Integrated Approaches to Modeling Late Paleozoic Petroleum Reservoirs in the Greater Midcontinent, U.S.

1:00-3:00 pm -- 3. Sequence stratigraphy and reservoir architecture of late Paleozoic strata in the Midcontinent.

Short Course

AAPG - Southwest Section

December 8, 2008 -- Abilene, Texas

December 9, 2008 -- Ft. Worth, Texas

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Take Home Points of Short Course

- Basement structures and distal tectonic events affecting them are important in defining location and properties of reservoirs.
- Process-based field, outcrop, and Recent analogs provide more appropriate, accurate interpolation of reservoir properties.
- Late Paleozoic reservoirs are dominated by depositional fabric selective diagenesis.
- Establishing petrofacies and pore types is essential to accurate calculations of water saturations, volumetrics, ROIP, establishing permeability correlations and predicting fluid flow.
- Infill locations and new pays within oil and gas fields remain significant targets for IOR in mature regions; requires comprehensive, integrated approach.
- Re-exploration and exploitation of mature producing areas can be substantially benefited by access to and mining of large data sets – digital and electronic data – logs, production, core/samples and descriptions, *in an integrated and quantitative manner.*

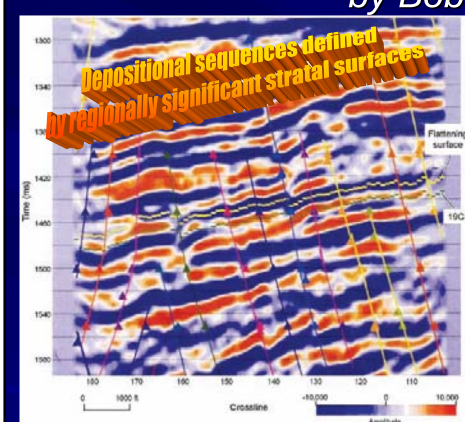
1:00-3:00 pm – Part 3. Sequence stratigraphy and reservoir architecture of late Paleozoic strata in the Midcontinent

- Overview:
  - Depositional sequences and lithofacies distribution defined by interaction of complex geological processes
    - *Eustacy, subsidence/compaction, sediment supply and accumulation, erosion, antecedent topography, climate*
  - Ooid shoals and grainstones – lithofacies and diagenetic variants that dominate late Paleozoic reservoirs in the greater Midcontinent
  - Siliciclastics (deltas and incised valleys)
  - Phylloid algal mounds/reefs

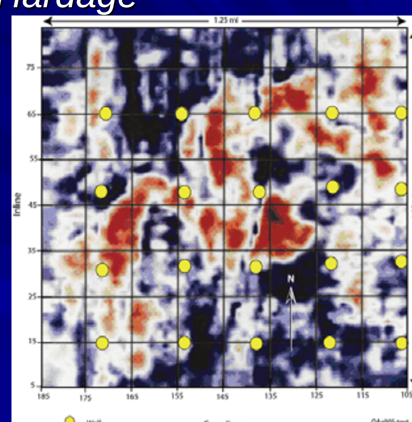
Nov. '08 AAPG Explorer Article

3-D changed patterns for drilling

by Bob Hardage



- Vertical section though 3-D seismic volume showing VSP-defined position of stratal surface used for time slicing across 19c reservoir.
- Analysis requires good stratigraphic control…



- Reflection amplitude across stratal surface corresponding to the VSP-defined position of the 19C unit
- 40-acre well pattern with no existing well making optimum contact with the 19C reservoir channel

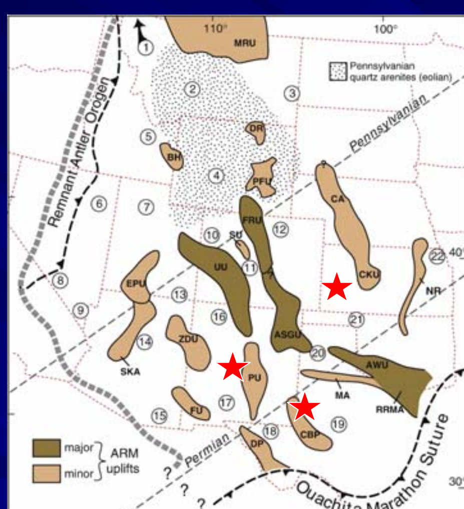
Re-exploration, Exploitation

- New technology and new resolution, *e.g., resolving significant surfaces (temporally distinct)*
- Old technology and new way of examining, e.g., *surfaces, lithofacies, pore types*
- Access to new data (3D seismic, logging tools, tests)
- New concepts, unconventional, e.g., *geological, geophysical, geochemical, geostatistical, etc.*
- Profile of an independent in the Texas oil and gas industry from BEG Survey:
  - **2.3 employees**

  Areas of expertise
  - **Engineering** – Almost every company had an engineer.
  - **Land and Legal** – Almost every company had someone who specialized in land deals and who took care of legal matters.
  - **Geologist** – Surprisingly, many small independents did not have a geologist on staff but used geological consultants.
  - **Geophysicist** – A geophysicist was rarely found on a company's staff. Small independents relied almost totally on seismic contractors and consultants for their geophysical support and advice

  Hardage (Nov. 2008, AAPG Explorer)

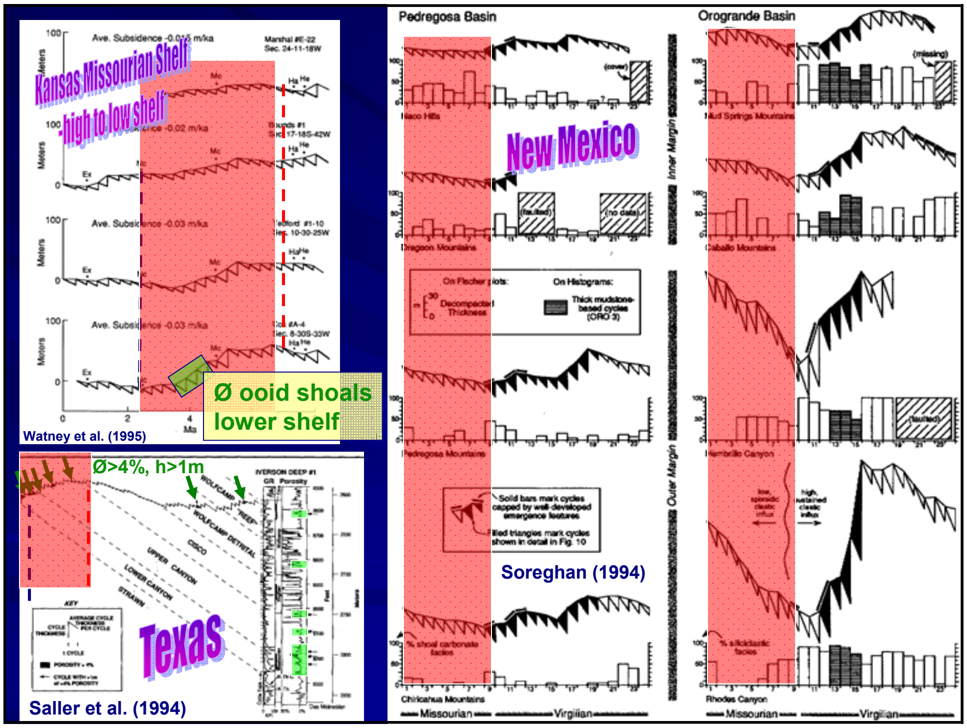
Varying subsidence coupled with eustacy define depositional sequences -- sediment accommodation, strata geometry, sedimentologic "fidelity", lithofacies, and diagenesis

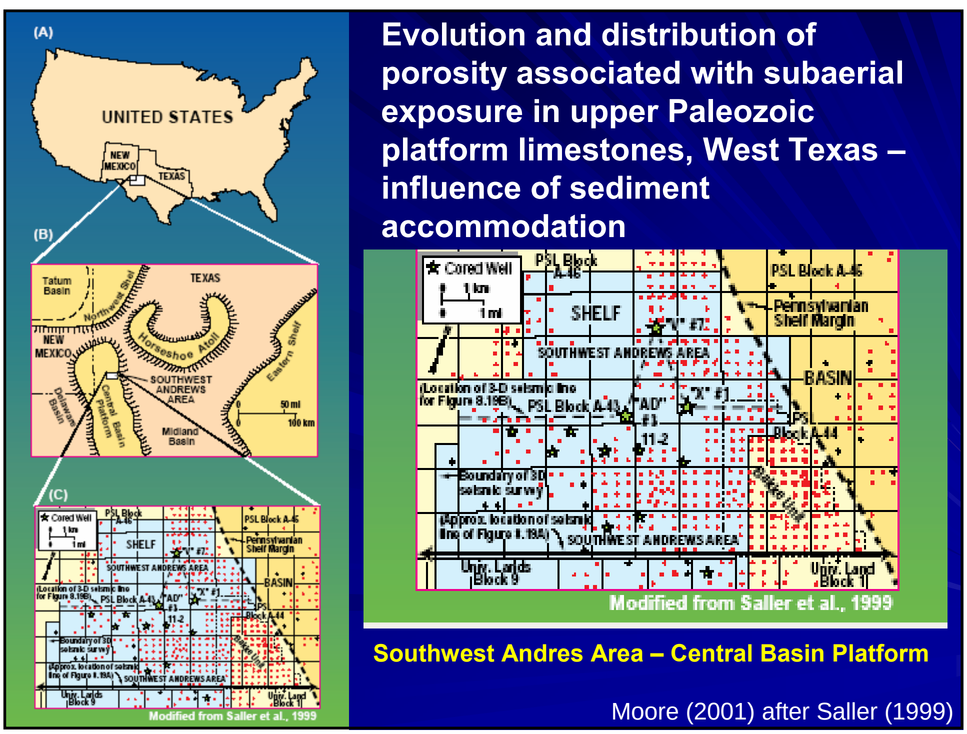


Map from Soreghan et al. (2008)

Measure of sediment accommodation

1-D Fisher plots ***(Sediment accommodation plots)***


Kansas Missourian Shelf
-high to low shelf
Ø ooid shoals
lower shelf
Watney et al. (1995)
Ø>4%, h>1m
Texas
Saller et al. (1994)
Pedregosa Basin
Orogrande Basin
New Mexico
Soreghan (1994)
Missourian
Virgilian

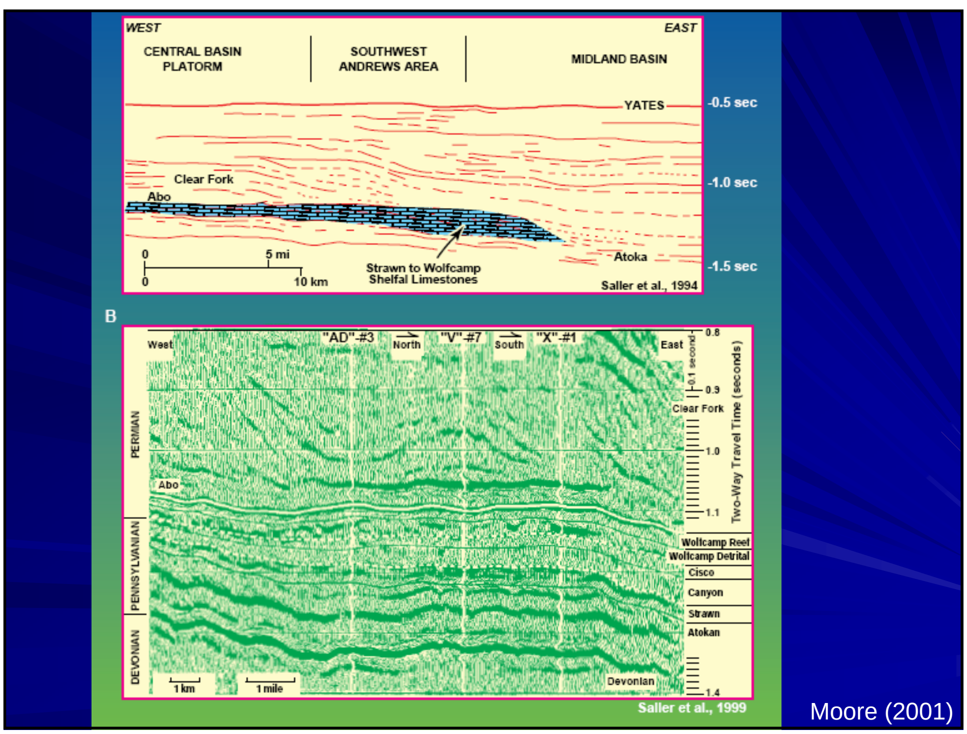

(A)
UNITED STATES
NEW MEXICO
TEXAS
(B)
(C)
Evolution and distribution of porosity associated with subaerial exposure in upper Paleozoic platform limestones, West Texas – influence of sediment accommodation
Cored Well
SHELF
SOUTHWEST ANDREWS AREA
BASIN
Modified from Saller et al., 1999
Southwest Andres Area – Central Basin Platform
Moore (2001) after Saller (1999)

