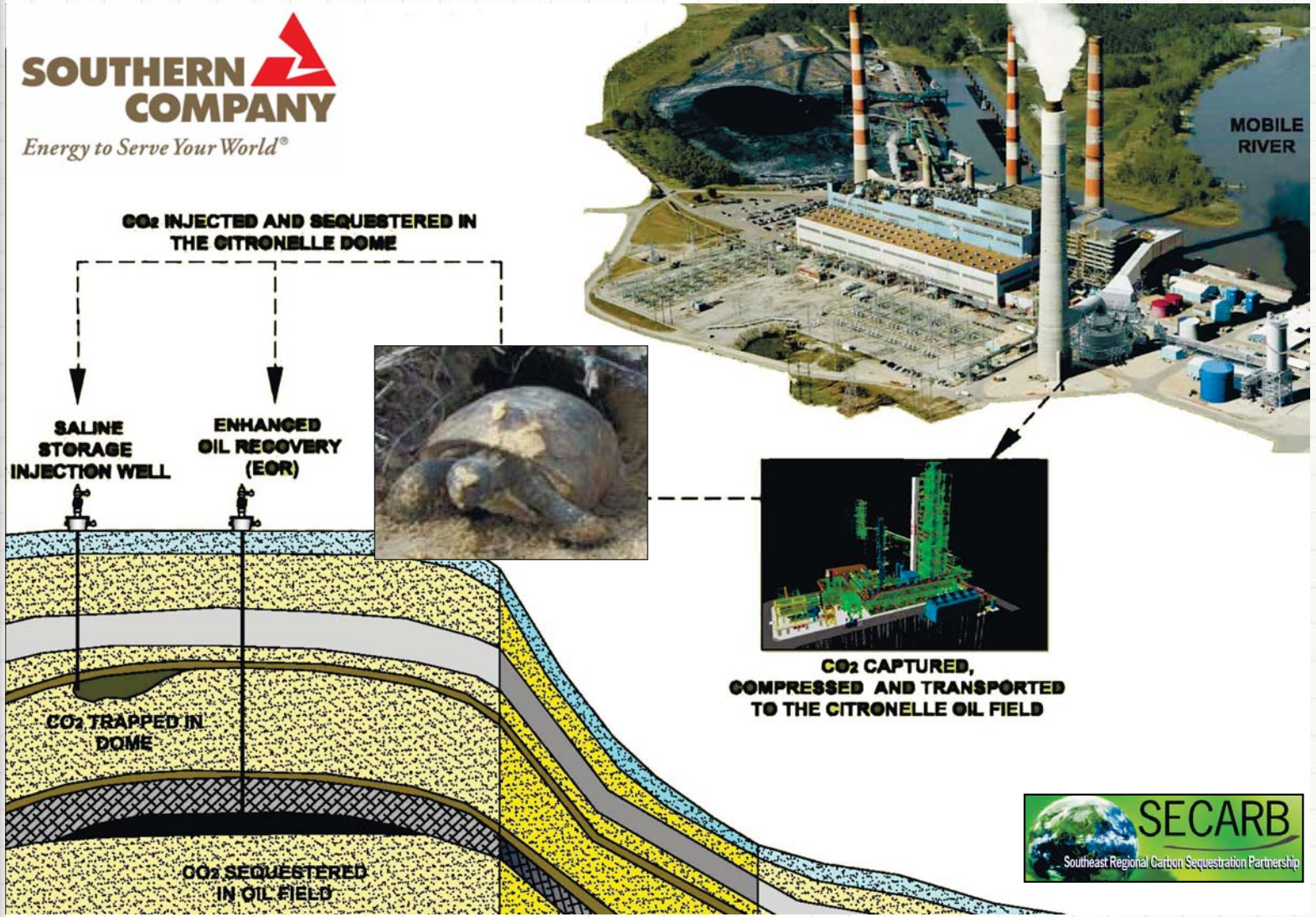
EARLY BREAKTHROUGH



FLOOD RESULTS

- ✓ Initial waterflood (~220 bbl/d @ 3400 psig) resulted in significant incremental recovery with steep (~20% decline).
- ✓ CO_2 injection facilitated rapid incremental oil response.
- ✓ Extremely early breakthrough of CO_2 along maximum horizontal stress direction.
- ✓ Return to water injection resulted in major loss of injectivity (rate declined to ~40 bbl/d @ 3400 psig). CO_2 blocking? Paraffin blocking?
- ✓ Surfactants had little effect on injectivity.

