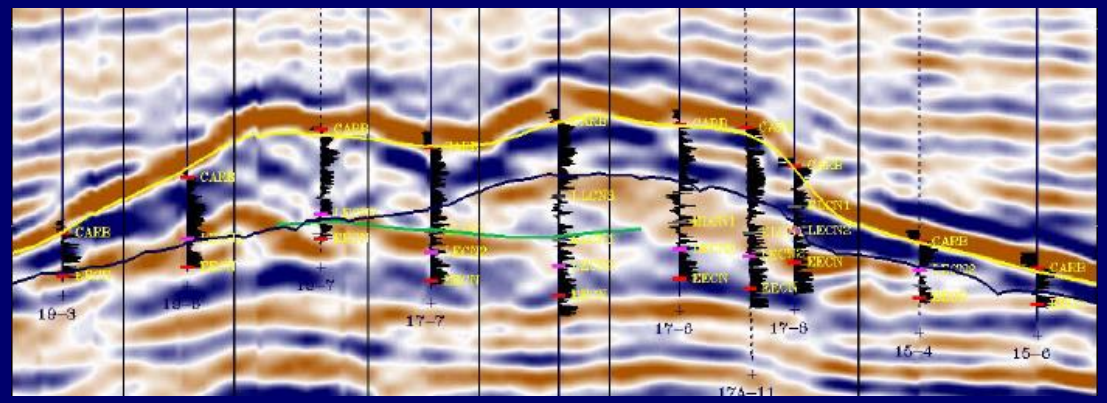
Reefs of the Permo-Penn Caribbean

The Horseshoe Atoll of the Midland Basin

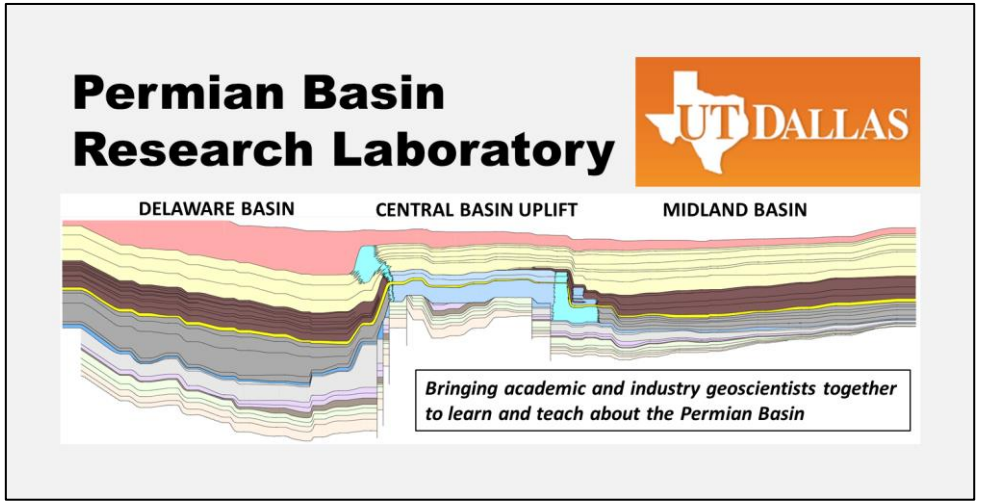


Lowell Waite
UT Dallas
June 7, 2021

Permian Basin Research Lab at UT Dallas

Dr. Robert J. Stern and Mr. Lowell Waite, Co-Directors

-- established January 2019 --



Goals:

- Advance understanding of all geologic aspects of the Permian Basin through open applied research, **linking academia and industry**

- Educate and better prepare students for professional careers in the oil and gas industry

  - Graduate courses offered:
    - Geology of the Permian Basin
    - Petroleum Geoscience
    - Paleo Earth Systems: Global Themes
    - Carbonate Sedimentology

https://labs.utdallas.edu/permianbasinresearch/

Geology of the Permian Basin: Fall 2020 Syllabus

UNIVERSITY OF TEXAS ARLINGTON

August 27	Class intro, grading policy
Sept 1 / 3	Region & basin overview / Exploration history
Sept 8 / 10	Tectonic history
Sept 15	Stratigraphic overview
Sept 17	Basement rocks
Sept 22	Cambrian – Lower Ord (Wilberns Ss., Ellenburger Gp)
Sept 24	Mid – Upper Ord (Simpson – Montoya)
Sept 29	Early Silurian (Fusselman)
Oct 1	Late Sil – Early Dev (Wristen Gp – Thirty One Fm)
Oct 6	Mississippian
Oct 8	Review
Oct 13	**Mid-term exam (in-class)**
Oct 15	**no class**
Oct 20	Exam results and review
Oct 22	Pennsylvanian
Oct 27	Lower Permian
Oct 29	Middle Permian
Nov 3	Upper Permian
Nov 5	Post-Permian units
Nov 10	Permian Basin Petroleum System
Nov 12	Horseshoe Atoll
Nov 17	Unconv. shale plays of the Permian Basin
Nov 19	Course wrap-up/Review
Nov 24 / 26	**no class (Thanksgiving break)**
Dec 1	Review (on-line; attendance not mandatory) (No class on Dec 1)
Dec 3	No Class; Final exam mail-out
Dec 10	**Final Exams due by 2pm**

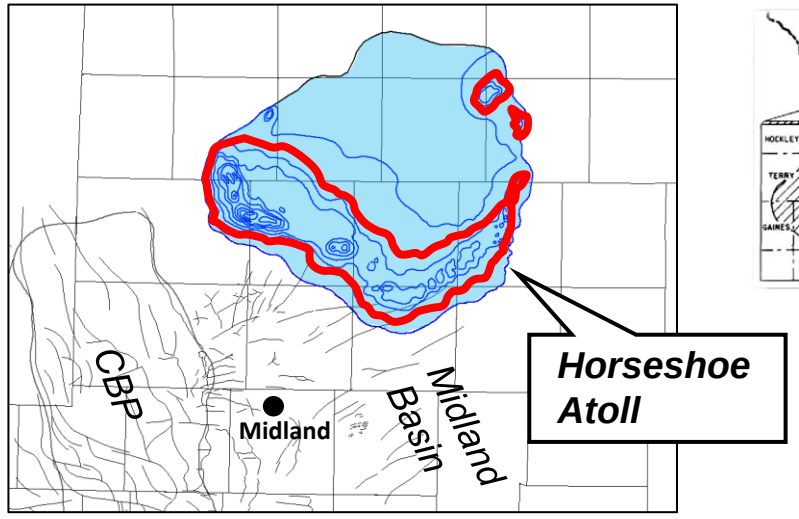
Horseshoe Atoll of the Midland Basin

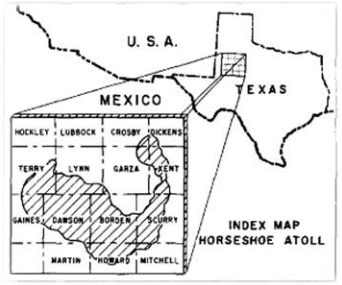
Outline

- What is the Horseshoe Atoll ?
- Geology of the Atoll
- Why it is important
  - Conventional reservoir perspective
  - Unconventional shale play perspective

Horseshoe Atoll – what is it?

- An enormous, isolated carbonate platform including an arcuate chain of reef-shoal complexes of Pennsylvanian and early Permian age, located within the northern portion of the Midland Basin, west Texas





- This organic feature encompasses portions or all of 14 counties (Terry, Lynn, Garza, Kent, Scurry, Mitchell, Howard, Borden, Dawson, Gaines, Martin, Lubbock, Crosby, and Dickens); an area of approximately **8,100 mi^2** (5.2 million acres) (for reference, New Jersey = 8,722 mi^2)
- It contains 70 conventional oil fields stretched out over 175 miles along its outer rim, including a few giants (>100 MMBO) and one supergiant (Kelly-Snyder field, 1.3 BBO)
- It is so-named because the **Cisco – Canyon** portion of the complex, outlined by the thick red lines on the index map, resembles this →

Horseshoe Atoll – what is it?

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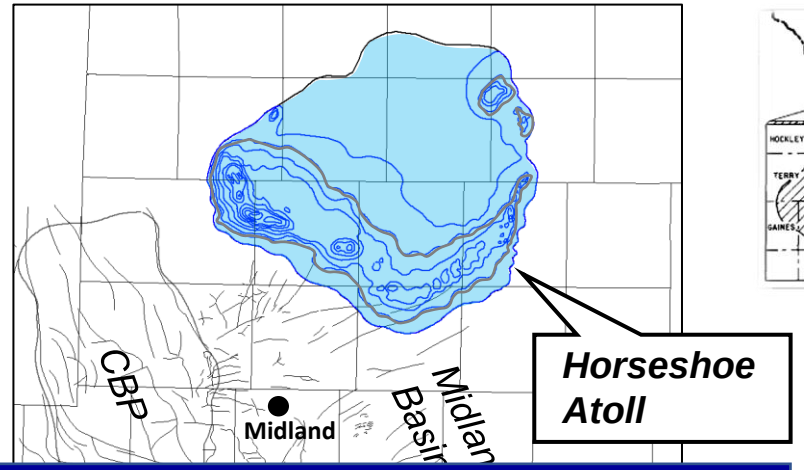
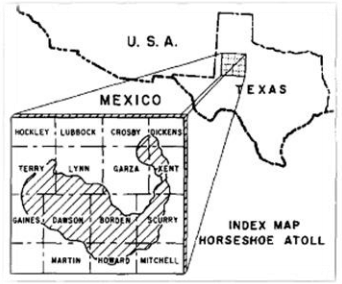




Atoll

An atoll, sometimes called a coral atoll, is a ring-shaped coral reef including a coral rim that encircles a lagoon partially or completely. There may be coral islands/cays on the rim. The coral of the atoll often sits atop the rim of an extinct seamount or volcano which has eroded or subsided partially beneath the water.

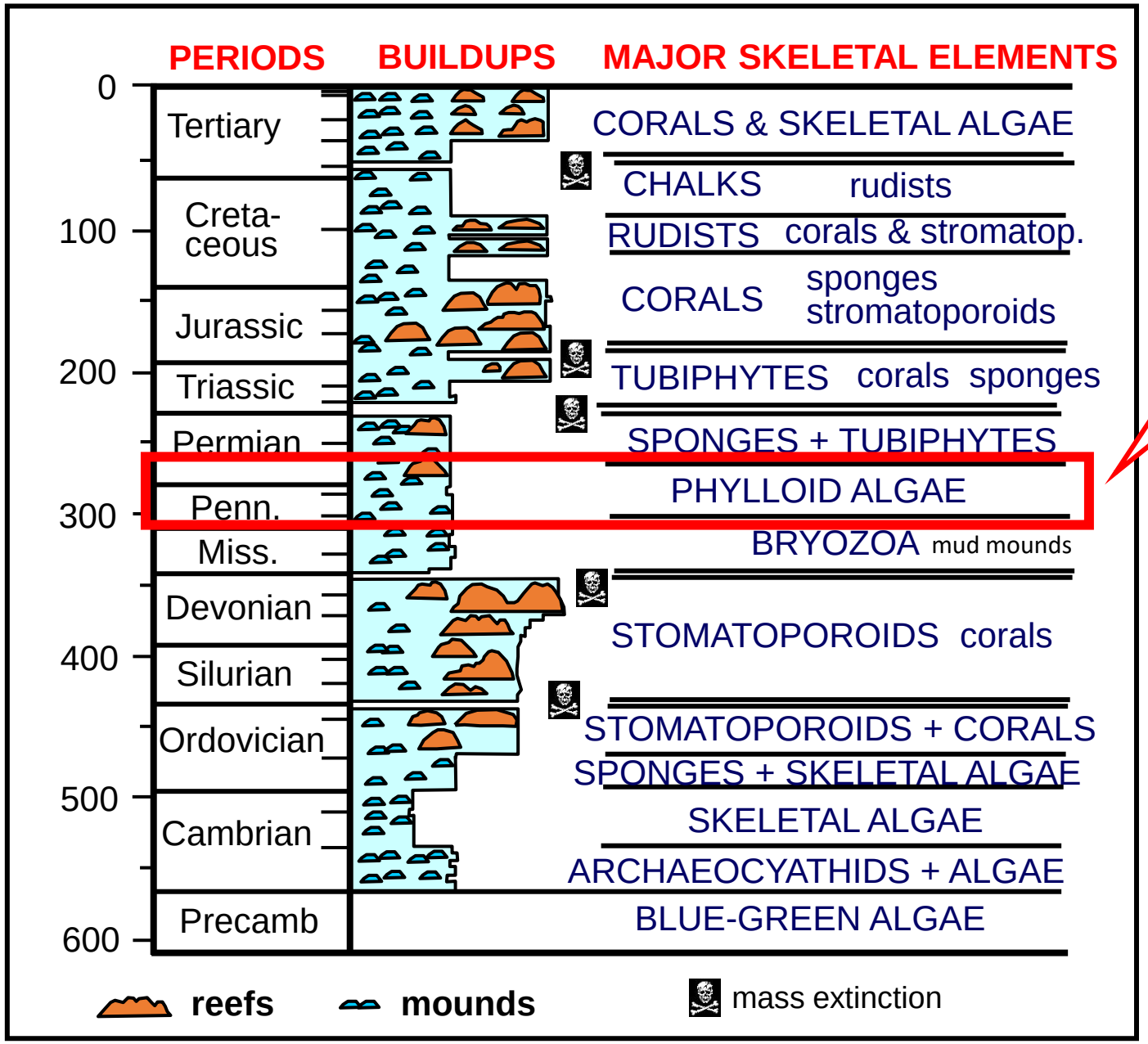
en.wikipedia.org

Horseshoe Atoll is composed mainly of algae (not coral) and certainly does not have an extinct volcano at its center