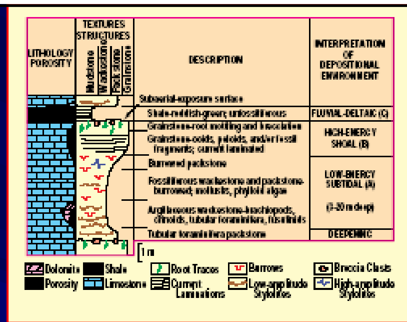
SERIES	MID-CONTINENT STAGE	WEST TEXAS FORMATION
LOWER PERMIAN	Leonardian	Leonard
	Wolfcampian	Wolfcamp
	286 ± 6 m.y.	
PENNSYLVANIAN	Virgilian	Cisco
	Missourian	Canyon
	296 ± 5 m.y.	
	Des Moinesian	Strawn
	Atokan	Atoka
	Morrowan	Morrow
	320 ± 10 m.y.	

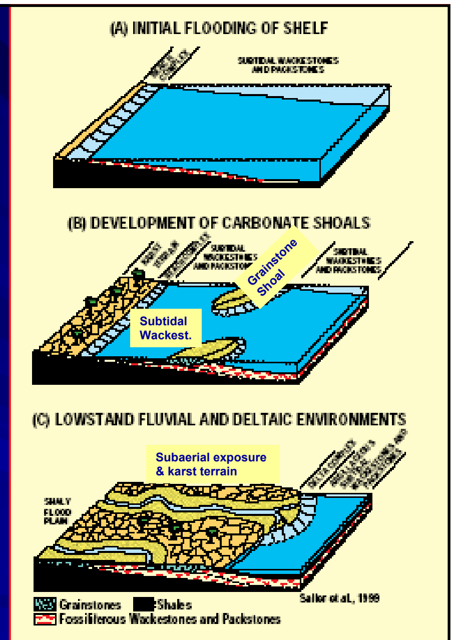
Southwest Andrews Area

- Central Basin Platform
- Strawn-Wolfcamp carbonates

Moore (2001) after Saller (1999)

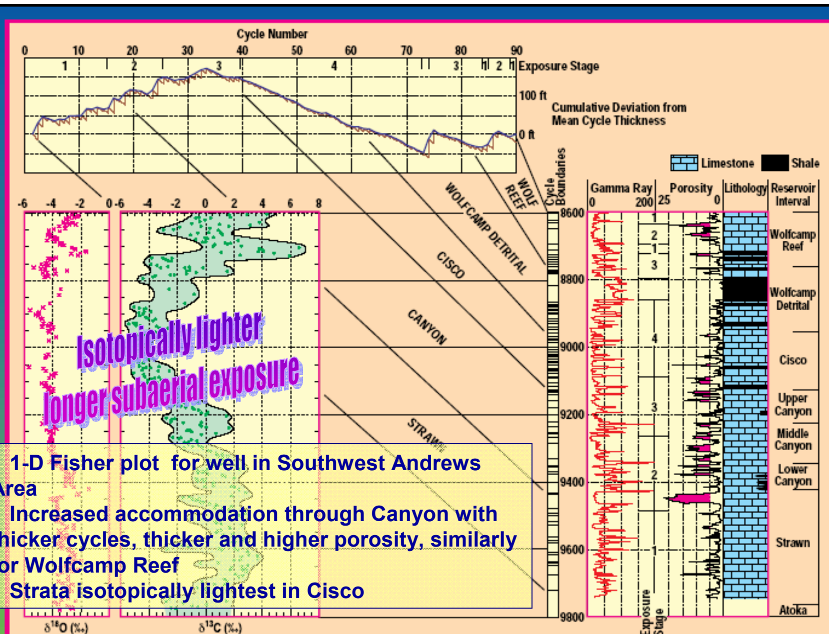






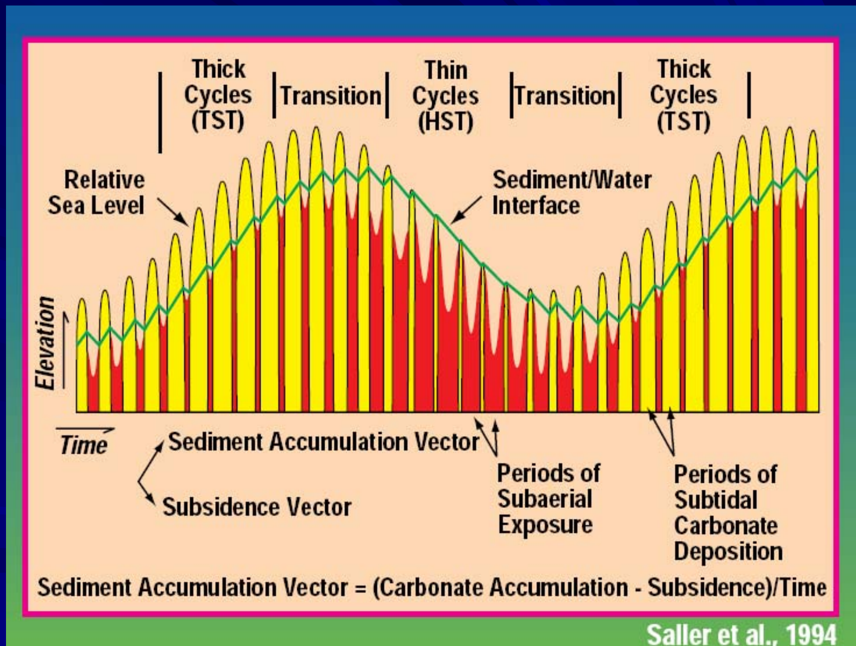
- Porosity is stratified, occurring in 1 to 6-m-thick intervals in the upper part of cycles that were subaerially exposed.
- Many cycles that were subaerially exposed now lack porosity.
- Present subsurface porosity in this field preferentially occurs in thick grainstones, phylloid algal boundstones, and a few wackestone/packstones in cycles subjected to brief subaerial exposure.
- Matrix porosity (molds, intercrystalline pores) is dominant.

Moore (2001) after Saller (1999)



- 1-D Fisher plot for well in Southwest Andrews Area
- Increased accommodation through Canyon with thicker cycles, thicker and higher porosity, similarly for Wolfcamp Reef
- Strata isotopically lightest in Cisco

Moore (2001)



Moore (2001)

Optimum length of subaerial exposure and thickness of grainstone & phylloid algal carbonate lithofacies improves conditions for *potential pay*

Table 1.1

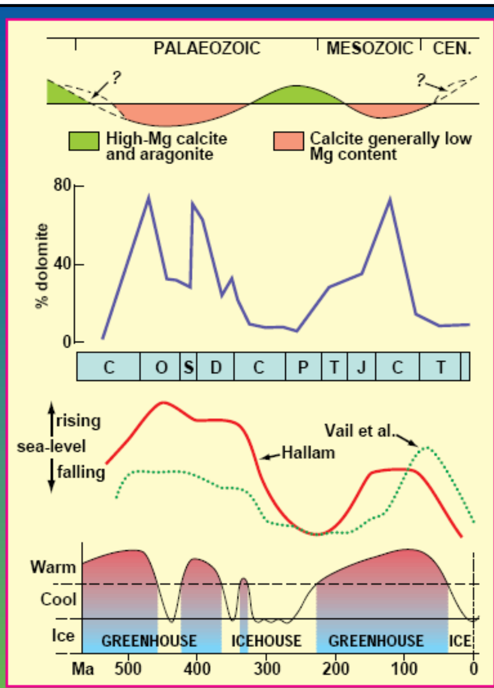
Number of Cycles	Average Cycle Thickness (m)	Average Limestone Porosity (%)	Average Limestone Permeability (md)	Average $\delta^{13}C$ (‰, PDB)	Average $\delta^{18}O$ (‰, PDB)	Limestone >4% Porosity/Total (ft)	Ave. Porosity Limestones >4% Porosity (%)	Ave. Permeability Limestones >4% Porosity (md)
Exposure Stage 1 22 SD*	7.93 (5.18)	1.63 (1.37)	1.33 (17.7)	1.05 (1.77)	-2.88 (0.54)	42/557 7.5%**	5.52 (1.7)	8.68 (46.6)
Exposure Stage2 74 SD*	5.49 (3.35)	4.27 (4.72)	10.77 (137.1)	0.10 (1.45)	-3.57 (0.62)	458/1313 35%**	9.54 (4.45)	19.4 (184.4)
Exposure Stage 3 53 SD*	3.35 (1.65)	3.13 (3.26)	1.89 (6.41)	-2.46 (1.46)	-4.26 (0.50)	112/455 25%**	8.03 (3.07)	4.31 (9.63)
Exposure Stage 4 92 SD*	2.38 (1.13)	2.24 (1.84)	0.18 (0.39)	-4.29 (0.81)	-4.54 (0.36)	61/512 12%**	6.04 (2.0)	0.49 (0.78)

*SD = Standard deviations for average values.
**Percentage of gross reservoir section with porosity >4%

Saller et al., 1999

Moore (2001)

Global Sea Level and Climate

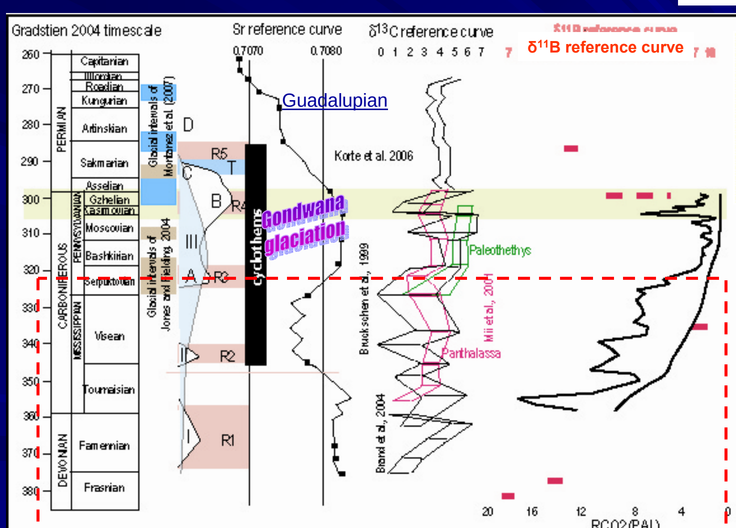


- Climate dependent change between high-magnesium calcite and aragonite and low-Mg calcite
- Shift toward aragonitic carbonates during Late Carboniferous and Permian under "Icehouse" conditions

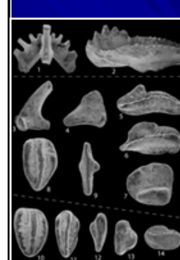
From C. Moore (2001)

Stable Isotopes and Climate Proxies from the Late Paleozoic

(**compiled** by T. Rasbury, 2008)