SECARB III – "ANTHROPOGENIC"

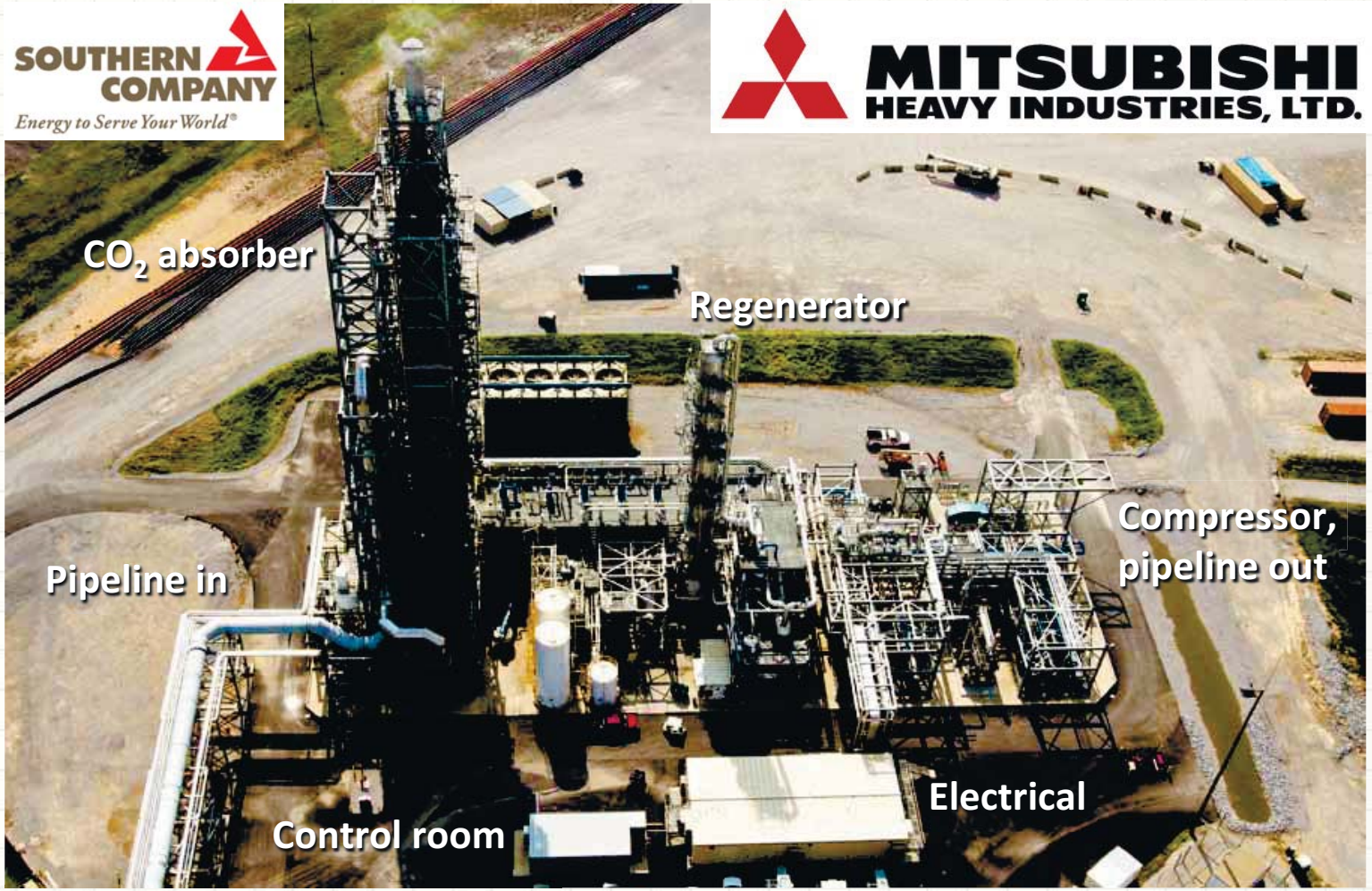


MODULAR CO_2 CAPTURE UNIT

MHI 25 Mw CO_2 CAPTURE PLANT, MOBILE

SOUTHERN COMPANY
Energy to Serve Your World®

MITSUBISHI HEAVY INDUSTRIES, LTD.