Geology of the Horseshoe Atoll

- Flora and Fauna
- Thickness / Age / Morphology
- Type logs, and Correlation
- Structure
- Seismic expression
- Depositional Facies

Major reef builders throughout Phanerozoic time

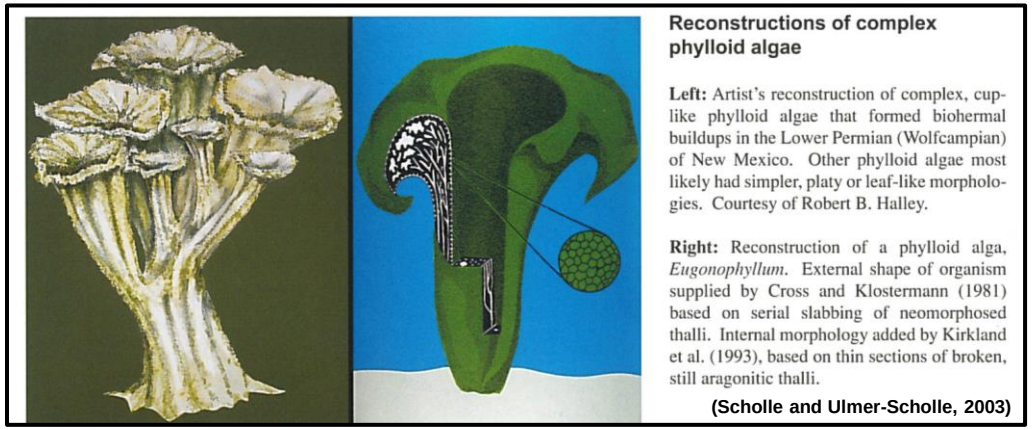


Pennsylvanian – Lower Permian reef systems including the Horseshoe Atoll

(modified from James and Mountjoy, 1983)

Phylloid Algae

- An extinct group of algae of problematic taxonomy – most likely a red algae
- Age range: Late Carboniferous (Pennsylvanian) to late Permian
- Dominant component of Penn – early Permian reefs and shelf limestones (common in Permian Basin)
- Present in middle – late Permian reefs, but much reduced; replaced by sponges and other algal forms
- Platy, “lettuce-like” morphology; mostly **aragonitic** forms (secondary porosity important in subsurface)
- Individual fronds have dark amber color in hand specimen and thin-section
- Major component of Horseshoe Atoll



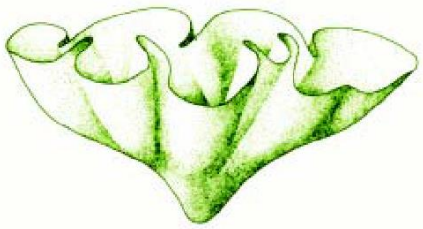
Reconstructions of complex phylloid algae

Left: Artist’s reconstruction of complex, cup-like phylloid algae that formed biohermal buildups in the Lower Permian (Wolfcampian) of New Mexico. Other phylloid algae most likely had simpler, platy or leaf-like morphologies. Courtesy of Robert B. Halley.

Right: Reconstruction of a phylloid alga, *Eugonophyllum*. External shape of organism supplied by Cross and Klostermann (1981) based on serial slabbing of neomorphosed thalli. Internal morphology added by Kirkland et al. (1993), based on thin sections of broken, still aragonitic thalli.

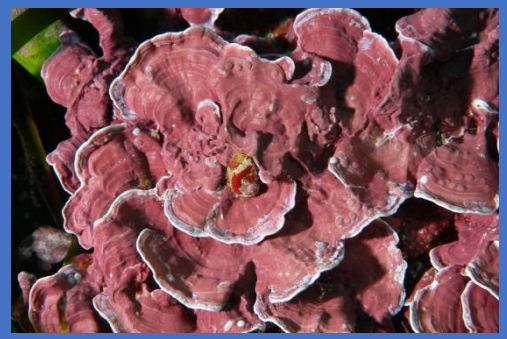
(Scholle and Ulmer-Scholle, 2003)

(N. King, University of Southern Indiana)



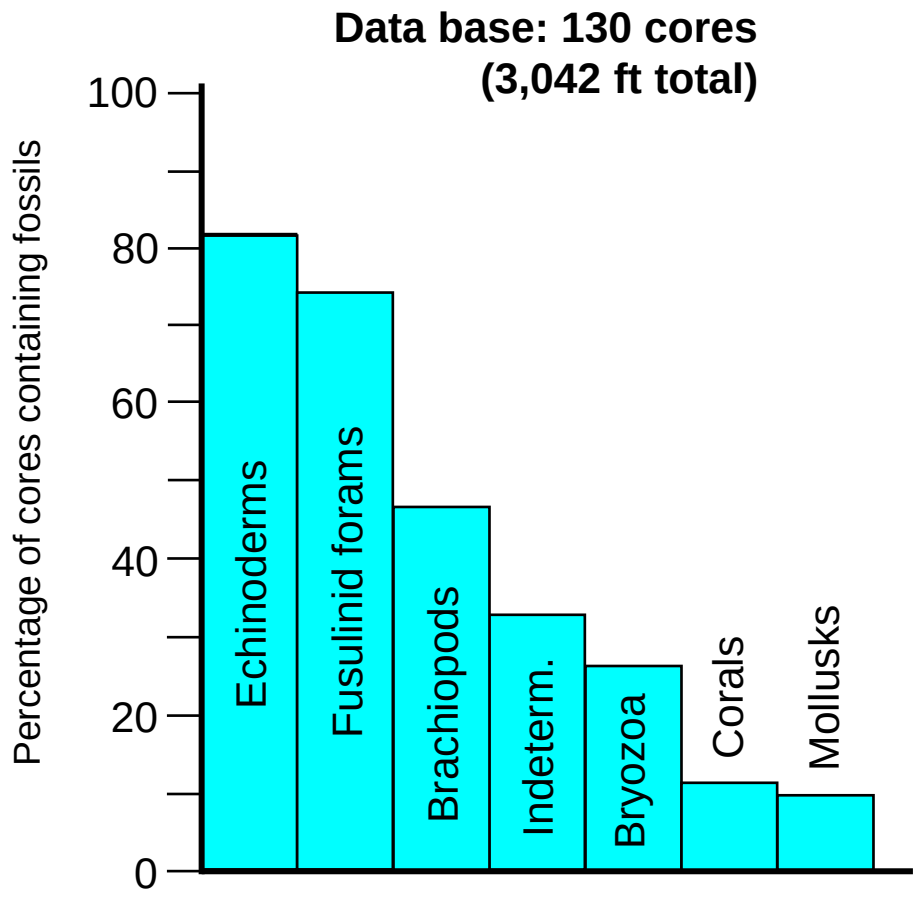
Calcipatera, a phylloid algae from the Wolfcamp of Kansas (Sawin and Wood, 2005)

Modern red algae – analog



(www.thefossilforum.com)

Other major fossil constituents of the Atoll



Note: ooids constitute a large % of grain types in places along outer margin of Atoll

Carbonate rock types

- Grainstone: 46.3%
- Packstone/ Wackestone/ Mudstone 35.2%
- Rudstone (debris flows) 15.9%

97.4% $CaCO_3$

- Shale 2.6%

Main depositional facies

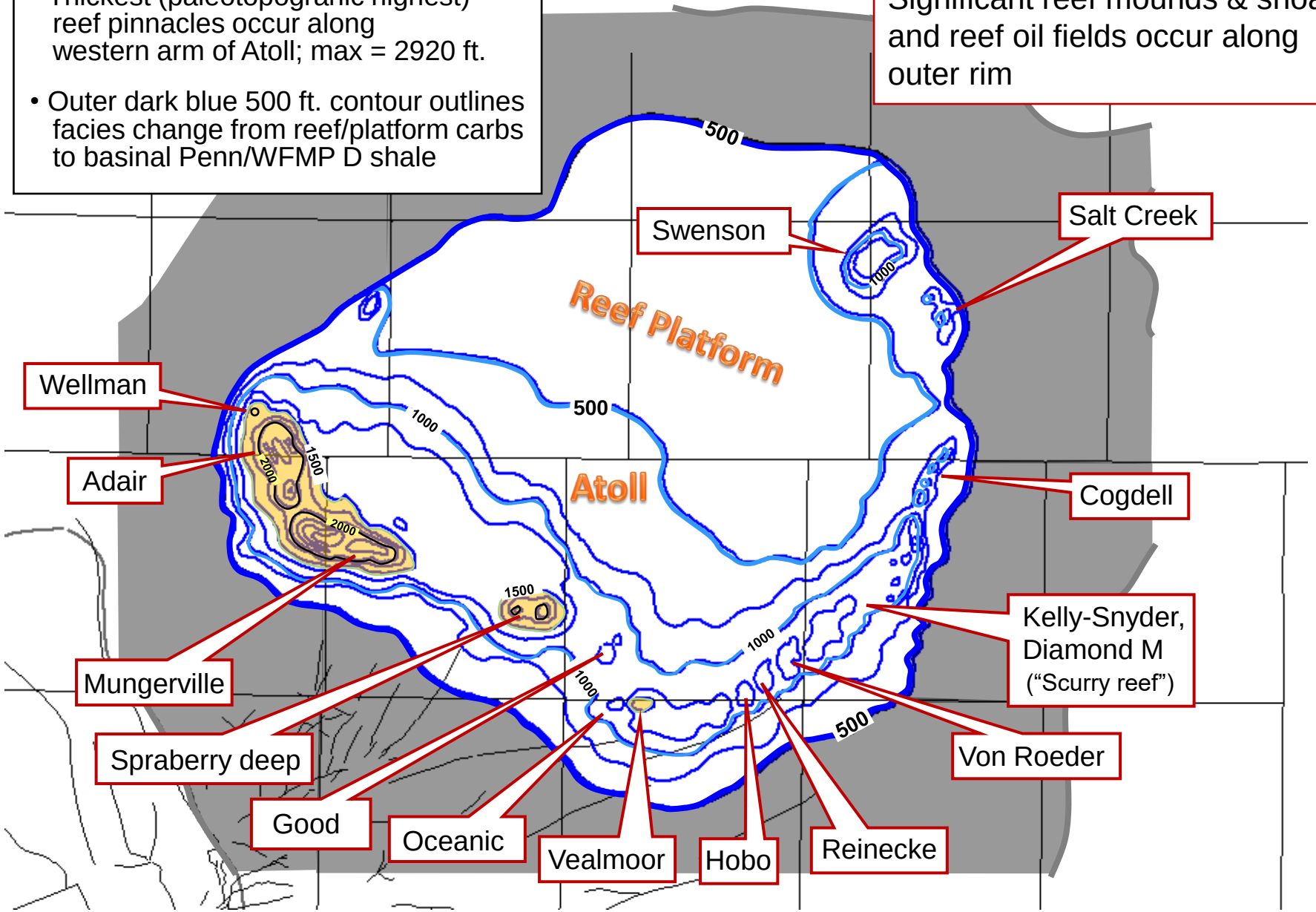
- **Phylloid algal mounds**
- **Sponge-bryozoan mounds**
- **Ooid shoals**
- **Shallow open shelf (crinoid-fusulinid)**
- **Tidal flat**
- **Slumps / Debris flows**

(data from Myers et al., 1956; Bergenback and Terriere, 1953; Schatzinger, 1983)

Atoll Isopach (in feet)