Geochemical analysis of sediments and conodont elements



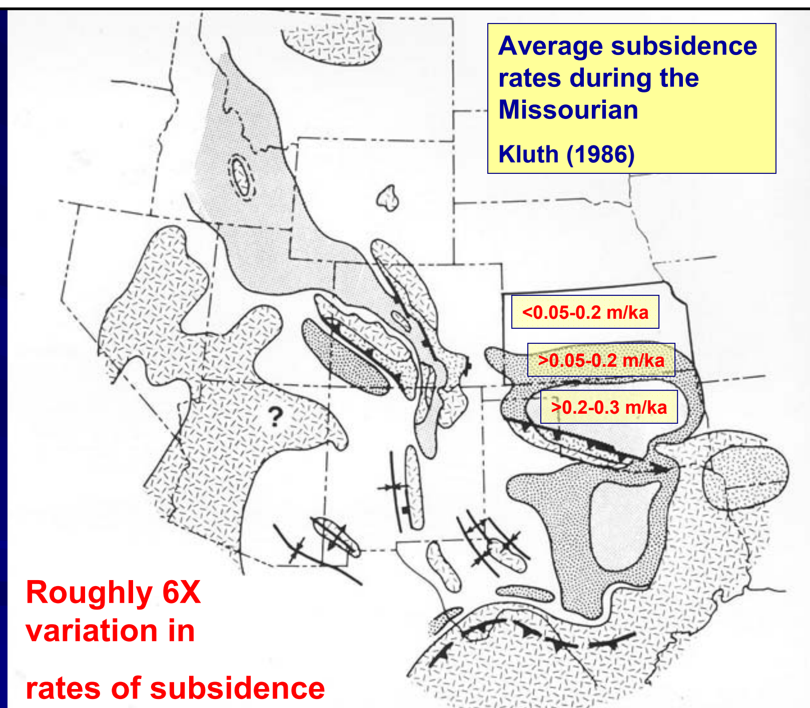
PAL: present atmospheric level

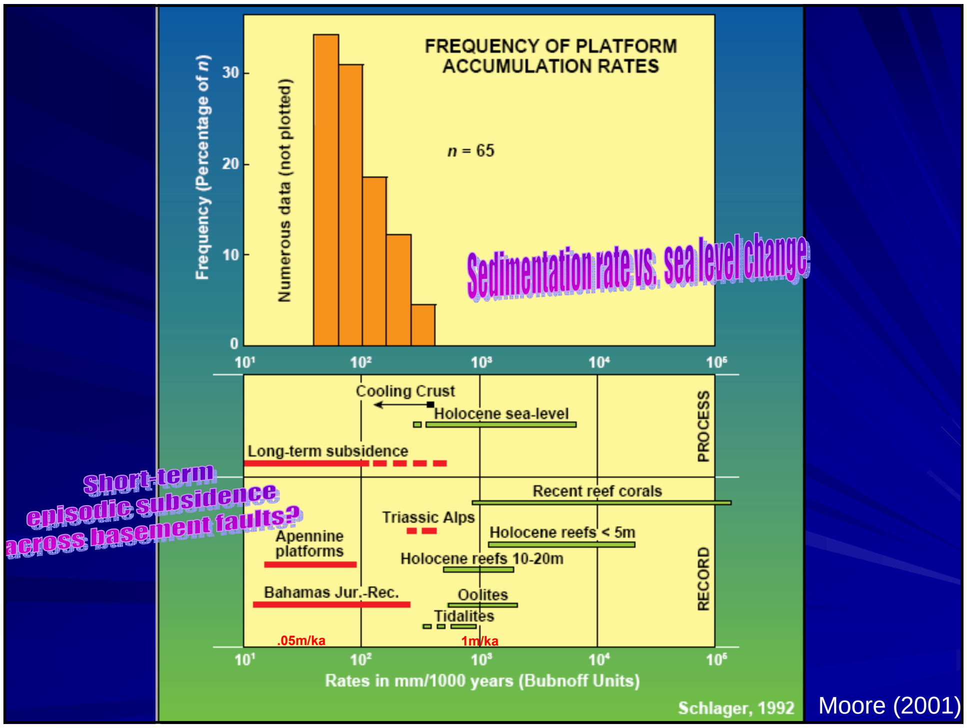
N. AMERICAN MIDCONTINENT cyclothems [MAJOR (core shale), Intermediate, Minor]	MOSCOW BASIN, Afanasievo Quarry; cores [MAJOR CYCLE; Lesser cycle]	DONETS BASIN, esp. Kalinovo [MAJOR CYCLE; Lesser cycle]
LECOMPTON (Queen Hill) / NECESSITY [Tx]: *I. tersus* *S. pawhuskaensis, S. ruzhencevi, S. vitali*	**AMEREVO**: *S. ruzhencevi, S. vitali; I. simulator* fus. abundant *Rauserites stuckenbergi*	**O7** [?]: *I. tersus, I.* cf. *simulator* fus. *Rauserites rossicus*
Spring Branch or **Clay Creek**: *S. pawhuskaensis;* *I. tersus, I. lobulatus*	[not identified]	**O6/1** [?]: *S. firmus, I. toretzianus*
OREAD (Heebner) / FINIS [Texas]: *S. pawhuskaensis* first *I. simulator, I. tersus* [types in Ks]; *S. firmus* amm. *Vidrioceras uddeni*; first global *Shumardites* [Tx]	**UPPER RUSAVKINO**: *S. pawhuskaensis* first *I. simulator [s.s.]; I. tersus, S. firmus* fus. cotype *R. rossicus* **[best base Gzhelian]**	**O6**: *S. firmus, I. toretzianus* first *I. simulator [s.s.]* fus. *Triticites* sp.
CASS (Little Pawnee)/LR COLONY CK [Tx]: *S. firmus* *S. zethus, S. pawhuskaensis, I.* aff. *simulator* [transit.] amm. *Vidrioceras conlini, Pseudaktubites stainbrooki*	**MIDDLE RUSAVKINO**: *S. pawhuskaensis* *S. zethus, S. firmus; I.* aff. *simulator* [transit.] fus. rare, poorly known	**O5**: type *S. firmus* dominant *S. pawhuskaensis* fus. primitive *Rauserites rossicus*
Iatan: *S. pawhuskaensis, S. firmus*	Lower Rusavkino: *S. firmus; I. toretzianus*	[not identified]
South Bend (Gretna): *S. pawhuskaensis* *S. firmus, I.* aff. *simulator* [transitional?]	Basal Rusavkino: *I.* aff. *toretzianus*	[not identified]
STANTON (Eudora) / UPR WINCHELL [Tx]: 'type' *I.* aff. *simulator; S. firmus* in top, *S. gracilis* gp. in base amm. *Pseudaktubites newelli* [Midcontinent]	**TROSHKOVO**: *I.* aff. *simulator; I. toretzianus; Gondolella* fus. rare *Rauserites quasiarcticus*	**O4/6**: *S. firmus* dom.; *S. isakovae* *I. toretzianus, I. bachmuticus*
Plattsburg (Hickory Creek): *S. gracilis* group	Myasnitskaya: type *S. isakovae;* flat forms	O4/5: [poorly known]
Wyandotte (Quindaro): *S. gracilis* group	Sadovaya: troughed and flat forms	O4/4: [poorly known]
IOLA (Muncie Creek) / LR WOLF MOUNTAIN [Texas] *S. gracilis* group [type *S. elegantulus, S. excelsus* in Tx]	Presnya: *S. isakovae, I. toretzianus*	**O4/3**: *S. firmus, S. isakovae* [type *S. kalitvensis; S. cf. excelsus*]
DEWEY (Quivira) / MID-POSIDEON [Texas]: *S. gracilis* group; *I. magnificus* [types in Texas]	**MESTSHERINO**: *Gondolella* *S. isakovae*, type *I. mestsherensis*	**O4/1**: first *S. firmus; S. isakovae* [type *I. toretzianus, I. bachmuticus*]
Cherryvale (Wea): *S. gracilis* group	Perkhurovo: *S. neverovensis;* flat forms	O4: mostly troughed forms
Hogshooter: forms transitional to *S. gracilis* group	[not identified]	O3: flat plus troughed forms
DENNIS (Stark): many forms, flat and troughed, incl. type *S. confragus* fus. *Triticites* [not most primitive]	**UPPER NEVEROVO**: many forms, including *I. sagittalis, S. neverovensis, S.* cf. *cancellosus* fus. *Montiparus subcrassulus*	**O2**: mostly flat forms, but including *S.* cf. *confragus* fus. *Triticites;* advanced *Montiparus*
Mound Valley: first *S. confragus*	[not identified]	O1/2: *S.* cf. *confragus*
SWOPE (Hushpuckney): many forms, including type *S. cancellosus, I. sulciferus;* rare *I. sagittalis* fus. *Eowaeringella ultimata*	**MID-NEVEROVO**: flat + troughed forms, incl. *S.* cf. *cancellosus, I.* cf. *sulciferus, I. sagittalis* fus. typical-advanced *Montiparus*	**O1**: flat and troughed forms *I.* cf. *sulciferus;* type *I. sagittalis* fus. adv.protrit.; prim. trit., *Montiparus*
HERTHA (Mound City): nodose *Idiognathodus*, including *I. eccentricus,* rare *I. sagittalis* [no fusulines]	Lower Neverovo: type *S. neverovensis;* some flat forms [no fusulines]	**N5/1**: *Idiognathodus*, many nodose, *I. sagittalis; I.* cf. *eccentricus* [no fus.]
Exline: flat forms, incl. *I. sagittalis;* first *I. eccentricus* [no fusulines]	Basal Neverovo: *S. neverovensis;* flat forms, incl. *I.* cf. *eccentricus* [fus. prim. *Montiparus*]	N5: [poorly known]
Checkerboard-S. Mound: flat, incl. *I. sagittalis* [no fus.]	[not identified]	[not identified]
Glenpool [upper Lost Branch]: last *Neognathodus;* *Sw. nodocarinata; I.* n. sp. of B. & R. [no fusulines]	Ratmirovo: flat forms; several in base, including *I.* cf. *trigonolobatus, Sw. makhlinae*	N4: [poorly known] [last *Neognathodus* reported]
LOST BRANCH (Nuyaka Creek): *I.expansus; G. magna* type *Swadelina nodocarinata; I.* n. sp. of B. & R. fus. *Beedeina eximia*	**VOSKRESENSK**: *I. trigonolobatus, I. fischeri;* type *Swadelina makhlinae; Sw. nodocarinata* fus. typical protriticitids	**N3/3**: *I. expansus; Gondolella magna* *Sw. neoshoensis; Sw. nodocarinata* fus. typical protriticitids
Norfleet: mostly *Neognathodus; Sw. nodocarinata,* *I.* n. sp. of Barrick & Rosscoe [transit.]; *S. subexcelsus*	Upper Suvorovo [Sharsha]: *S. subexcelsus;* type *I. fischeri*	N3/2: several, incl. *Sw. neoshoensis* [no fusulines known]
ALTAMONT (Lake Neosho): broad *I.* in upper part; type *Swadelina neoshoensis* fus. *Beedeina megista, B. acme*, etc.	**MID-SUVOROVO [Garnasha]**: type *S. subexcelsus; I. fischeri* fus. typical protriticitids	**N3/1**: forms incl. *S. subexcelsus,* *I. trigonolobatus; Swadelina?* [no fusulines known]
Farlington: first *Swadelina neoshoensis* fus. present, but unidentified	Lower Suvorovo: first *S. subexcelsus* fus. incl. rare typical protriticitids **[current base of Kasimovian Stage]**	N3: first *S. subexcelsus* and *Sw. neoshoensis; Sw. nodocarinata?* fus. primitive protriticitids, like Peski
Coal City (Joe): flat forms including type *Idiognathodus delicatus, I. claviformis* fus. *Beedeina* [primitive protriticitid level in W. U.S.]	Upper Peski [Volodarsky]: last *Neognathodus;* flat forms, including *I. delicatus* fus. primitive protriticitids, *Fusulina, Fusulinella*	N2/1: [poorly known]
LOWER PAWNEE (Anna): all flat forms including *I. delicatus;* type *I. fustiformis* fus. *Beedeina* [primitive protriticitid level in W. U.S.]	Middle Peski [Lower + Upper Titovo]: flat forms, including *I. delicatus* fus. primitive protriticitids; *Fusulina, Fusiella*	**N2**: flat forms, incl. *I.* cf. *delicatus* fus. *Fusulina, Taitzehoella*

Correlation of disconformity-bounded cyclothems of various magnitudes (specified by type font) across Moscovian-Kasimovian and Kasimovian-Gzhelian stage (upper Desmoinesian through lower Virgilian) boundary intervals in North America and eastern Europe.