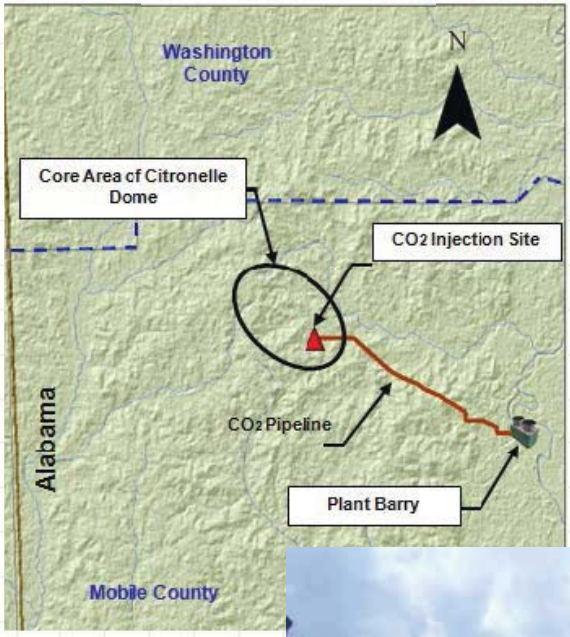


Capacity ~ 500 tons CO_2/d

Facility cost = ~$100 Million Taxpayer cost = $0

PIPELINE SYSTEM

Pipeline route

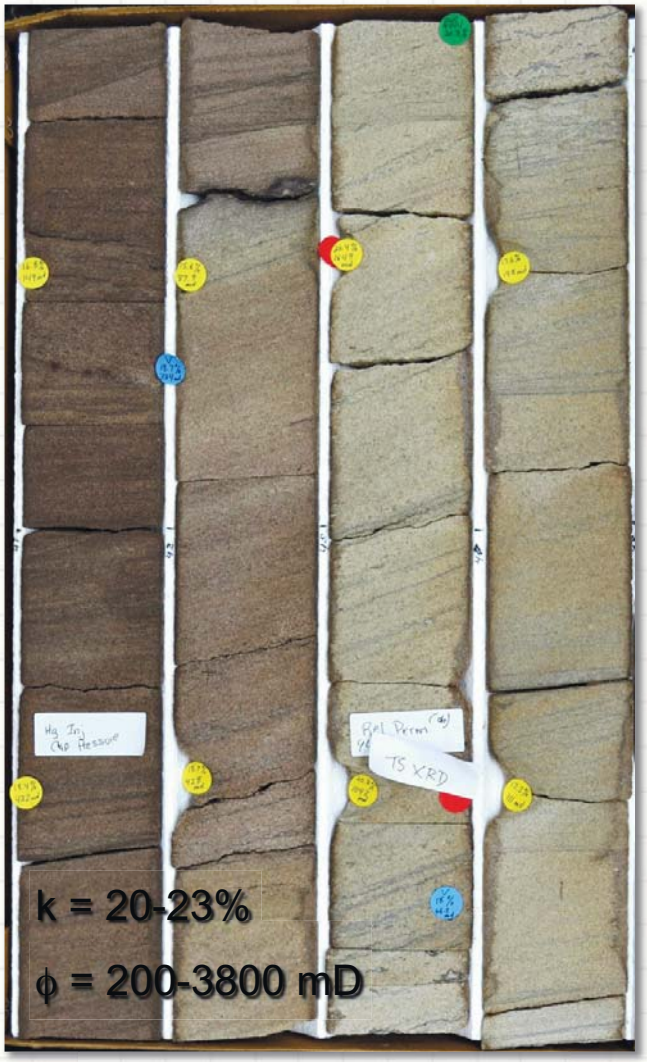


Metering station

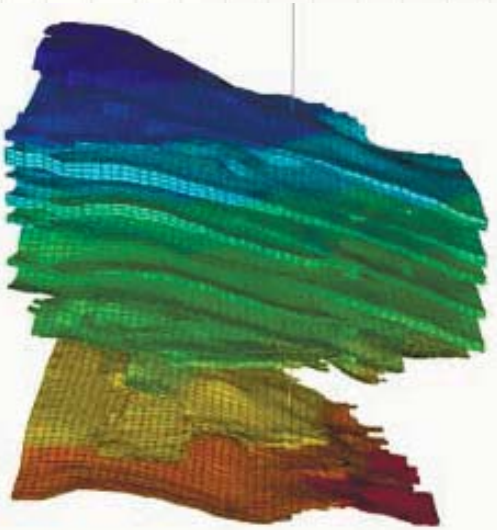
130-stage booster pump

PALUXY SALINE RESERVOIR TEST

Sandstone core

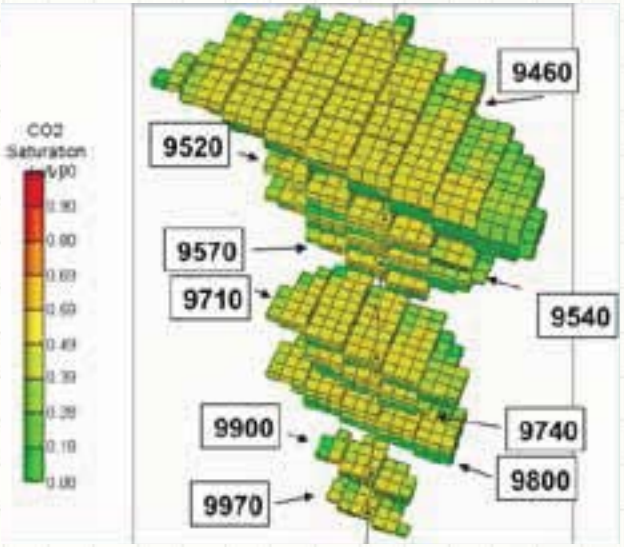


Reservoir model



Advanced Resources International, Inc.

Plume model



SUMMARY

- ✓ Large oil field containing ~ 50 sandstone units deposited in ~ 5 million years (100 ky sequences).
- ✓ Depositional setting is semi-arid, landward fringe of backreef lagoon (continental-estuarine facies).
- ✓ Interaction among depositional, biological, and diagenetic processes determined reservoir distribution and internal heterogeneity.
- ✓ CO_2 flood characterized by early breakthough, significant incremental oil recovery.
- ✓ Planning underway for major tests using anthropogenic CO_2 source at Plant Barry.