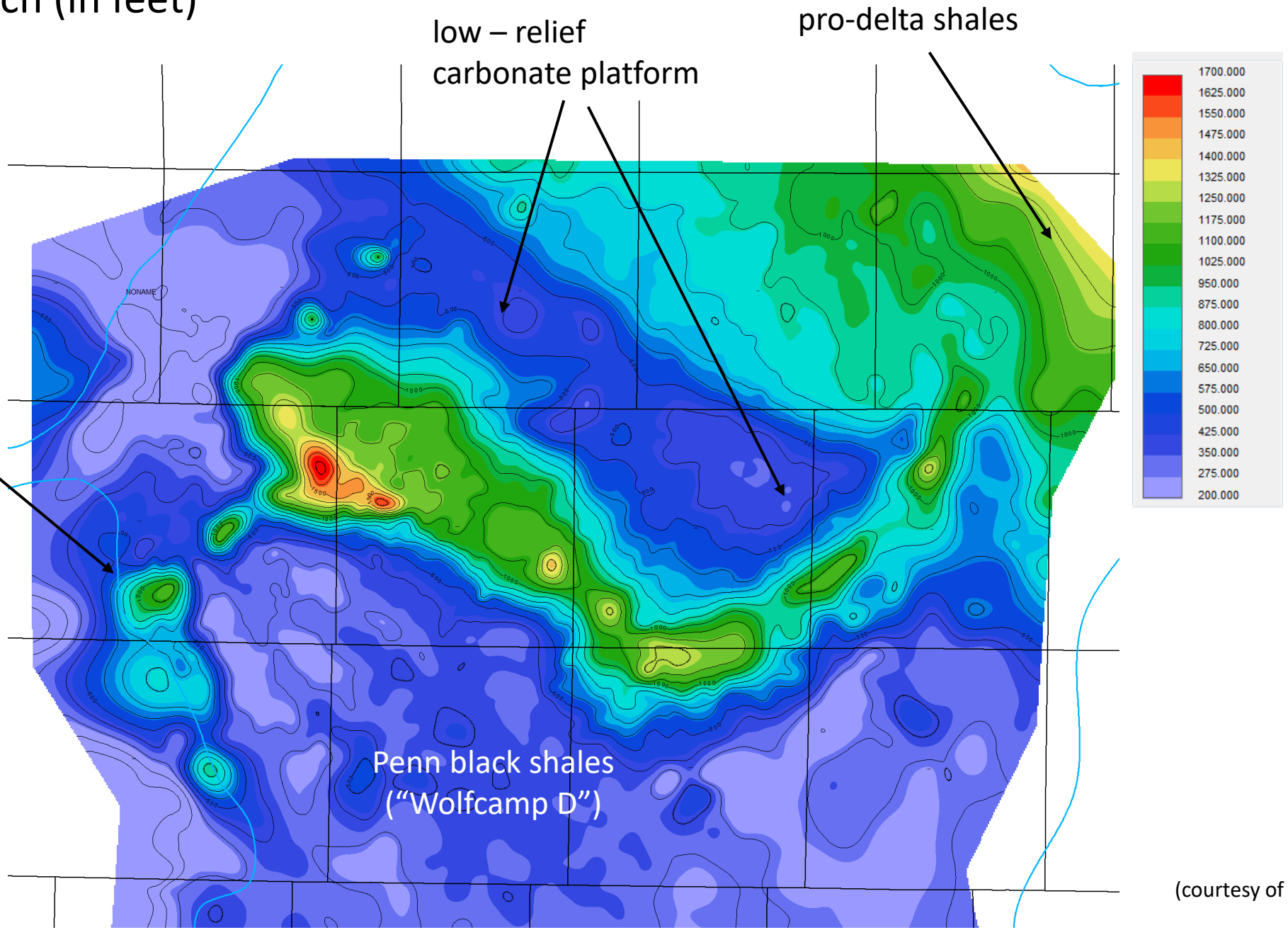
- Thickest (paleotopograhic highest) reef pinnacles occur along western arm of Atoll; max = 2920 ft.
- Outer dark blue 500 ft. contour outlines facies change from reef/platform carbs to basinal Penn/WFMP D shale

Significant reef mounds & shoals and reef oil fields occur along outer rim



(Vest, 1980)

Atoll isopach (in feet)



(courtesy of Tim Reed, Pioneer)

Age and Morphology

of the

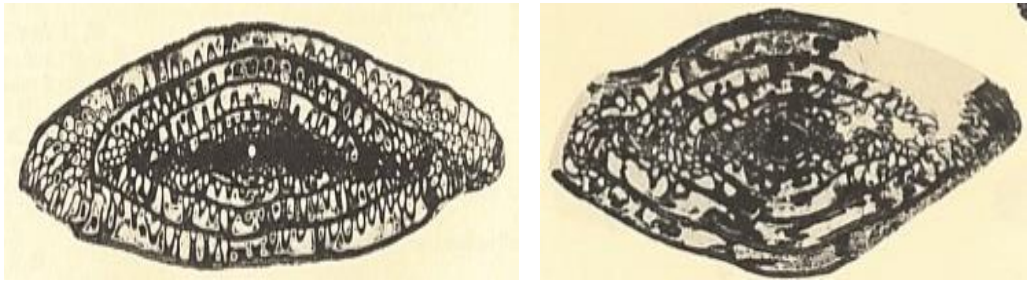
Horseshoe Atoll

Geologic Age of the Atoll

Midland Basin Stratigraphic Correlation Chart

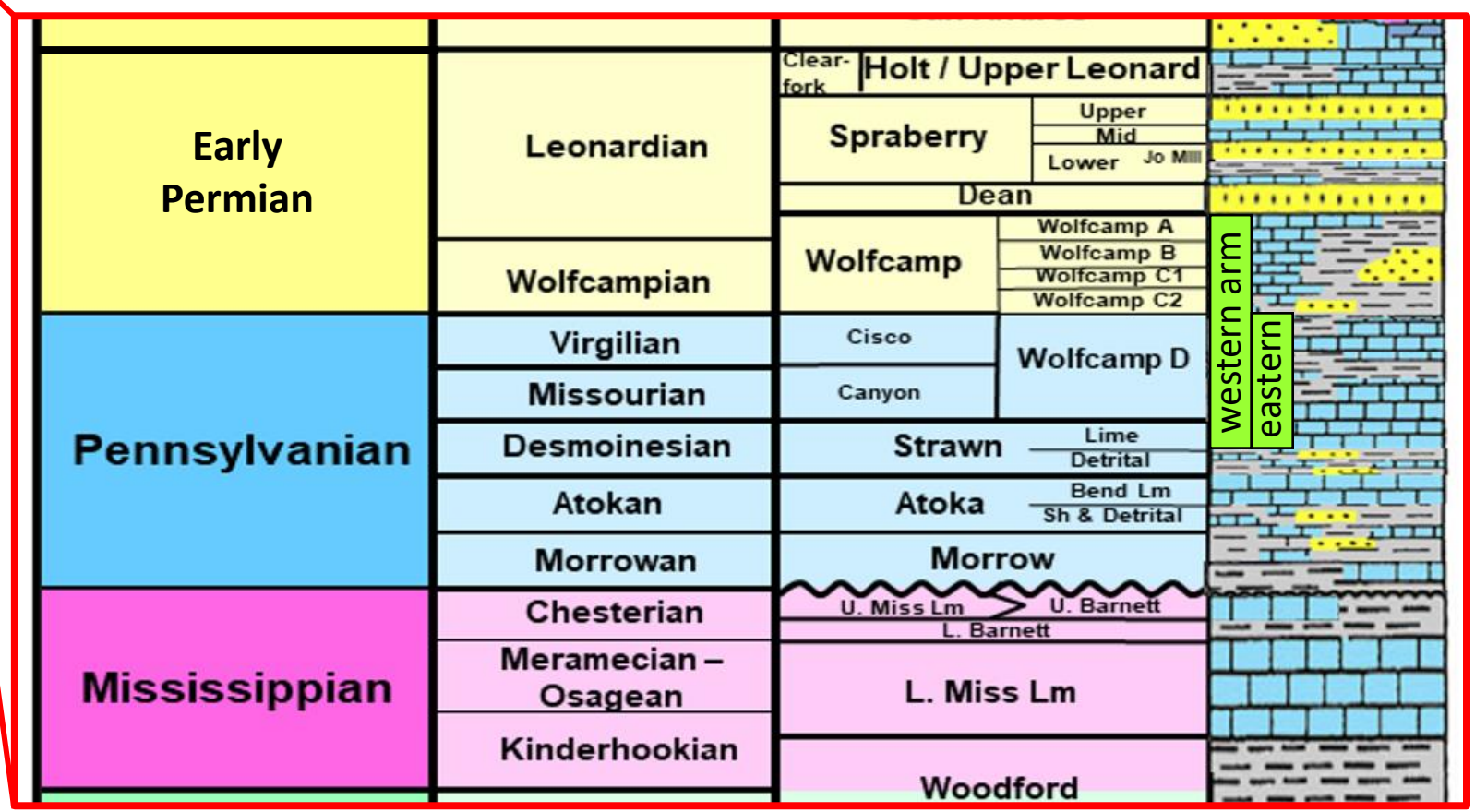
System	Series	Midland Basin Formations	Lithology
Permian	Ochoan	Dewey Lake Rustler Salado	
	Guadalupian	Tansill Yates Seven Rivers Queen Grayburg San Andres	
	Leonardian	Clear-fork: Holt / Upper Leonard Spraberry (Upper, Mid, Lower Jo Mill) Dean	
	Wolfcampian	Wolfcamp (Wolfcamp A, Wolfcamp B, Wolfcamp C1, Wolfcamp C2)	
Pennsylvanian	Virgilian	Cisco Wolfcamp D	
	Missourian	Canyon	
	Desmoinesian	Strawn (Lime Detrital)	
	Atokan	Atoka (Bend Lm Sh & Detrital)	
	Morrowan	Morrow	
Mississippian	Chesterian	U. Miss Lm > U. Barnett L. Barnett	
	Meramecian – Osagean	L. Miss Lm	
	Kinderhookian	Woodford	
Devonian	Middle	Devonian (Thirtyone)	
	Lower		
Silurian	U. Niagaran	Upper Silurian (Wristen)	
	L. Niagaran	Fusselman	
	Alexandrian		
Ordovician	Cincinnatian	Montoya (Sylvan Sh)	
	Mohawkian	Bromide	
	Chazyan	Simpson: Tulip Crk. / McKee Sd.; Mclish / Waddell Sd.; Oil Creek / Connell Sd.; Joins	
	Canadian	Ellenburger	
	Ozarkian		
Cambrian	Upper	Wilberns Bliss / Hickory / Riley	
Precambrian		Precambrian Basement	