"Digital correlation"

Heckel et al. (2007)





Sequence stratigraphic models -

conceptual tools to define accommodation, depositional profile, and sediment supply in space-time framework (vital components in sedimentary modeling)
also basis to infer sediment accumulation and erosion

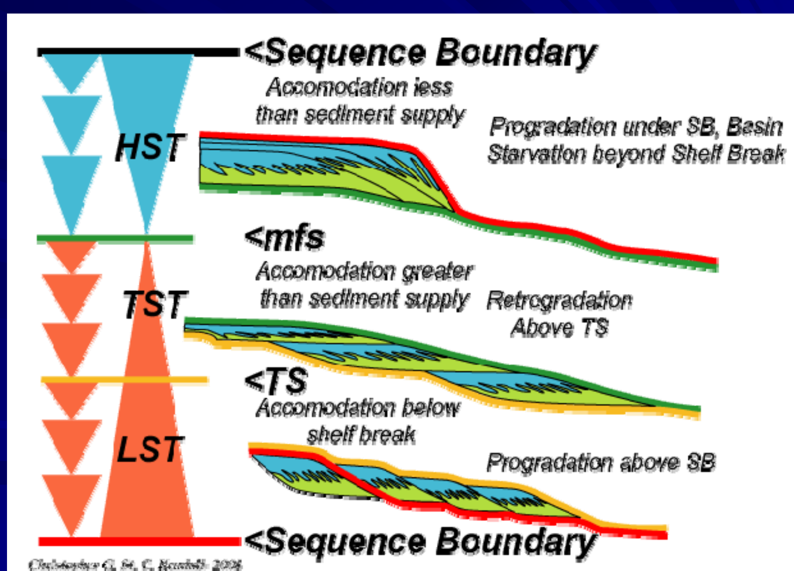
Definitions:

- **Depositional sequence**: Stratigraphic unit composed of relatively conformable succession of genetically related strata bounded at top and base by unconformities or their correlative conformities (Mitchum et al., 1977)
  - **Temporally distinct depositional packages**
  - **Architectural framework** to understand controls on sedimentation
  - **Systematic, predictable facies assemblages** within a sequence
  - **Sequences within sequences** (composite sequences)
    - hierarchy of stratal patterns
- **Sequence boundary**: Bounding unconformities or correlative conformities

Definitions (Continued)

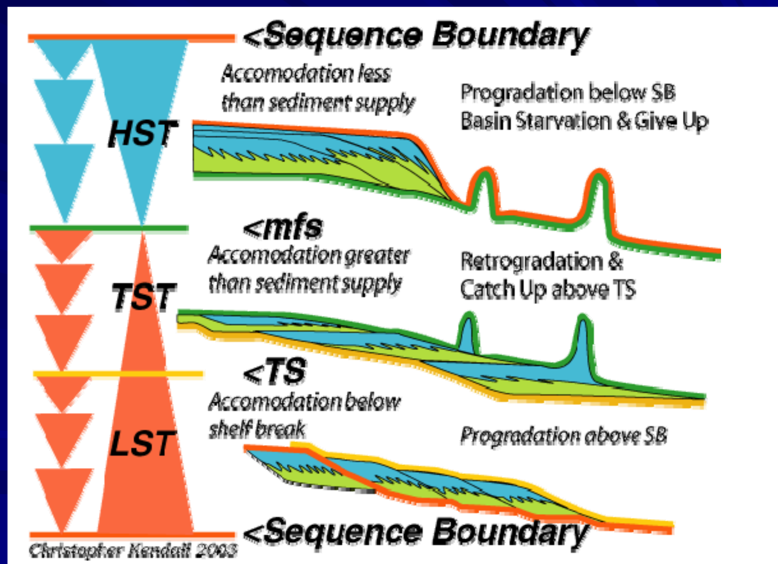
- **Hiatus:**
  - fall in relative sea level or base level or
  - change in rates of base level rise or
  - climate or tectonic processes in source area influencing erosion and clastic influx
- **Parasequence: Basic building block of sequences** (Van Wagoner et al., 1988)
  - Characterized by aggradation, progradation and retrogradation
  - Affected by sediment supply and minor base level fluctuations
- **Accommodation space:**
  - Space available for potential sediment accumulation (Jervey, 1988); space available below base level (Shanley and McCabe, 1994)
  - Provided by tectonic subsidence and eustacy

Depositional sequence for marine sediments



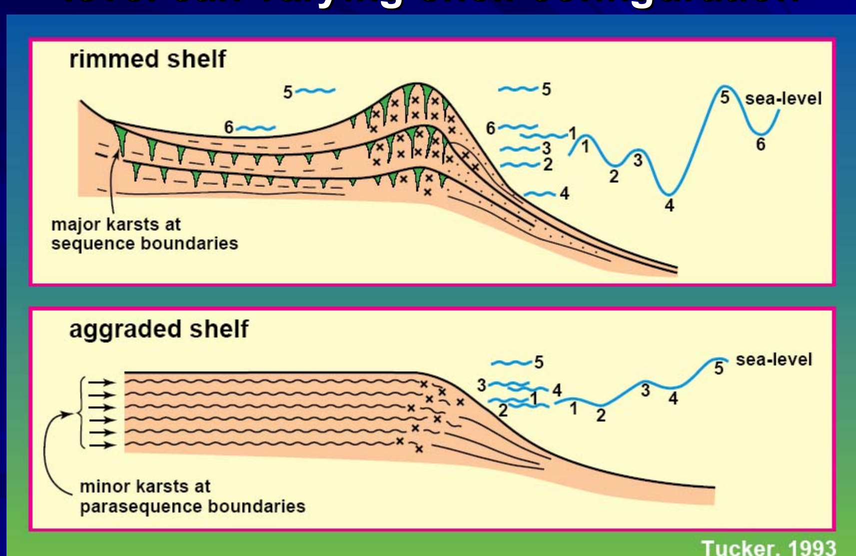
C.G.St.C. Kendal (2004)

Carbonate depositional sequences



C.G.St.C. Kendal (2003)

Varying amplitude and magnitude of sea level can varying shelf configuration



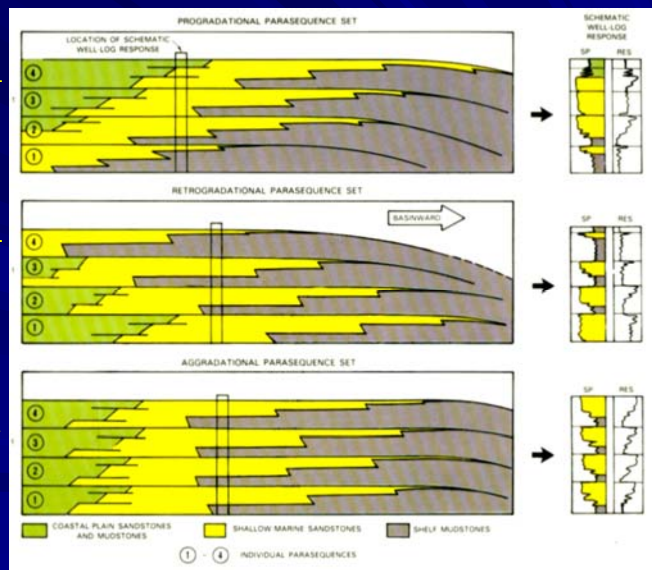
From Moore (2001)

Parasequence stacking pattern

Ratio rate of deposition / Rate of accommodation >1

Ratio rate of deposition / Rate of accommodation <1

Ratio rate of deposition / Rate of accommodation =1



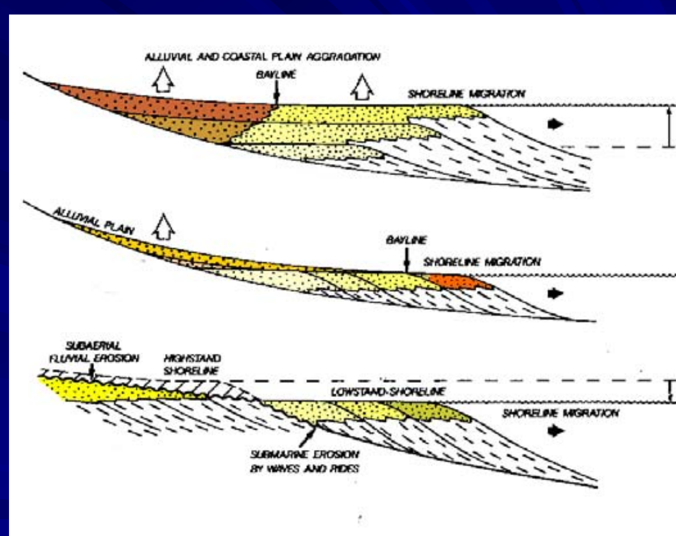
Van Wagoner et al. (1987)

Forced Regression - basinward shift in lithofacies

A. **Normal regression** with rising sea level

B. **Normal regression** with constant relative sea level

C. **Forced regression**: falling relative sea level



Posamentier (1992)

Transgressive systems tract (unit a)

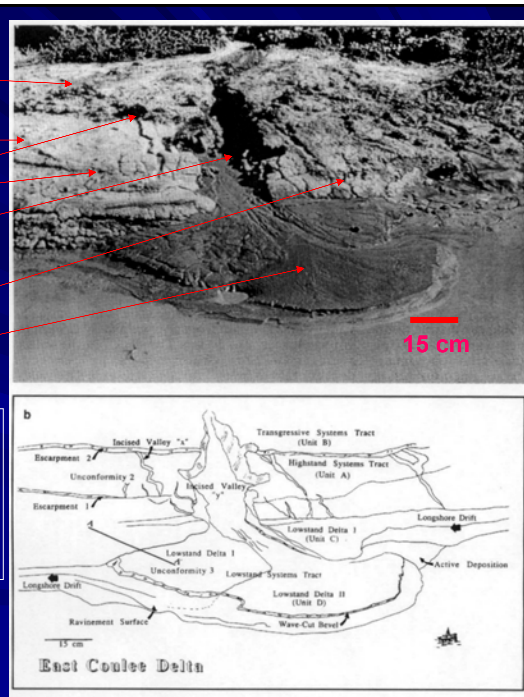
Highstand systems tract (unit b)

escarpments

Incised valley along major trunk valley

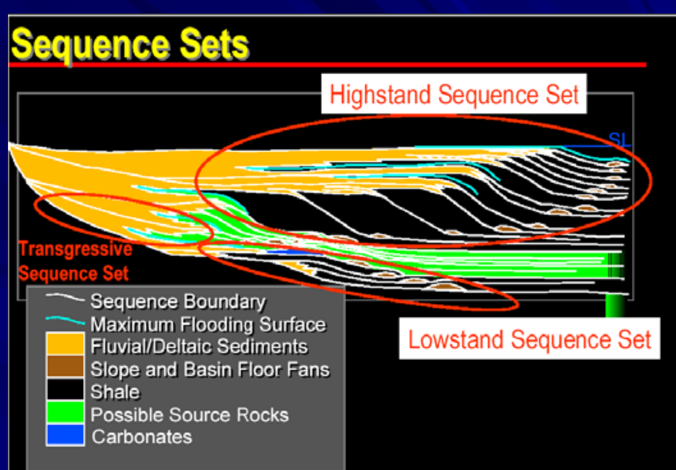
Minor incised valleys

Lowstand deltas (3)



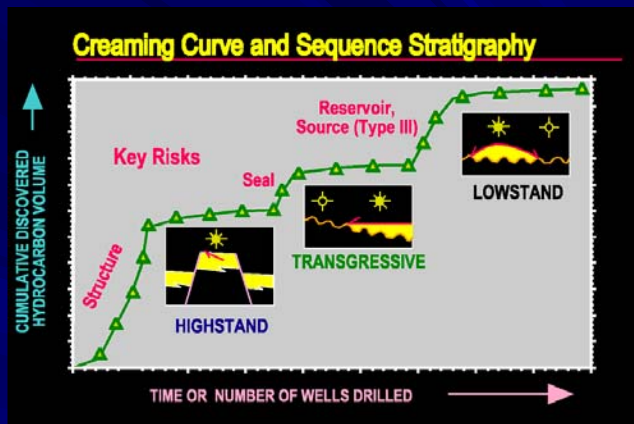
Sedimentation processes encompassed by sequence stratigraphy cover wide range of temporal and spatial scales!

Posamentier (1992)



Idealized succession of lowstand, transgressive, and highstand sequence sets, each made up of sequences with embedded third-order lowstand, transgressive, and highstand systems tracts. Modified from Bartek *et al.* (1991).

From Snedden et al. (2003)

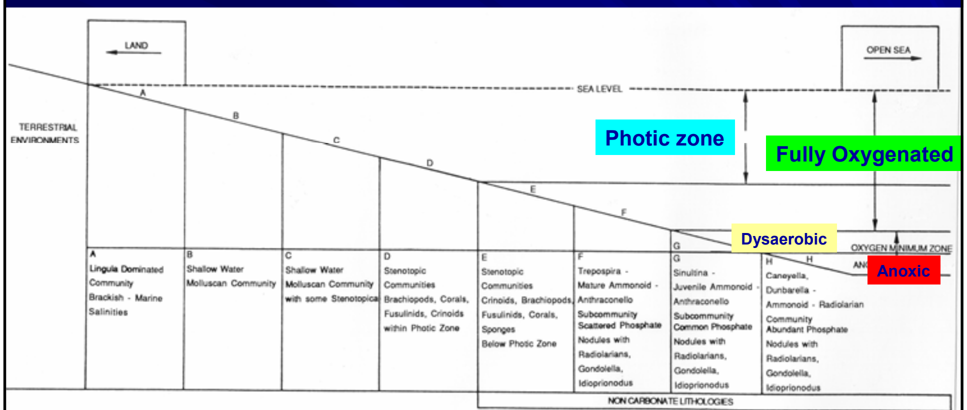


Idealized creaming curve from a sequence stratigraphic perspective. The components of the creaming curve refer to systems tract or sequence set, depending upon the size and scale of the play being considered.

Sneeden et al. (2003)

Process sequence stratigraphy

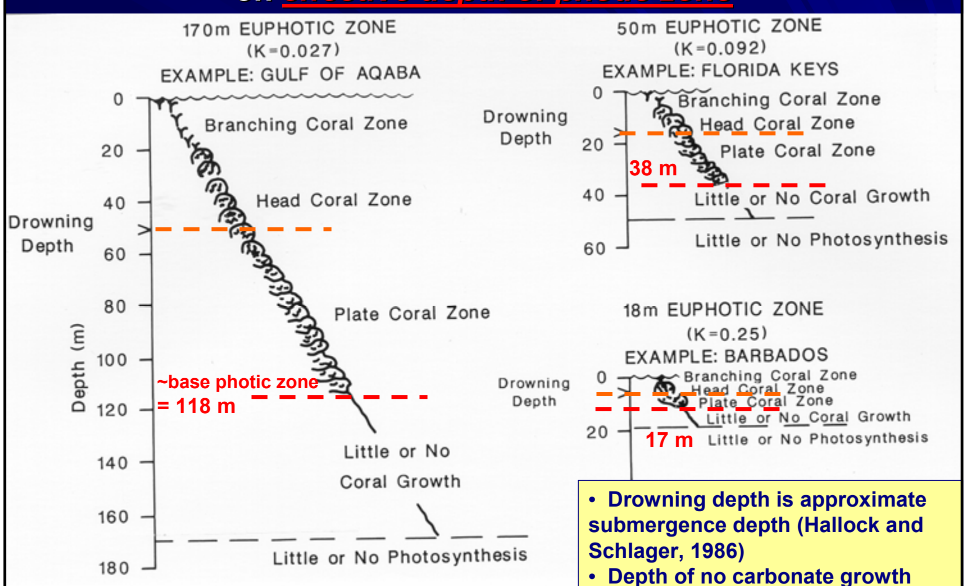
Paleoecologic Model for Late Paleozoic Sedimentation



Variables: water depth, stagnation, nutrients, sediment supply, water salinity, climate

Boardman et al. (1984)

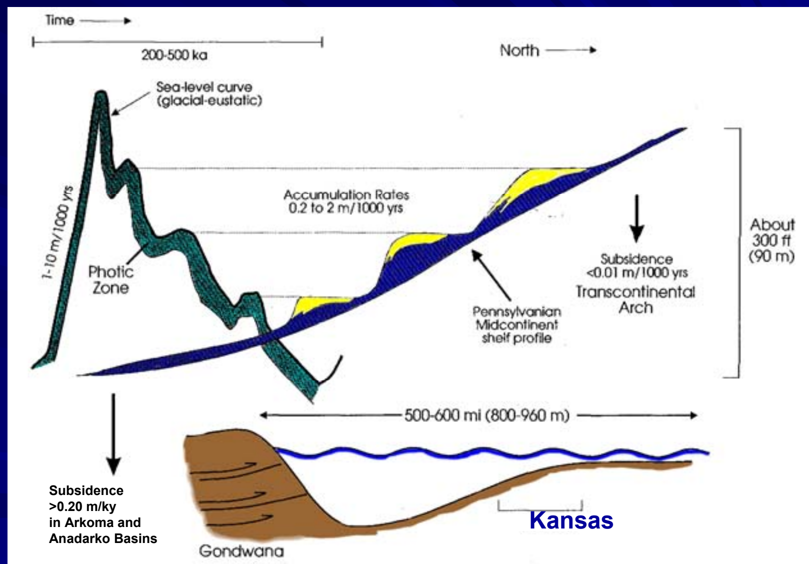
Influence of water clarity on Zooxanthellae corals and impact on *effective depth of photic zone*



- Drowning depth is approximate submergence depth (Hallock and Schlager, 1986)
- Depth of no carbonate growth varies by water conditions, not only depth

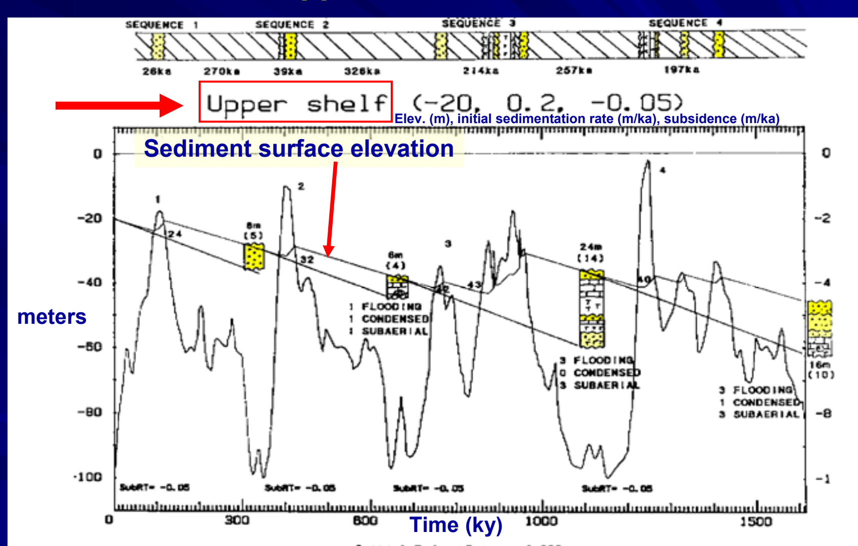
Hallock and Schlager (1986)

Conceptual model of Pennsylvanian cyclothem



Refining parameter list and reducing assumptions through interdisciplinary studies.

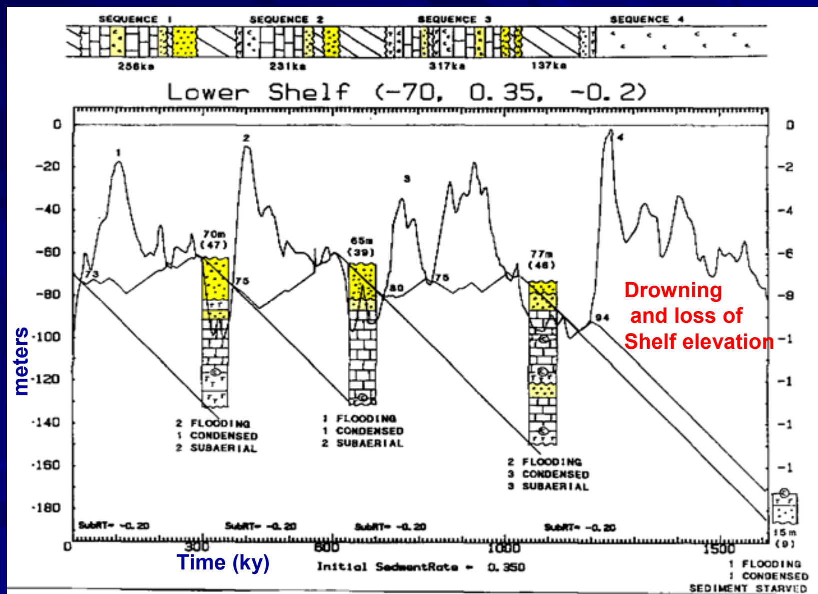
1-D simulation of Missourian cyclothemic depositional sequences in Kansas - Upper shelf simulation

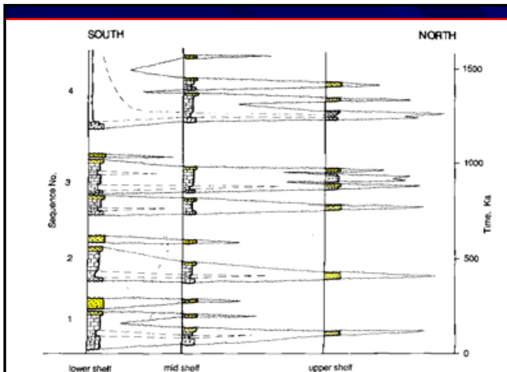


Using amplitude (110 m) and shape (sawtooth) of most recent Pleistocene eustatic curve
Depth of photic zone ~ 35 m

Watney et al. (1991)

1-D model (continued) – Lower Shelf





Wheeler Diagram bringing together sedimentation in time and space for three shelf positions

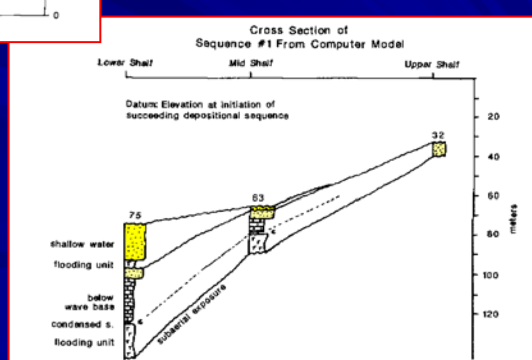
"We can not measure time with a ruler."