Fusulinid foraminifera: main biostratigraphic control

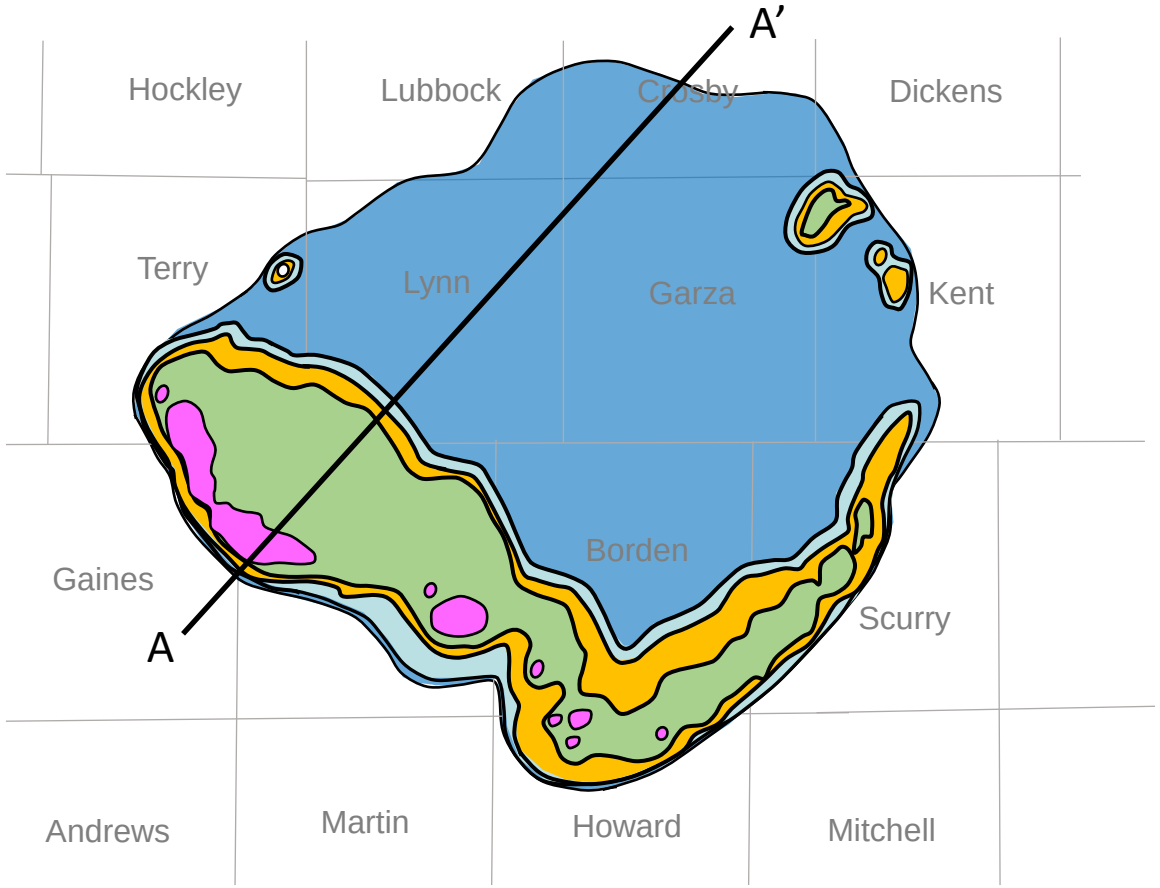


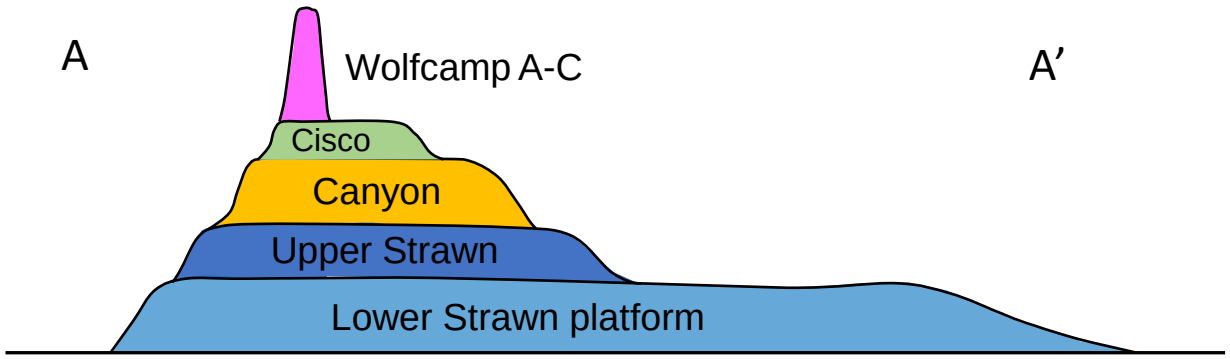
0.5 mm

(Myers et al., 1956)

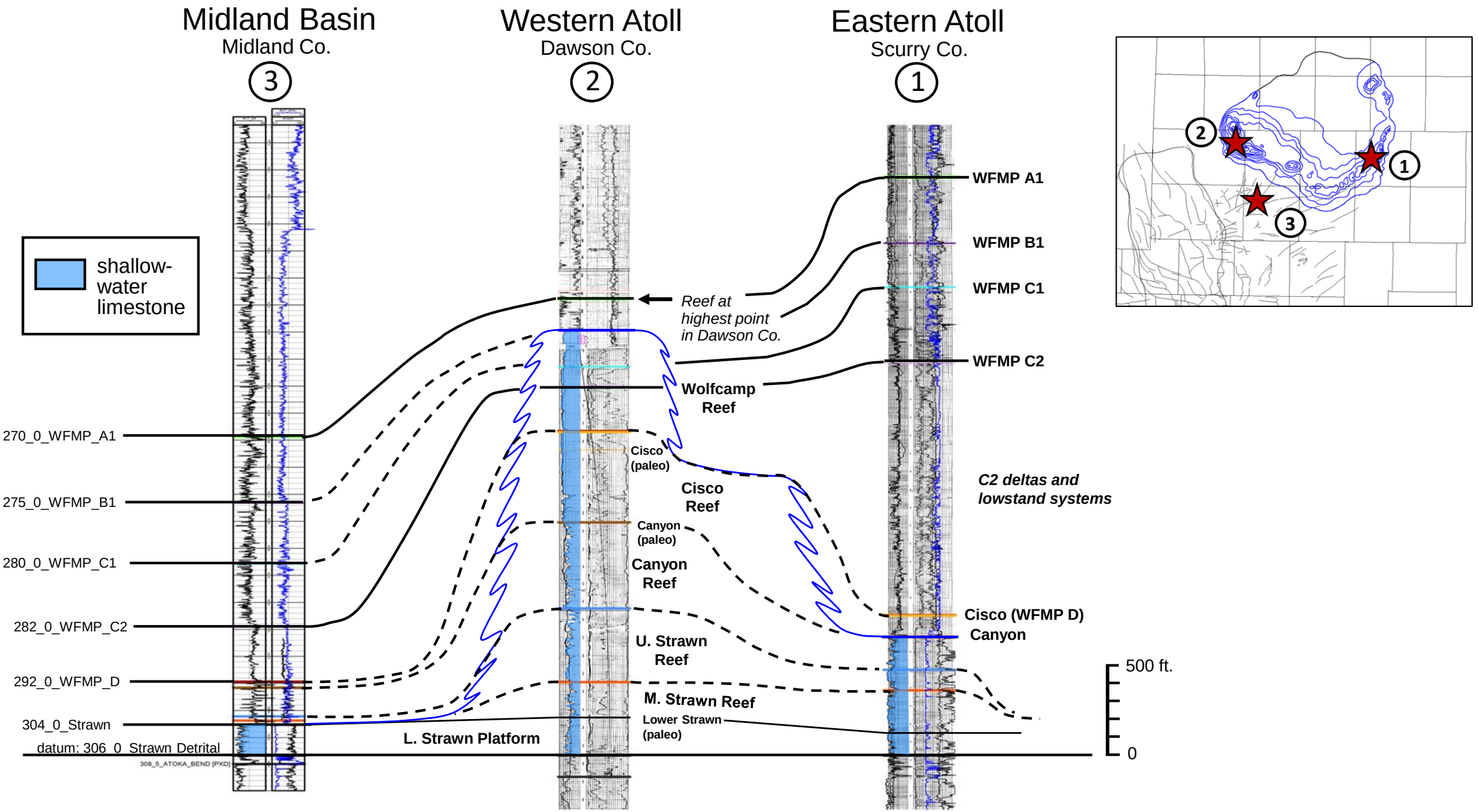


Distribution of sediments show a classic backstepping to aggradational pattern



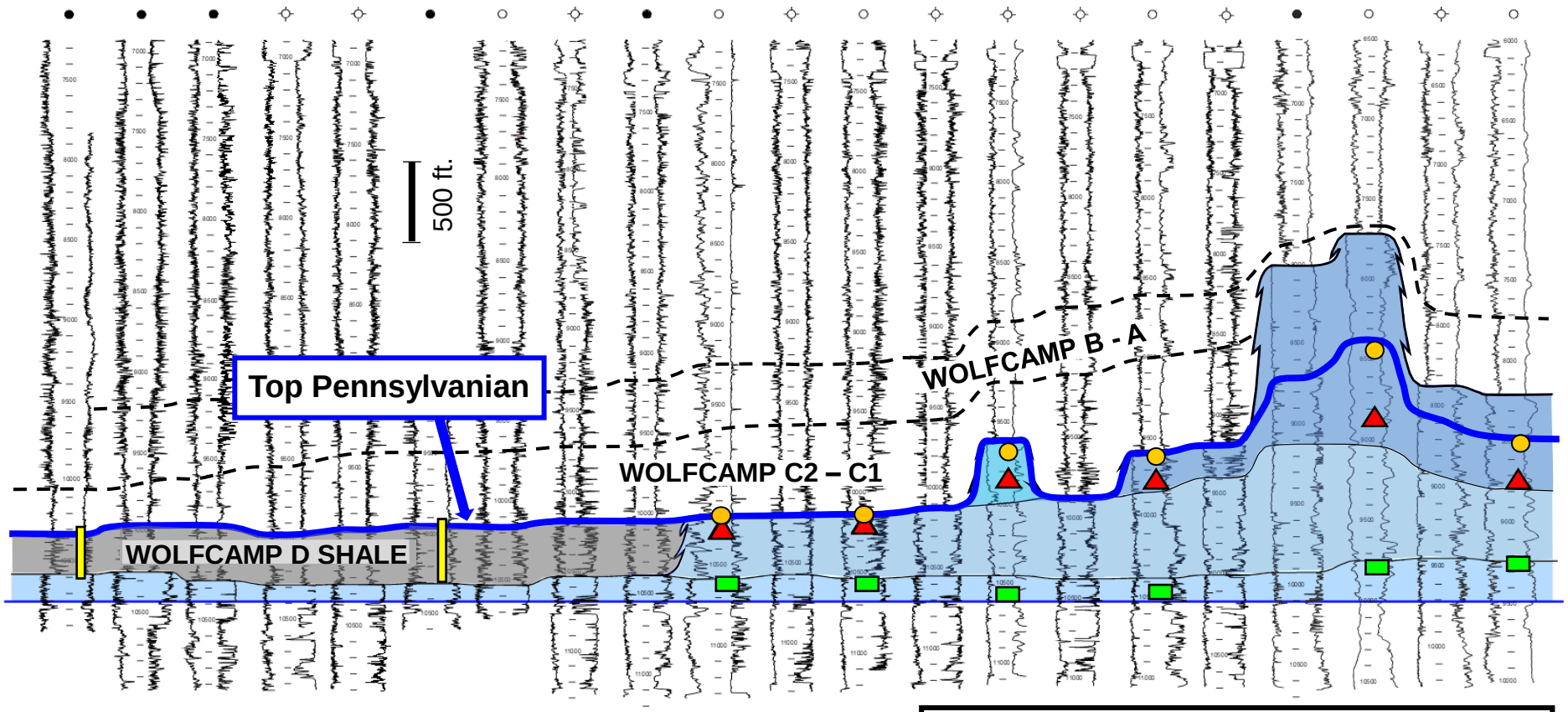


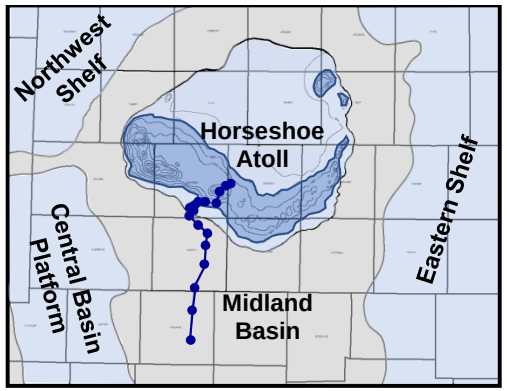
Horseshoe Atoll type logs and correlation



Wire-line log correlation from Midland Basin to Horseshoe Atoll

(datum: base Lower Strawn Lime; no horiz. scale)





Paleo control

- Cisco fusulinids
- Canyon fusulinids
- Lower Strawn fusulinids
- **cored interval**

Observations:

- Shale facies (basin) transition abruptly into carbonate reef facies (Atoll)
- Wolfcamp D shale is Penn. age (correlation to fusulinid-bearing LS)