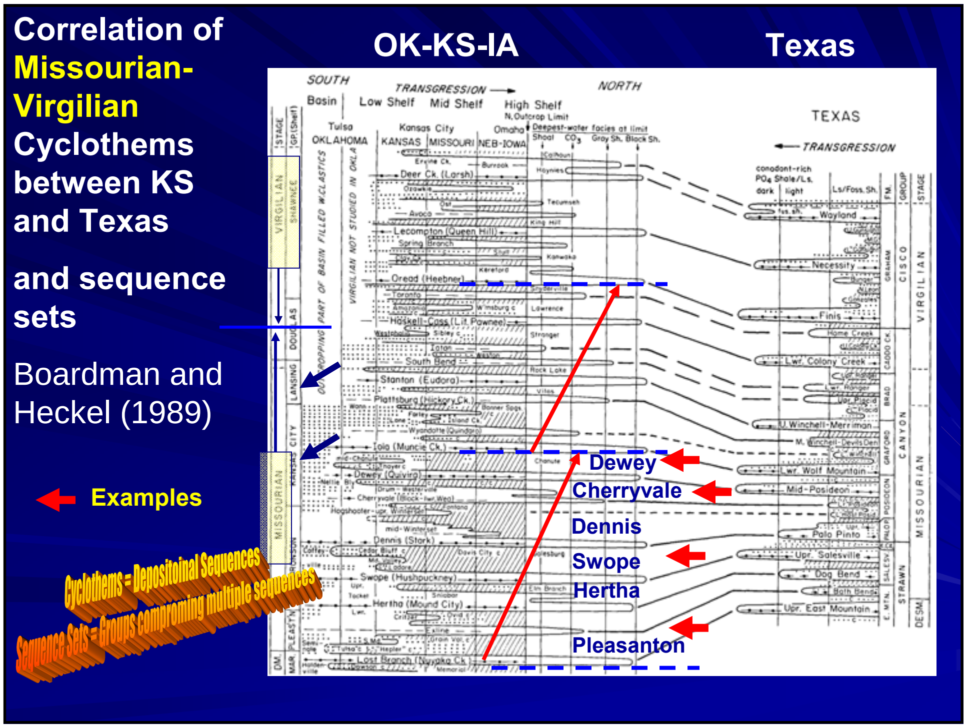
Single depositional sequence as composite of three shelf positions

-- what we observe

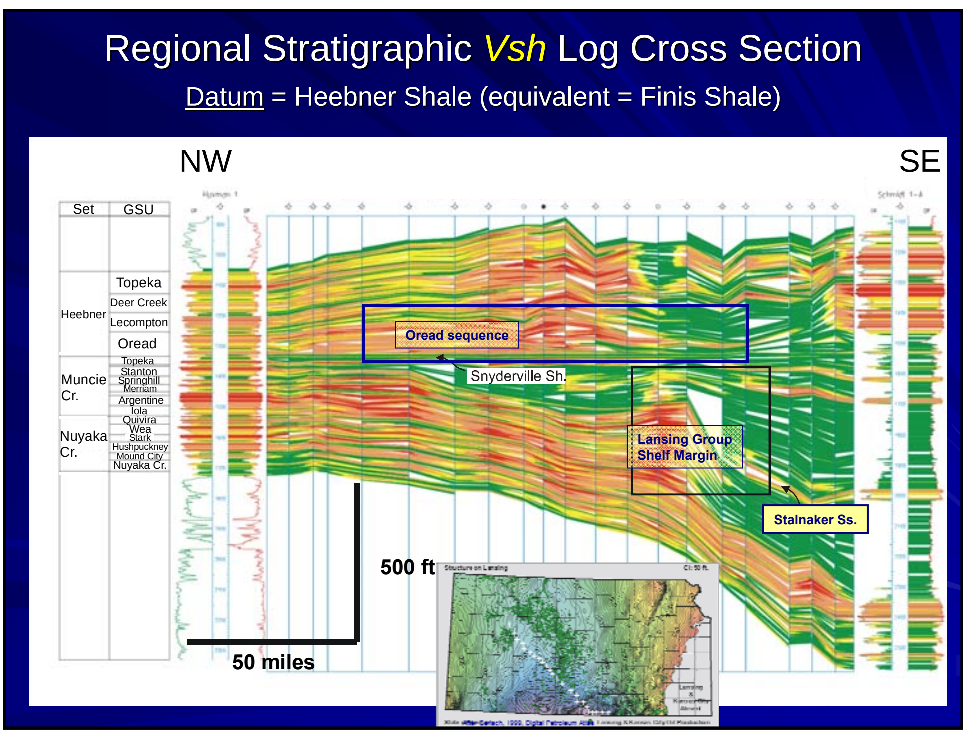
-- what we can interprete

-- limits of inferring processes?

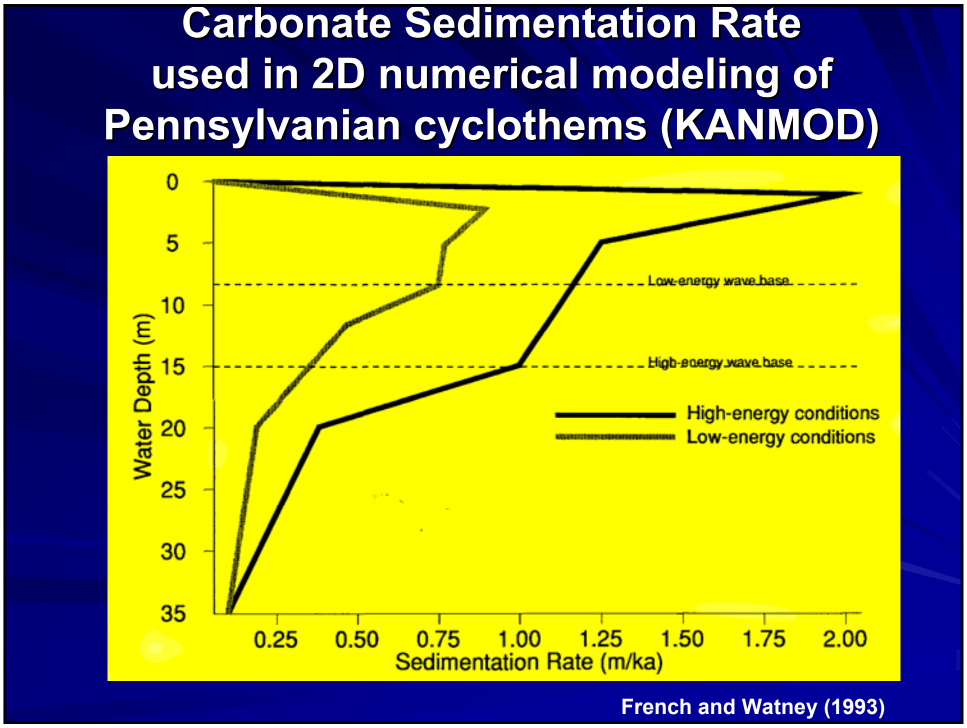


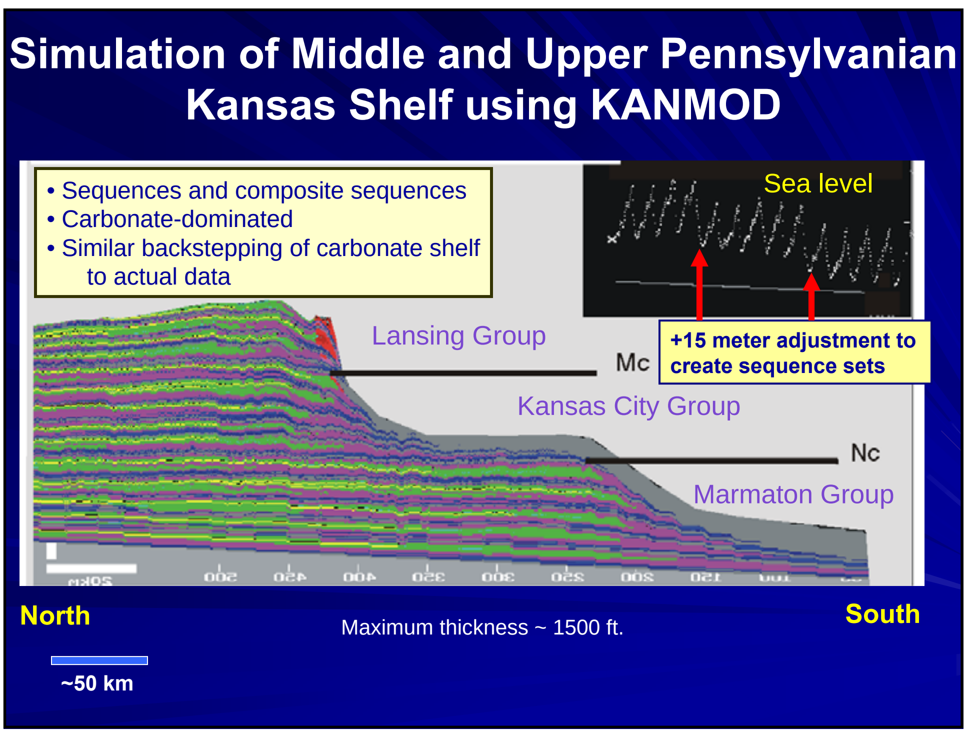


Correlation of Missourian-Virgilian Cyclothems between KS and Texas
and sequence sets
Boardman and Heckel (1989)
Examples
OK-KS-IA
Texas
SOUTH
NORTH
TRANSGRESSION
TEXAS
Dewey
Cherryvale
Dennis
Swope
Hertha
Pleasanton
Cyclothems = Depositoinal Sequences
Sequence Sets = Groups compromising multiple sequences



Regional Stratigraphic Vsh Log Cross Section
Datum = Heebner Shale (equivalent = Finis Shale)
NW
SE
Set
GSU
Topeka
Deer Creek
Lecompton
Oread
Heebner
Muncie Cr.
Nuyaka Cr.
Oread sequence
Snyderville Sh.
Lansing Group Shelf Margin
Stalnaker Ss.
500 ft
50 miles


Carbonate Sedimentation Rate
used in 2D numerical modeling of
Pennsylvanian cyclothems (KANMOD)
Water Depth (m)
Sedimentation Rate (m/ka)
Low-energy wave base
High-energy wave base
High-energy conditions
Low-energy conditions
French and Watney (1993)


Simulation of Middle and Upper Pennsylvanian
Kansas Shelf using KANMOD
• Sequences and composite sequences
• Carbonate-dominated
• Similar backstepping of carbonate shelf to actual data
Sea level
+15 meter adjustment to create sequence sets
Lansing Group
Mc
Kansas City Group
Nc
Marmaton Group
North
South
Maximum thickness ~ 1500 ft.
~50 km

Three-Dimensional Seismic Imaging and Reservoir Modeling of an Upper Paleozoic "Reefal" Buildup, Reinecke Field, West Texas, United States

By

Arthur H. Saller, Skip Walden, Steve Robertson, Robert Nims, Joe Schwab, Hiroshi Hagiwar, and Shigeharu Mizohata

Search and Discovery Article 20044 (2006)
Posted December 20, 2006

Horseshoe Atoll

Abstract

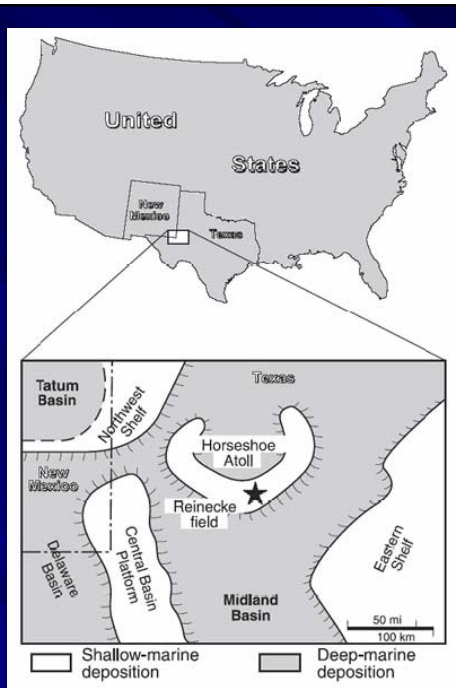
- Reinecke field is an upper Pennsylvanian to lowest Permian carbonate buildup
- Southern part of the Horseshoe Atoll, west Texas, United States.
- The field and surrounding areas have been imaged with three 3-D seismic surveys and penetrated by many wells. Although Reinecke is commonly referred to as a reefal reservoir, deposition occurred in stratified sequences, 50-100 ft (15-30 m) thick, dominated by wackestones, packstones, and grainstones. Boundstones (mainly rich in phylloid algae) constitute only 16% of the buildup.
- Seismic reflectors within the buildup parallel sequence boundaries and are truncated at the margins of the buildup.
- Three-dimensional seismic surveys show that the top of the Reinecke buildup is highly irregular with more than 470 ft (143 m) of relief.
- Deep-marine shales overlie the reservoir and act as a seal for this stratigraphic trap.
- Reinecke's irregular, mounded morphology is the result of localized carbonate growth and erosional truncation.

Abstract (continued)

- Much of the erosional truncation probably occurred in a deep-marine environment.
- Reinecke's south dome acts a single continuous reservoir dominated by limestone (70%) with 25% dolomite.
- Limestone porosity is generally 5-18% (average of 11.2%) and permeability is 1-1000 md (average of 166 md).
- Dolomite porosity is lower (average of 8.3%), but permeability is higher (average of 894 md).
- Discontinuous low-permeability layers parallel to stratification serve as low-permeability baffles; however, patchy replacive dolomites cut through stratification and act as high-permeability vertical conduits.
- Good reservoir continuity, low-permeability baffles, and artificially enhanced bottom-water drive helped to recover more than 50% of the original oil in place.
- Excellent vertical reservoir continuity has allowed implementation of a crestal CO_2 flood at Reinecke field. CO_2 is being injected into the top of the structure, displacing residual and bypassed mobile oil downward for recovery in lower parts of the reservoir.

Three-Dimensional Seismic Imaging and Reservoir Modeling of an Upper Paleozoic "Reefal" Buildup, Reinecke Field, West Texas, United States

- Reinecke and other fields on the south and west sides of the Horseshoe Atoll have vertical permeability pathways that allow the top of the reservoir to be in pressure communication with the underlying aquifer (i.e., *they produce like reefal reservoirs*) (Crawford et al., 1984; Saller et al., 1999).
- **"The area has no significant tectonic deformation."**
- Stratigraphic tops from wells were merged with seismic surfaces in EarthVision to create stratigraphic surfaces used in the geocellular model. Porosity and permeability were extrapolated between wells by ordinary kriging and then gridded in EarthVision.
- A model with 35 layers was built. A RESCUE export format was used as an interface between the EarthVision geocellular model and the Eclipse flow simulator.

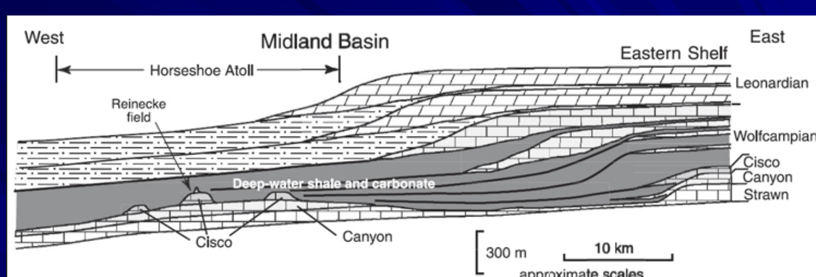


Three-Dimensional Seismic Imaging and Reservoir Modeling of an Upper Paleozoic "Reefal" Buildup, Reinecke Field, West Texas, United States*

By

Saller et al. (2006)

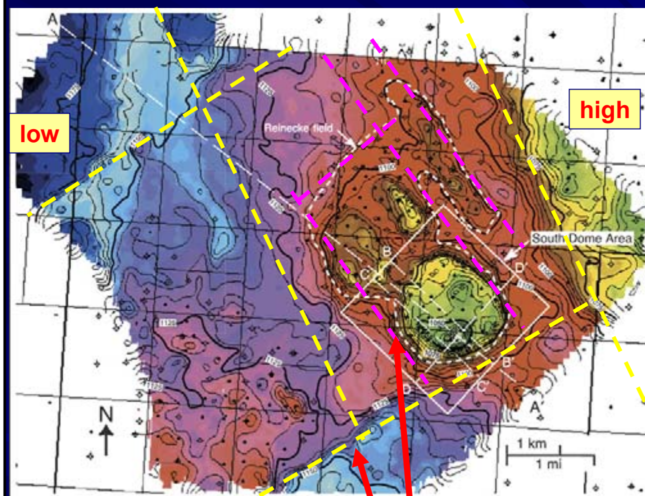
Diagrammatic cross section



Shelf margin - eastern shelf may be defined by deep-seated faults (Ft. Chadbourne Fault Zone)

- Horseshoe Atoll – keep-up sedimentation prior to drowning

Isotime map – Reinecke Field

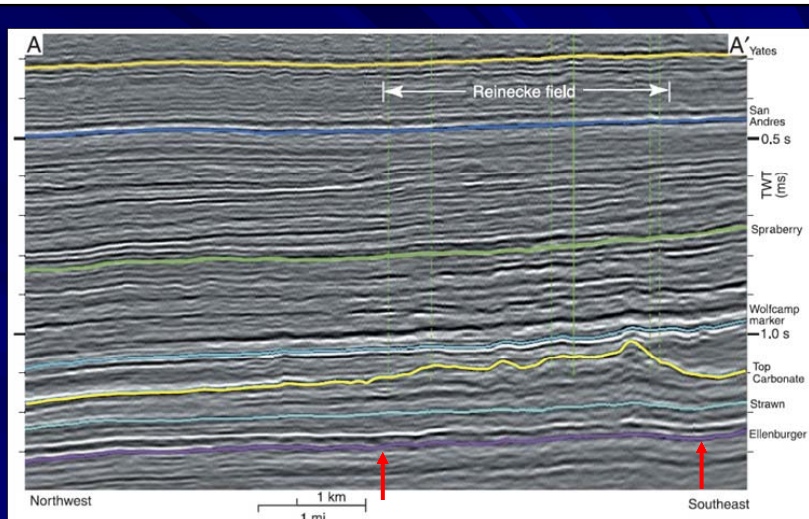


- **Seismic time of the upper Pennsylvanian-lowest Permian carbonate**
- **"The area has seen little tectonic deformation since the Pennsylvanian; hence, this structure represents the shape of the carbonate buildups after deposition and erosion."**
- **Contour interval is 5-ms two-way traveltime (TWT).**

Possible basement lineaments that may control general location of Horseshoe

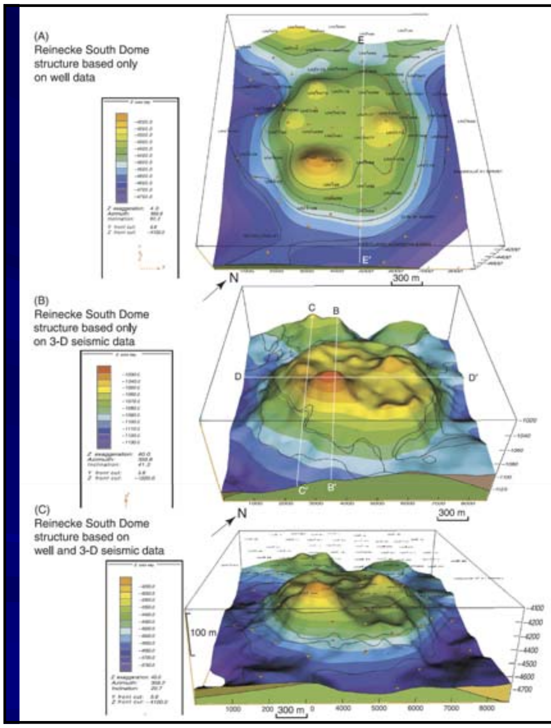
Lineaments added

Saller et al. (2006)



Saller - -"Arbitrary 3-D seismic line. Note the lack of structural deformation. Selected formation tops are shown. Carbonates started accumulating over a relatively flat surface. Basinal shales and carbonates of Wolfcampian age overlie the irregular upper surface of the reservoir carbonate."

Saller et al. (2006)



Structure of the top of carbonate, south dome of Reinecke field.

All views are from the southeast. Vertical exaggeration is 4X.

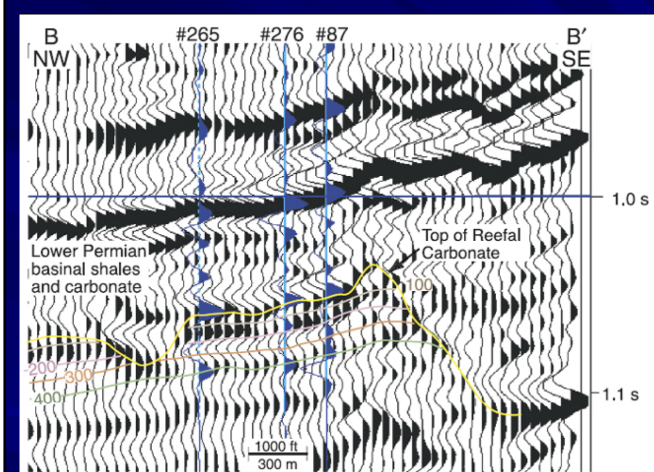
(A) Map (*in ft subsea*) based solely on well data.

(B) Seismic two-way travel time map (*in ms*).

(C) Map (*in ft subsea*) based on well and 3-D seismic data.

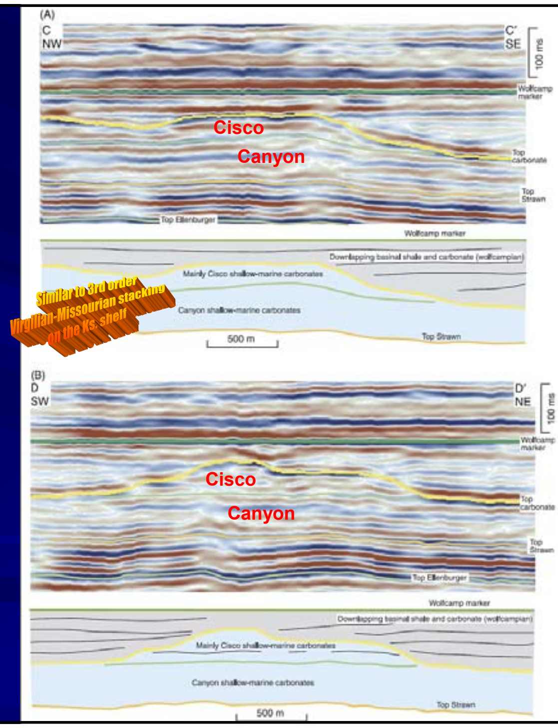
Saller et al. (2006)

Wiggle display of an arbitrary line from the 3-D seismic survey showing sequences defined by cores



- Synthetic seismograms for wells have been inserted.
- Note the truncation of reflectors (sequences) at the margins of the buildup.

Saller et al. (2006)

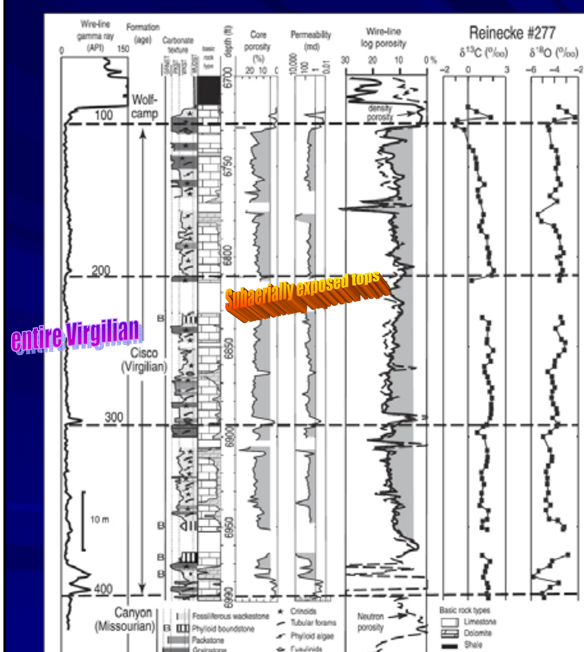


(A) Seismic line 237 (CC ') and

(B) trace 243 (DD') flattened on a Wolfcamp reflector in the basinal sediments overlying the Reinecke reef carbonates.