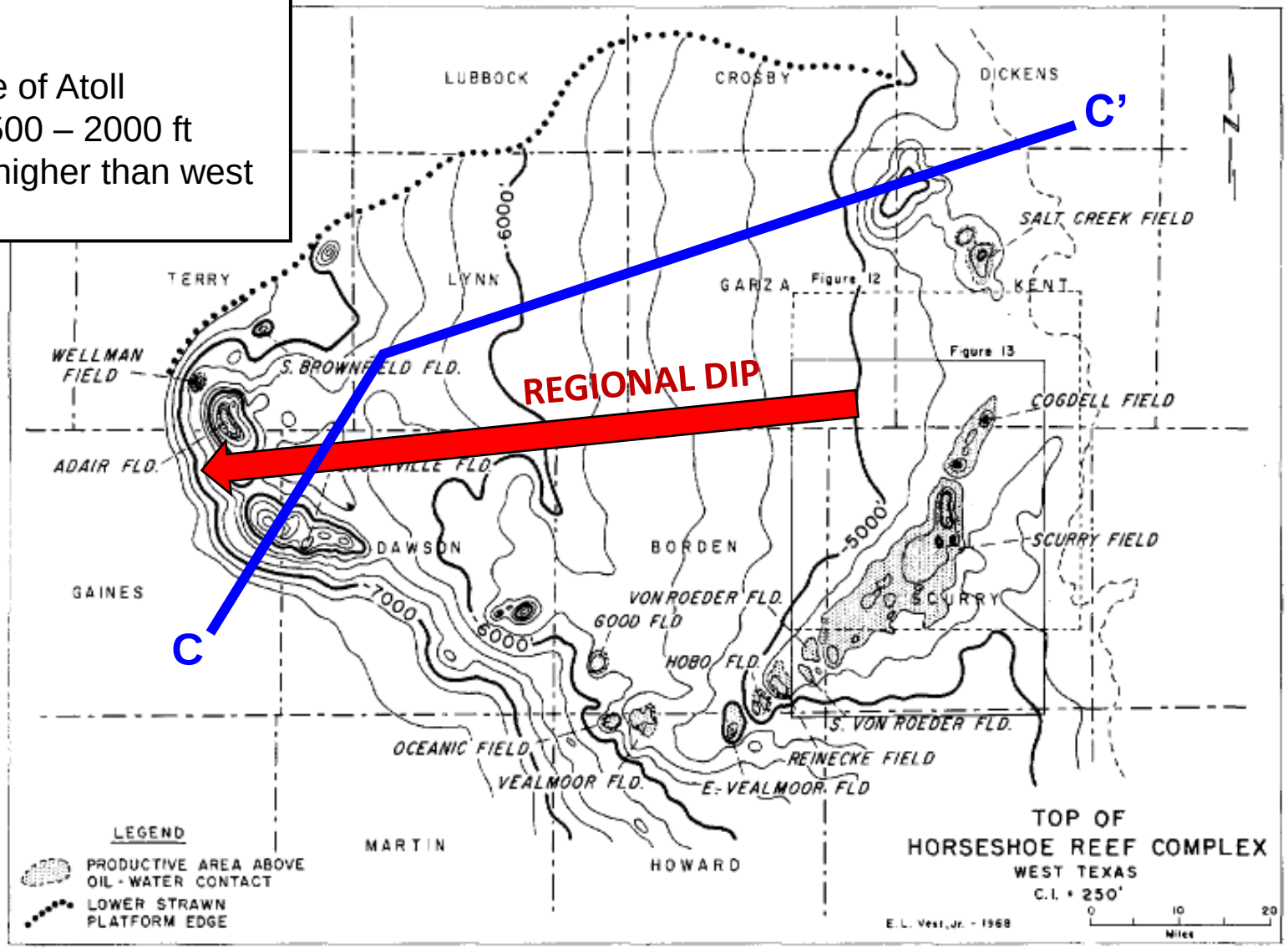
(L. Waite, unpublished, 2015)

Geology of the Horseshoe Atoll

- Flora and Fauna
- Thickness / Age / Morphology
- Type logs, and Correlation
- Structure
- Seismic expression
- Depositional Facies

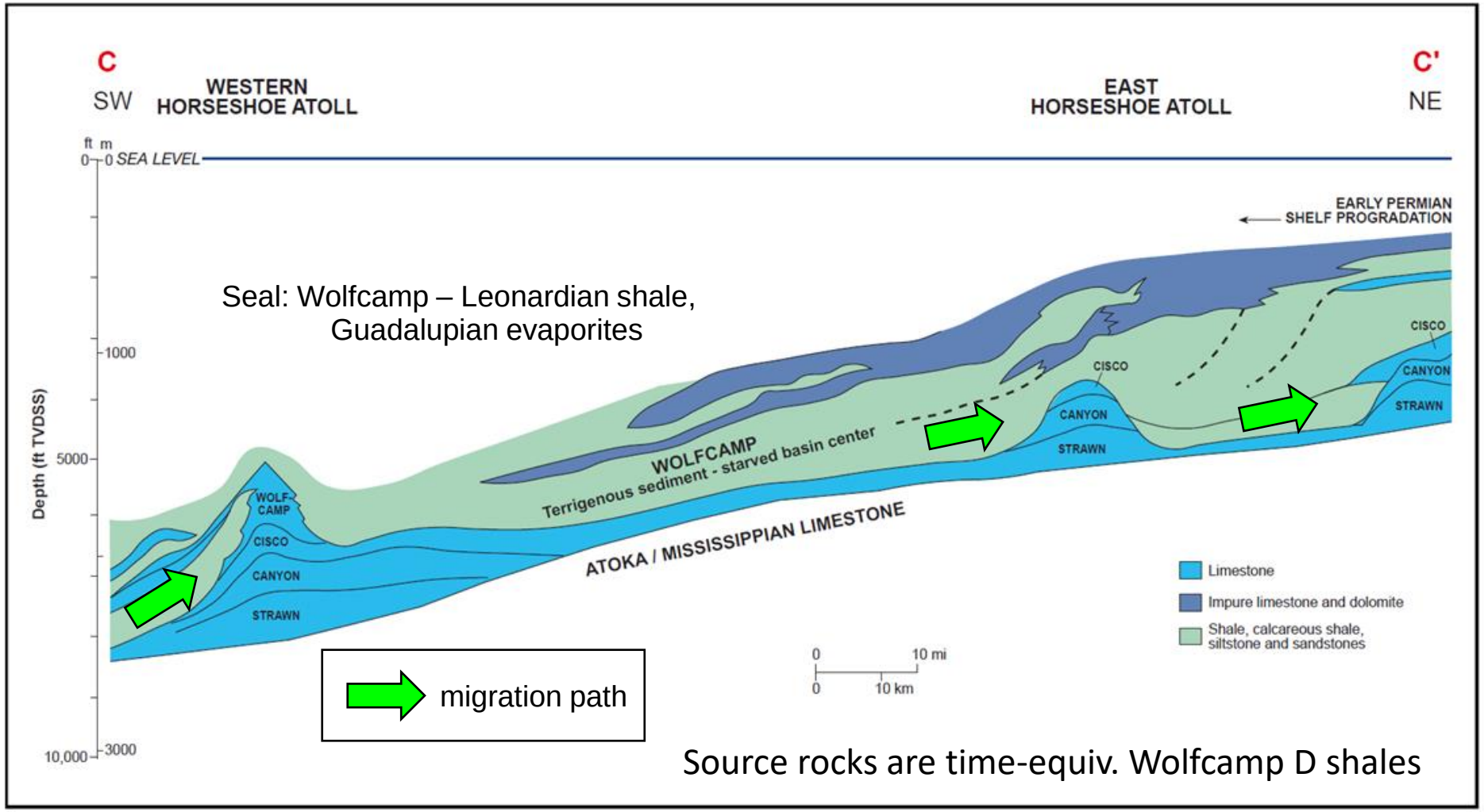
Atoll Top Carbonate Structure

- Top of reef platform currently dipping west, avg. of 0.30° (26 ft/mi)
- Eastern side of Atoll presently 1500 – 2000 ft structurally higher than west



Westward dip of Atoll

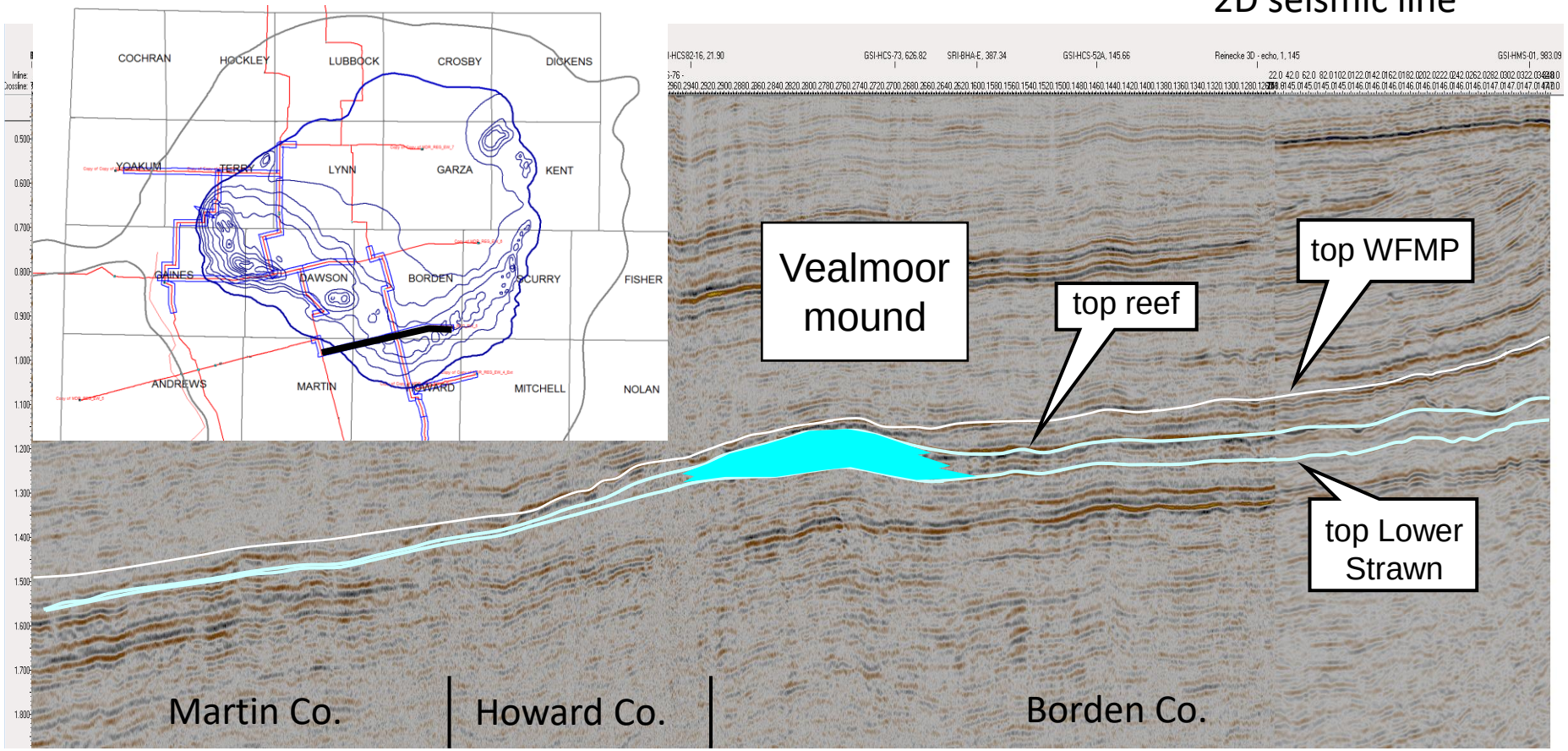
- Greater subsidence in western portion during upper Wolfcamp time; east side drowns during lower Wolfcamp with clastic influx
- Westward structural tilting took place during Late Permian time
- Largest conventional oil accumulations occur in reefal highs along eastern flank (regional migration apex)



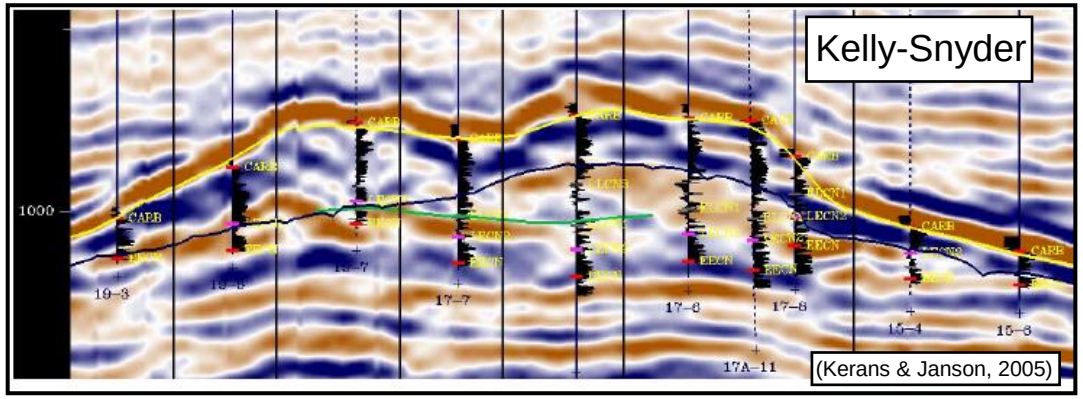
(C&C Reservoirs, 2013)

Seismic expression of Atoll

2D seismic line

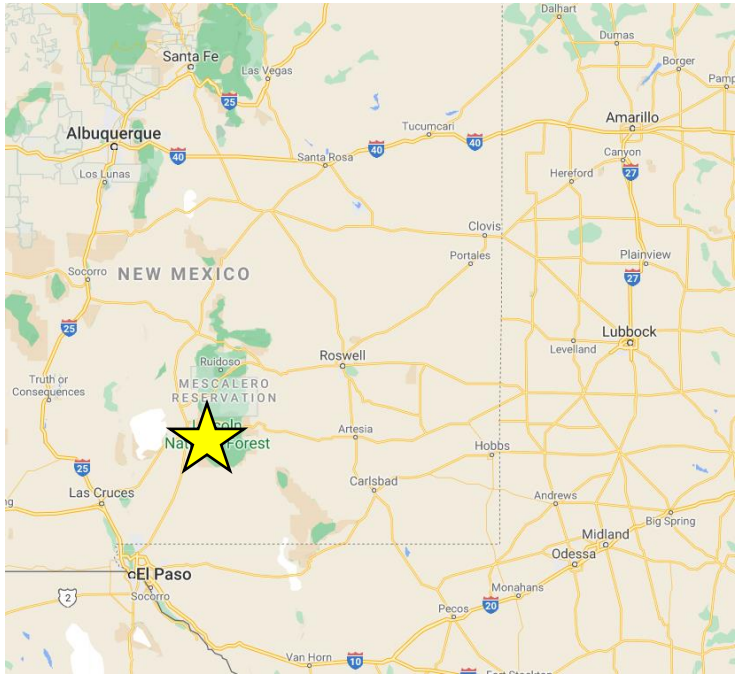


3D seismic



- Mounded geometry w/ flat base
- Pronounced onlap of younger units
- Inflection point in basement (?)
- Complex internal reflectors within mound complex (reefs, debrites)

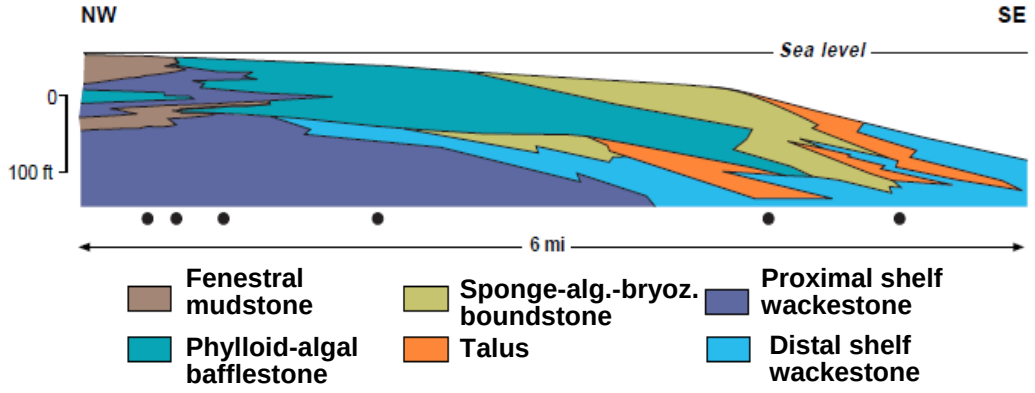
Yucca mound (Cisco reef) complex, Sacramento Mtns., New Mexico



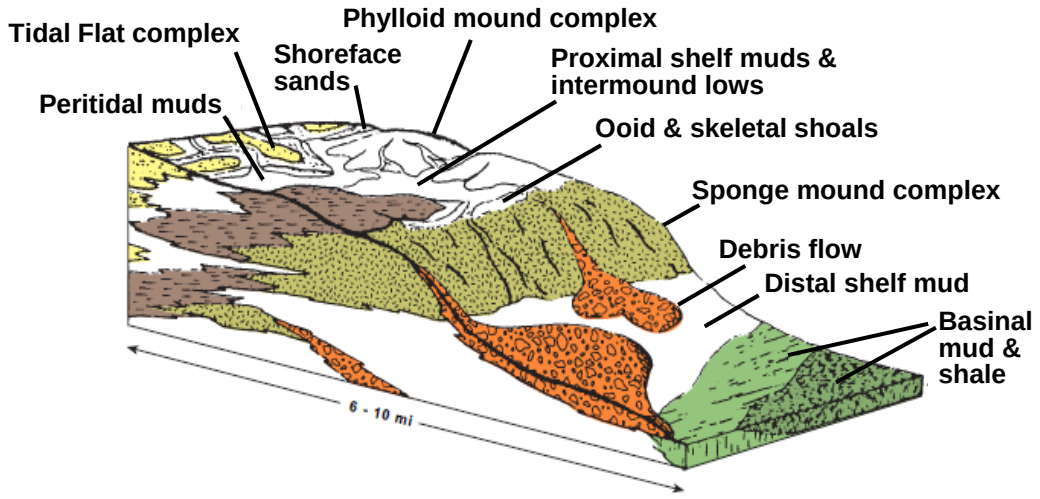
(photo by Matt Cannady, Pioneer Field Trip, May 2015)

Depositional Facies, Kelly-Snyder Field, Scurry Co.

Idealized Facies Tract

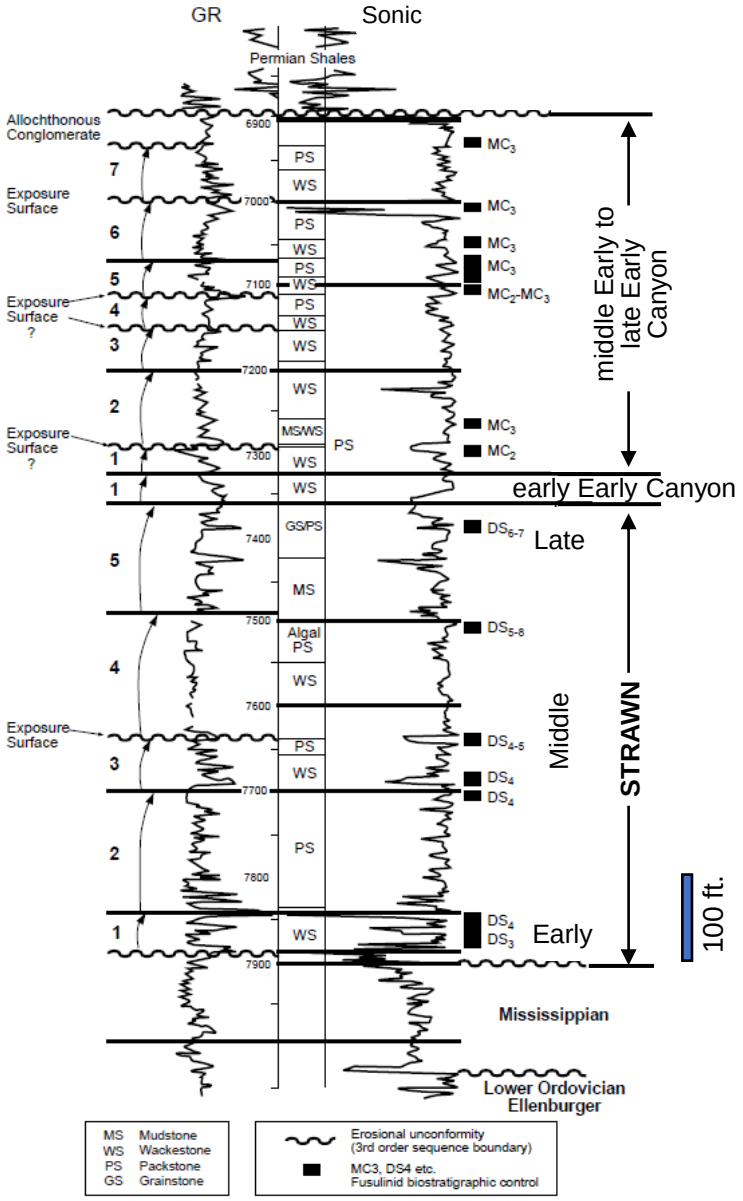


Depositional Model



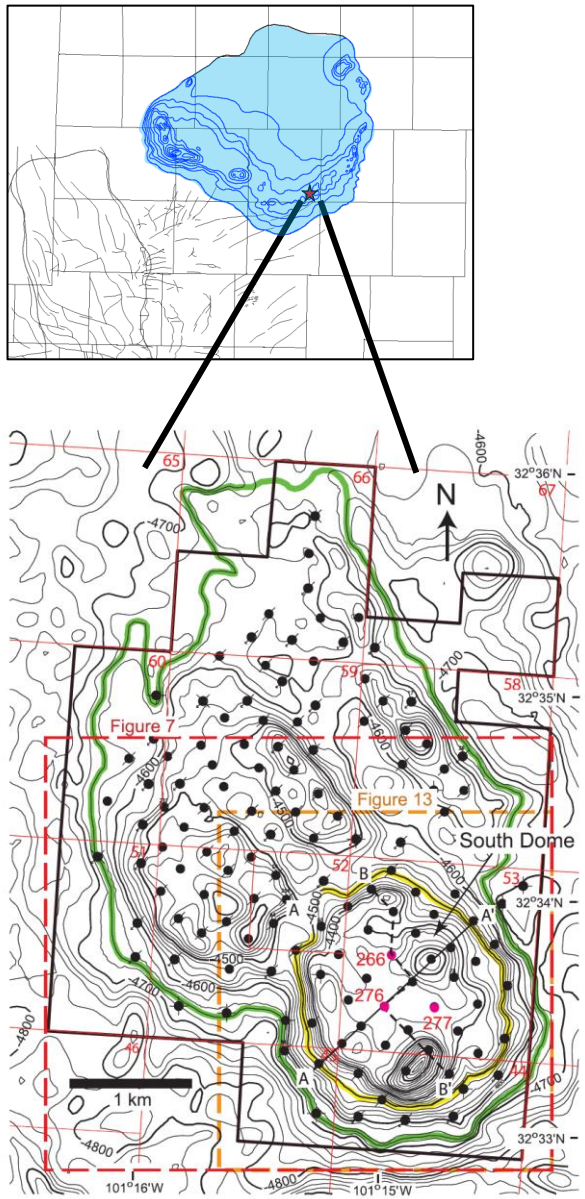
(Schatzinger, 1983)

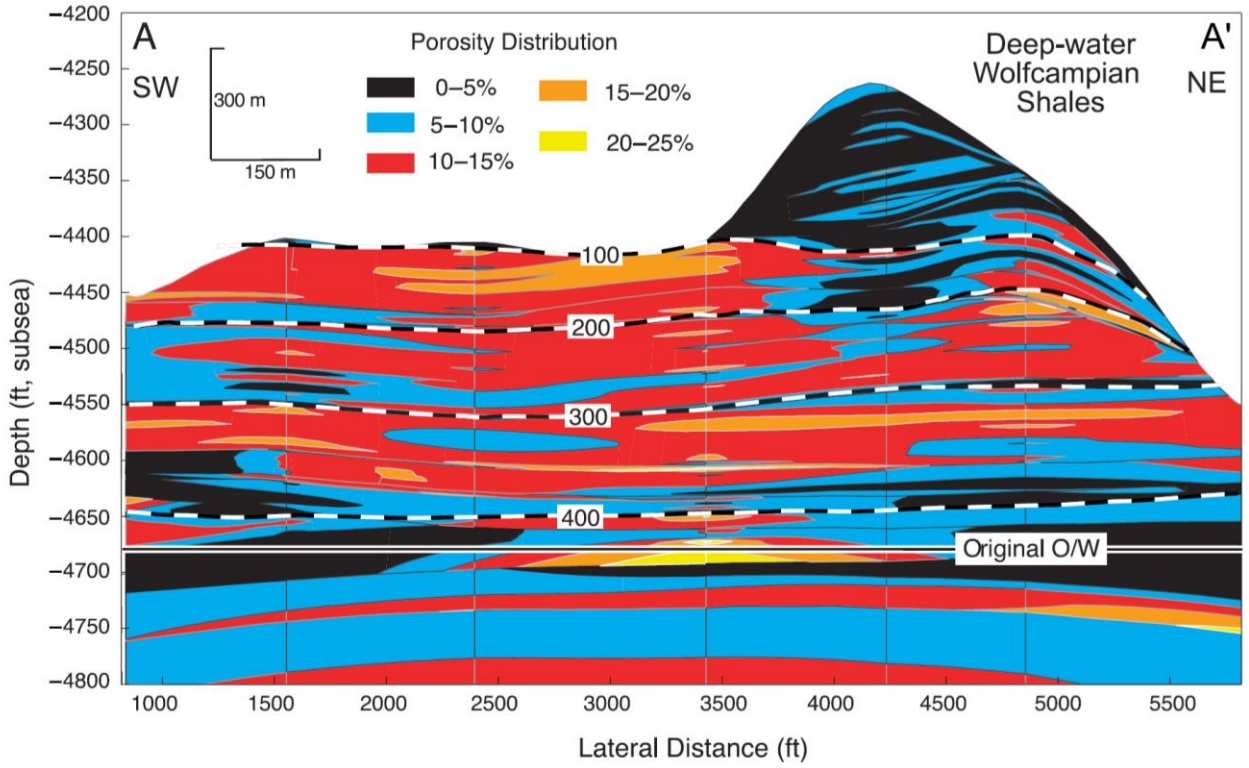
Multiple subtidal cycles capped by exposure surfaces (Pennsylvanian shelf margin cyclothems)

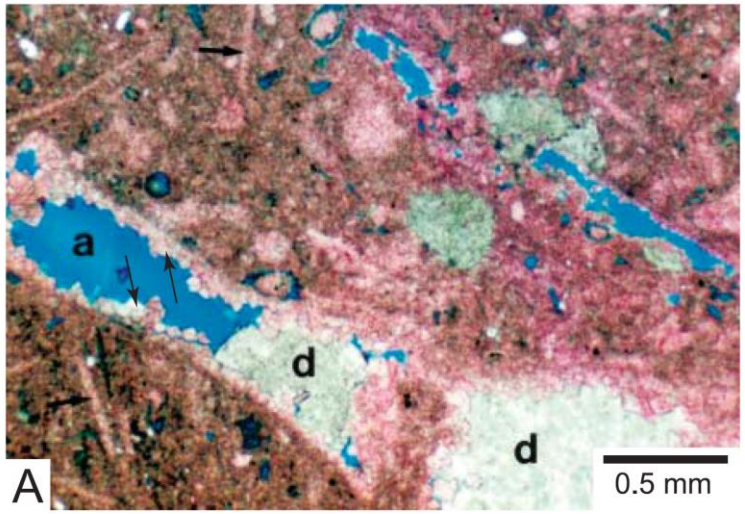


(modified from Waite, 1993)

Reineke Field, Borden Co. (from Saller and Dickson, 2011)







Early preserved leached,moldic, secondary porosity generated during Penn icehouse sea-level changes

Geology of the Horseshoe Atoll

- Flora and Fauna
- Thickness / Age / Morphology
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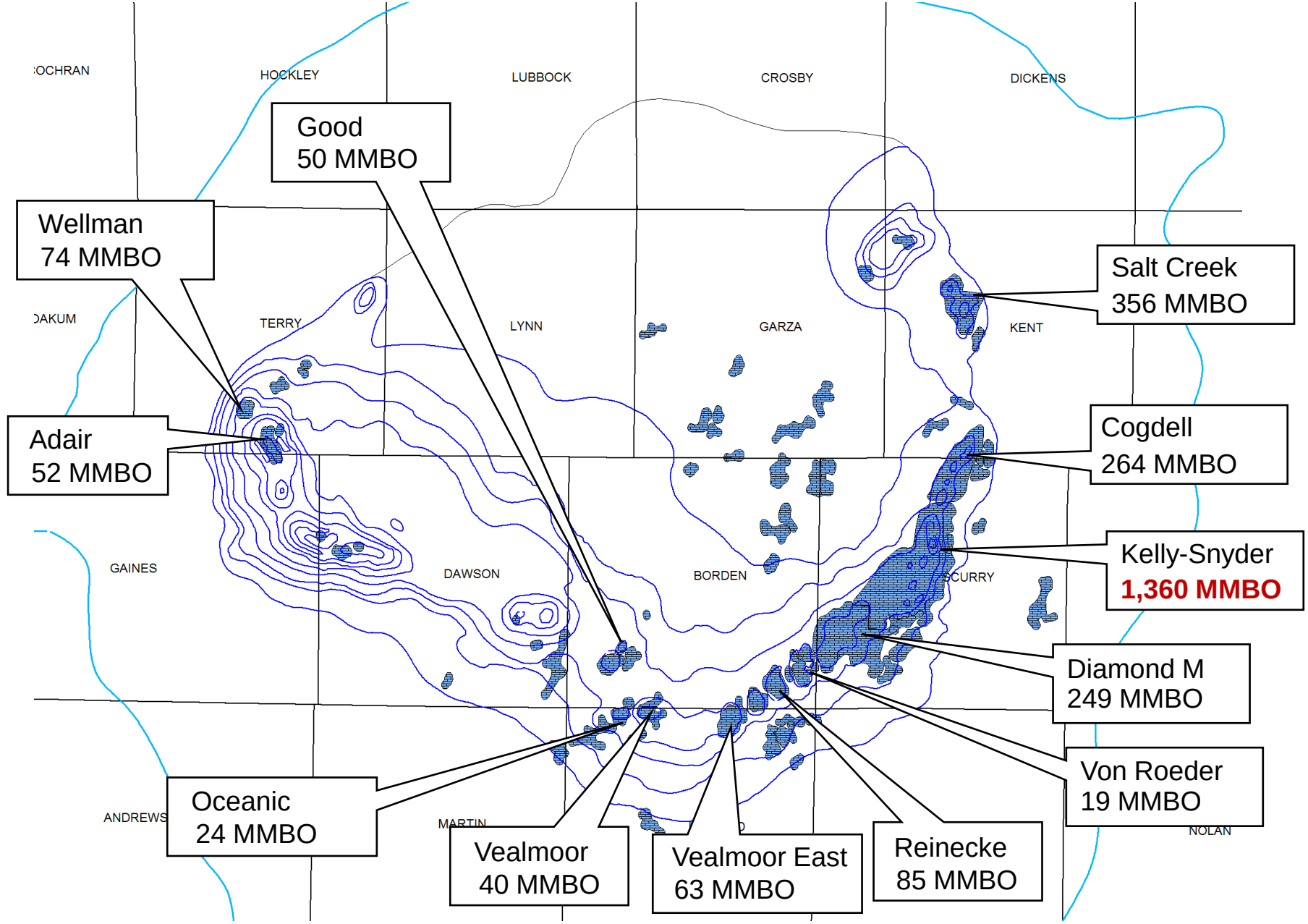
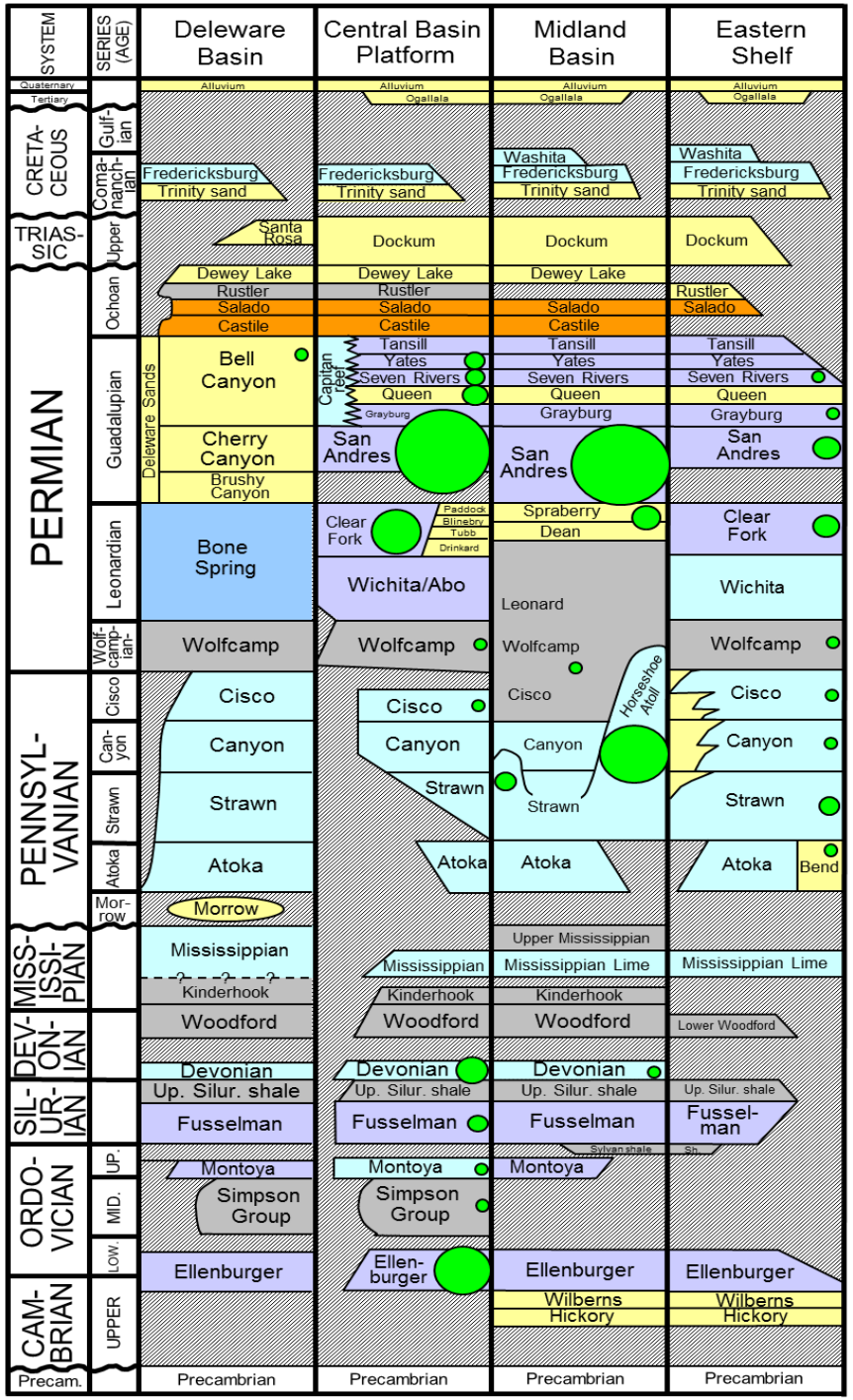
Why it matters:
Conventional reservoirs of the Horseshoe Atoll

Major oil fields of the Horseshoe Atoll (BEG)





Play	State	2000 Production (bbl)	Cumulative Production (bbl)
Pennsylvanian			
Upper Pennsylvanian and Lower Permian slope and basinal sandstone*	Texas	1,802,373	271,448,389
Pennsylvanian and Lower Permian Horseshoe atoll carbonate	Texas	13,686,639	2,699,242,936
Pennsylvanian platform carbonate	Texas	2,076,281	340,469,274
Northwest shelf upper Pennsylvanian carbonate	New Mexico	4,883,971	353,848,173
Northwest shelf Strawn patch reef	New Mexico	1,539,376	70,337,831
Pennsylvanian and Lower Permian reef and bank**	Texas	315,183	92,104,283
Upper Pennsylvanian shelf sandstone#	Texas	426,556	7,264,141
		24,730,379	**3,834,715,027**

(Dutton et al., 2005)

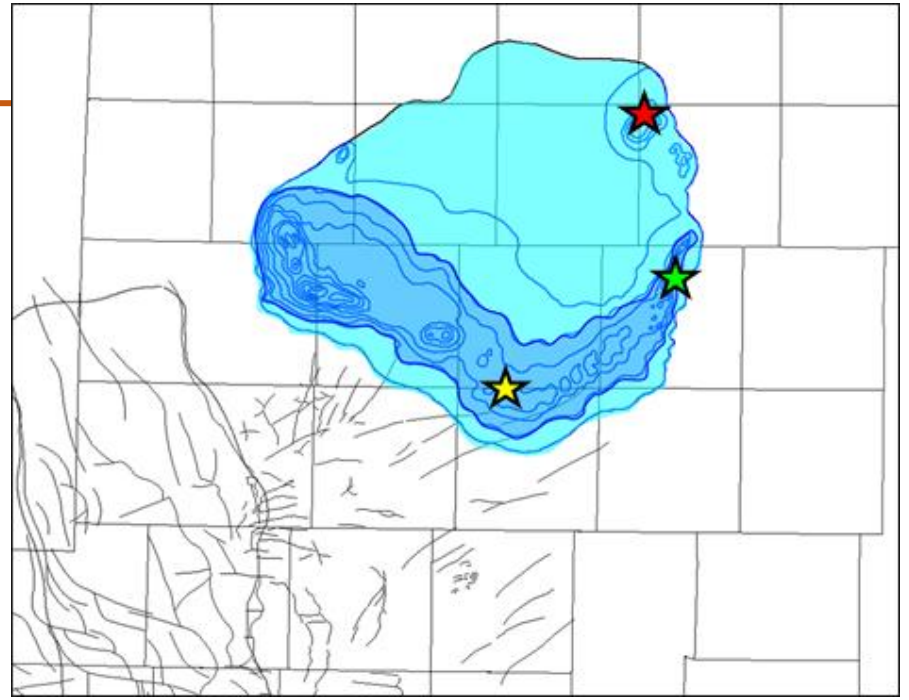
Main Lithologies

- Evaporites
- Dolomite
- Limestone
- Sandstone/siltstone
- Shale
- Missing section

(size of green bubble proportional to amount of conventional oil reserves)

(BEG)

Horseshoe Atoll Exploration History



- First well drilled into feature: Gulf Oil #1-B Swenson Land & Cattle Co., Garza Co. (42-169-00916-0000)
  - Spud: **2/21/1938**; Compl. (P&A) 3/8/1939
  - TD 8104 ft, in Precambrian basement
  - **Encountered large reef pinnacle; as fate would have it, only non-commercial reef structure in entire complex**

- Discovery well: Seaboard #1-B J.C Caldwell, Howard Co. (42-227-00265-0001)
  - Spud: 10/21/1944; Recompl. (oil) **1/13/1948**
  - Discovery well for Vealmoor Field (39 MMBO)

- Reef "boom" begins: Standard of Texas #1 J. Brown 2, (SACROC Unit TR 17A), Scurry Co. (42-415-03097-0000)
  - Spud: 8/10/1948; Compl. (oil) **11/29/1949**; **IPF 532 BO + 0BW**
  - Discovery well for Kelly-Snyder field

- By 1953, all major/giant fields had been discovered; by 1959, the geology & paleontology of the entire reef complex was well-known, described and published

Oil from the Atoll helped fuel the post-WWII expansion of the U.S. economy
"A National Treasure"

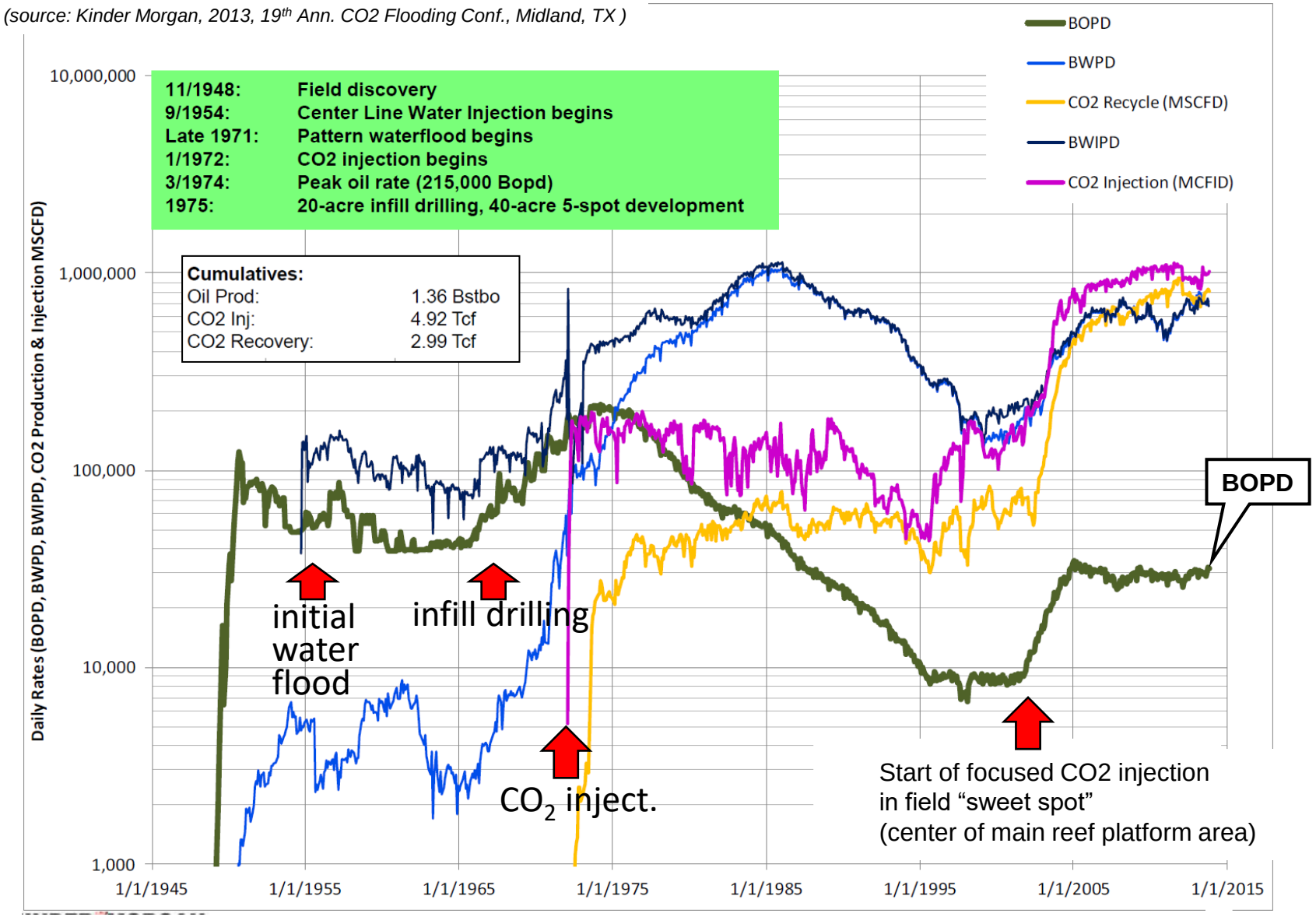
Horseshoe Atoll Reservoir and hydrocarbon properties

Trap type	Combination structural - stratigraphic Depth: 4,000 – 6,000 ft TVD ss
Reservoir thickness	800 ft. (gross, max); 270 ft. (avg. net)
Reservoir spacing	160 ac. (orig.); 20 – 80 ac. (current)
Porosity types	Moldic, vuggy, intercrystalline
Matrix porosity	2.5 – 20+% (avg. 7.6%)
Permeability (air)	0.1 – 51mD (avg. 19.4 mD)
Hydrocarbon type	Light oil (41^{o} API)
Initial GOR	1010 SCF/STB
Gas composition	28.7% C_1; 11.3 % C_2; 58.9 % C_3+; 0.18% S
Reservoir pressure (orig.)	3122 psi @ 4500 ft TVD ss (0.69 psi/ft)
Water saturation (orig.)	21.9 %
Production methods	Primary (1948); Secondary - water injection (1954); Enhanced – CO_2 miscible flood (1972)

(C&C Reservoirs, 2013)

Kelly-Snyder (SACROC Unit) reservoir performance (1949 – 2015)

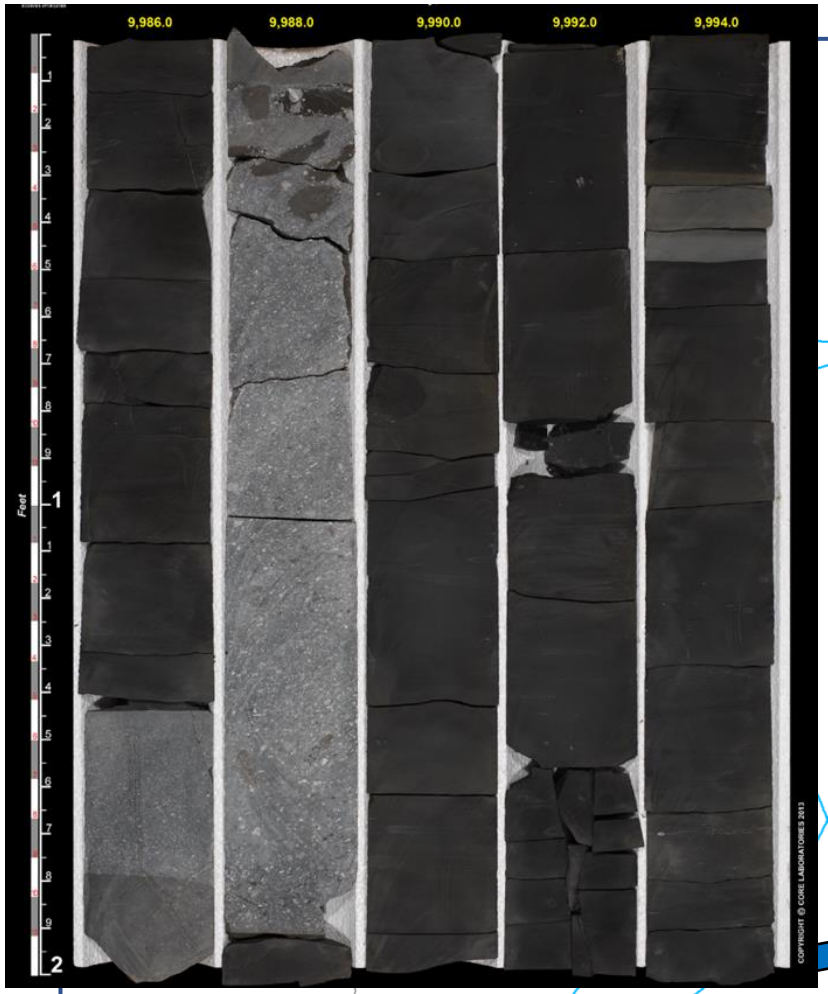
(source: Kinder Morgan, 2013, 19th Ann. CO2 Flooding Conf., Midland, TX)



Now testing horizontal well concept, particularly in flank areas

Why the Horseshoe Atoll matters: Unconventional play perspective

Horseshoe Atoll: Consequences for shale plays



Some impacts of the platform & reef complex:

- Redirection of oceanic circulation patterns within central Midland Basin (Mesoscale estuarine circulation, enhancing organic productivity and development of anoxic bottom waters)
- Limit of Wolfcamp D shale “playground”
- Prolific factory for carbonate mud, grains, and reef fragments for transport into the basin (density, grain, and debris flows); further limits shale play
- Modification of local heat flow patterns / thermal history (insulation effect of thick carbonates)
- Pinnacles on western arm represent conduit for younger Spraberry clastics (sands contain enhanced perm, yielding better vertical and horizontal wells)

Horseshoe Atoll of the Midland Basin: Summary

- The Horseshoe Atoll of the Midland Basin is a large, isolated carbonate reef – shoal complex of Pennsylvanian – early Permian age, composed largely of phylloid algae, together with crinoids, fusulinid forams, sponges, and ooids

- The Atoll, essentially a giant structural-stratigraphic trap has produced over 2.6 BBO, containing several significant oil fields (some >100 MMBO) and one supergiant (1.3 BBO)

    - Light, sweet crude oils from 4,000 – 6,000 ft TVD ss

    - Internal stratigraphy and development of early secondary porosity in reservoirs controlled by multiple high-frequency, high-amplitude glacio-eustatic sea-level cycles/exposure events during Pennsylvanian - early Permian icehouse

    - Abundance of data makes it a good reservoir analog for other Penn – early Penn buildups (e.g., Carboniferous – early Permian reef fields of N. Caspian Basin)

- Importance of Atoll has “resurfaced” during shale revolution because it limits the distribution of organic-rich facies within the Penn-Wolfcamp section in the northern Midland Basin (reef platform and slope to basinal debris flows)

Wish to drill a little deeper on this topic ?

Oil Fields of Pennsylvanian-Permian Horseshoe Atoll, West Texas[1]

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Abstract The Horseshoe atoll is an arcuate chain of reef mounds, composed of mixed types of bioclastic debris, that accumulated in the interior part of the developing intracratonic Midland basin during late Paleozoic time. The atoll is 175 mi (282 km) long and locally is almost 3,000 ft (914 m) thick. The reef environment was established early in basin history and retained because of the limited amount of terrigenous clastic material transported to the basin interior. About 1,800 ft (549 m) of limestone accumulated during the Pennsylvanian, and primary dips commonly as great as 8° developed along the margins of the atoll. During earliest Permian time the reef was restricted to the southwest side of the complex, where more than 1,100 ft (335 m) of additional limestone accumulated before death of the reef. Reef mounds were buried by prograding Early Permian terrigenous clastic material which progressively covered the atoll from northeast to southwest. Westward tilting of the reef complex after burial elevated Pennsylvanian mounds along the east side of the atoll 1,400 ft (428 m) higher than Permian mounds along the southwest side. The updip migration of hydrocarbons was uninhibited in the lower part of the reef, and most mounds

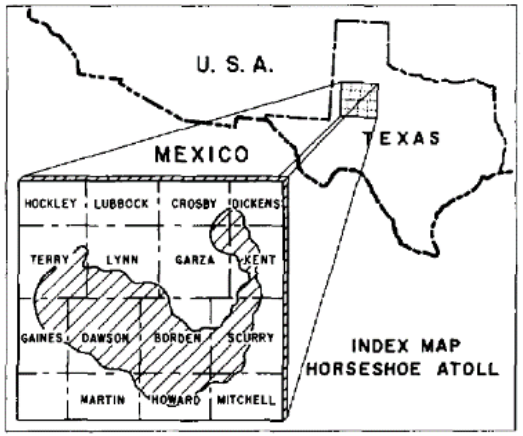

FIG. 1.—Index map showing location of Horseshoe atoll, West Texas.

Vest, E.L., Jr., 1970, AAPG Memoir 14 (Geology of Giant Petroleum Fields). p. 185 – 200.

Available on AAPG Datapages

UTD PBRL has a comprehensive library of published papers on the Atoll

QUESTIONS?