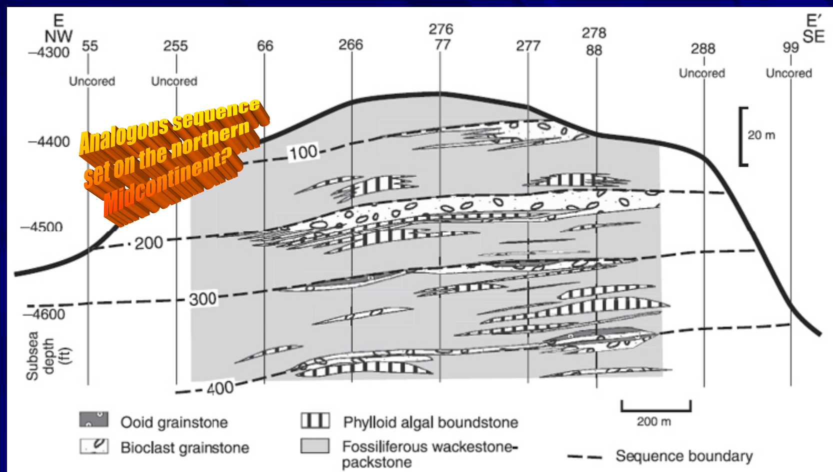
Reflectors apparently onlapping the Reinecke buildup are actually basinal strata down- or baselapping against the Reinecke carbonate buildup from the east (right) with the contemporaneous shelf margin 50-100 km farther to the east (right).

Saller et al. (2006)



- Core and wire-line logs for a "typical" south dome well, #277.
- Horizons 100, 200, 300, and 400 have paleosoil-related features below them and are interpreted as sequence boundaries.
- Thin shales are immediately above sequence boundaries 300 and 400.
- Stable isotope data are from whole rock samples.

Saller et al. (2006)



Structural cross section showing facies and stratigraphy across the south dome of Reinecke field. Facies are from core data. Horizons 100, 200, 300, and 400 are sequence *boundaries with soil-related features.*
(4 Virgilian Groups in Kansas – Admire, Waubaunsee, Shawnee, and Douglas)

Saller et al. (2006)

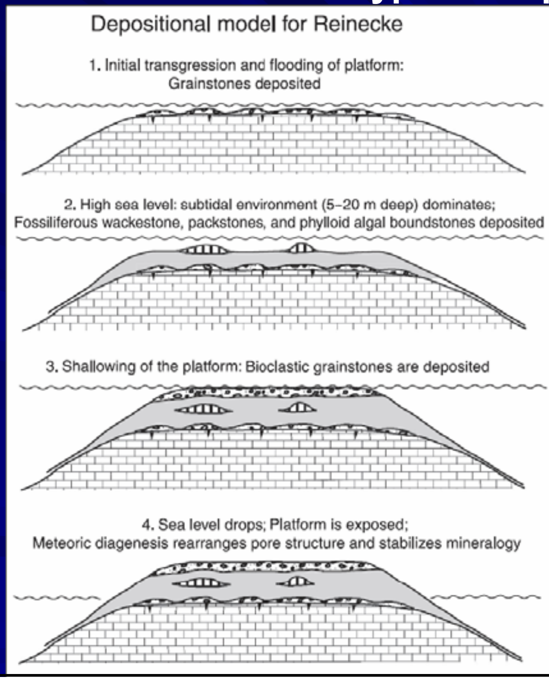
Facies	*Average porosity (%)*	*Average horizontal permeability (md)*	*Average vertical permeability (md)*	*Percentage of limestone facies*
1. Ooid grainstone	9.3	20.4		4
2. Bioclastic (crinoidal) grainstone	12.3	157.7	6.9	22
3. Packstone	11.8	199.6	6.0	9
4. Phylloid boundstone	12.0	690.3	82.6	13
5. Bryozoan boundstone	11.2	57.7		3
6. Phylloid wackestone-packstone	11.2	196.4	11.1	24
7. Bryozoan wackestone	12.9	20.0		2
8. Fossiliferous wackestone-packstone	10.5	29.5	12.1	22
9. Mudstone	1.4	0.79	0.01	1
Total limestone—average	11.2	165.8	11.0	100

Eight hundred and sixty-five feet of limestone were cored and analyzed.

Although the south dome of Reinecke field has a mounded or "reefal" morphology, it is composed of fairly stratiform sequences that apparently formed in response to variations in relative and probably eustatic sea level. Sequence boundaries are identified by soil- and exposure-related features (fractures, root traces, caliches, and brecciation) observed in core.

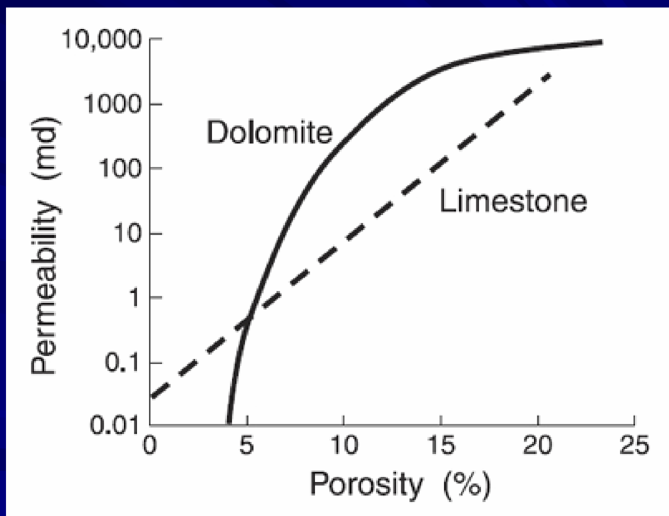
Saller et al. (2006)

Depositional model for a typical sequence

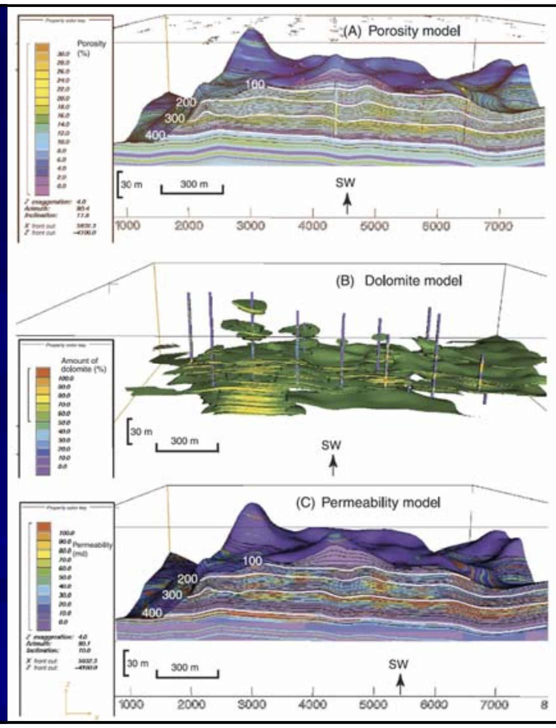


Saller et al. (2006)

Curvilinear and linear regressions of porosity vs. permeability for limestones and dolomites in Reinecke field



Saller et al. (2006)



Reservoir characteristics of Reinecke's south dome looking from the northeast to the southwest (at the top).

Vertical exaggerations are 4X.

(A) Model for porosity distribution across the south dome of Reinecke field.
(B) Model for dolomite distribution across the south dome of Reinecke field. Values are in percent dolomite.
(C) Model for permeability distribution across the south dome of Reinecke field. Values are in millidarcy.

Saller et al. (2006)

Reineche dolomitized depositional facies—

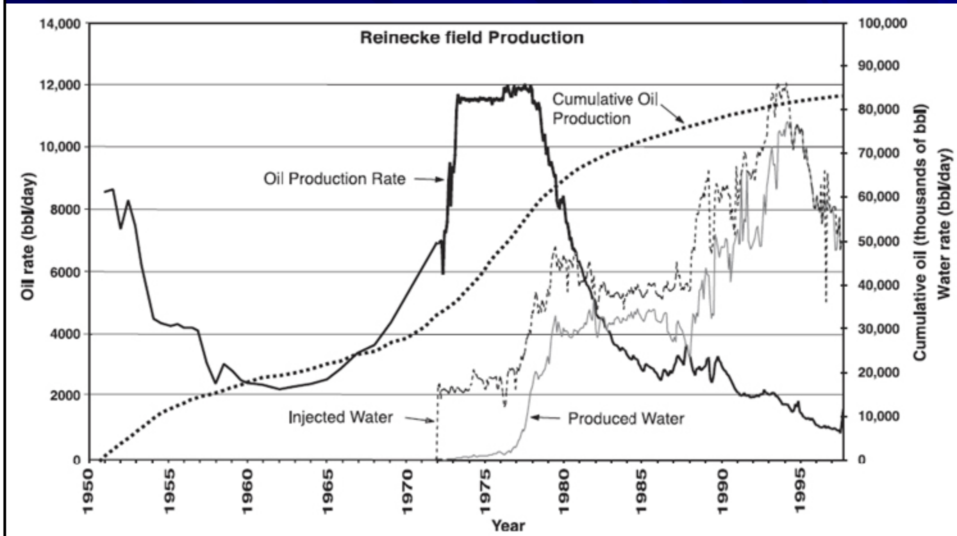
Facies	*Average porosity (%)*	*Average horizontal permeability (md)*	*Average vertical permeability (md)*	*Percentage of dolomite facies*
1. Ooid grainstone				0
2. Bioclastic (crinoidal) grainstone	8.0	360.7	322	4.5
3. Packstone	11.8	1780.8	30.9	4.9
4. Phylloid boundstone	12.0	140.8		0.8
5. Bryozoan boundstone				0
6. Phylloid wackestone-packstone	7.9	848.4	85.0	42.3
7. Bryozoan wackestone	4.9	3.8		3.7
8. Fossiliferous wackestone-packstone	7.7	846.7	1.9	41.8
9. Mudstone	2.0	1.5	<0.01	2.0
Total dolomite— average	8.28	894	334	100
Total— all (limestone, dolomite, mixtures of both)	10.5	323	131	

Three hundred and twenty feet of dolomite were cored and analyzed. The original depositional facies of some dolomites could not be determined. One thousand and two hundred and forty feet of limestone, dolomite, and mixed limestone-dolomite were cored.

Preferred lithofacies for dolomitization

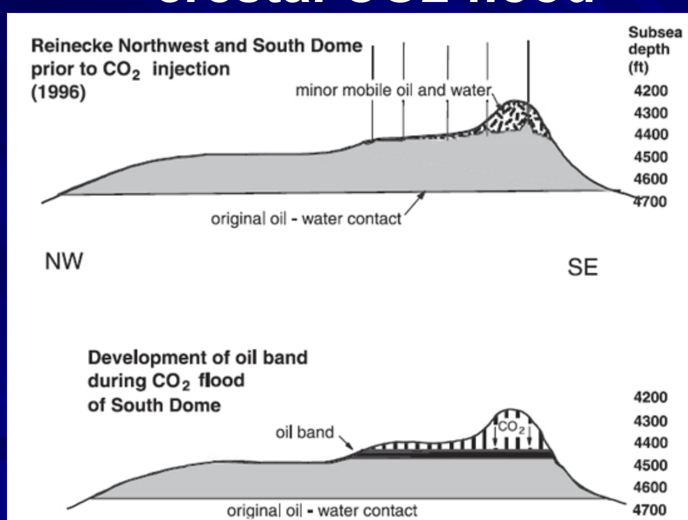
Saller et al. (2006)

Production history of Reinecke field



Saller et al. (2006)

Schematic diagrams of the crestal CO2 flood



Saller et al. (2006)

Conclusions

- The final geometry of Reinecke's reservoir was the product of localized carbonate growth, karstification, and deep-marine erosion after the buildup was drowned.
- Deep marine erosion was apparently responsible for much of the very irregular top of the Reinecke carbonate.
- Although reefal in its morphology, the Reinecke reservoir is composed of stratiform sequences with only minor boundstone.

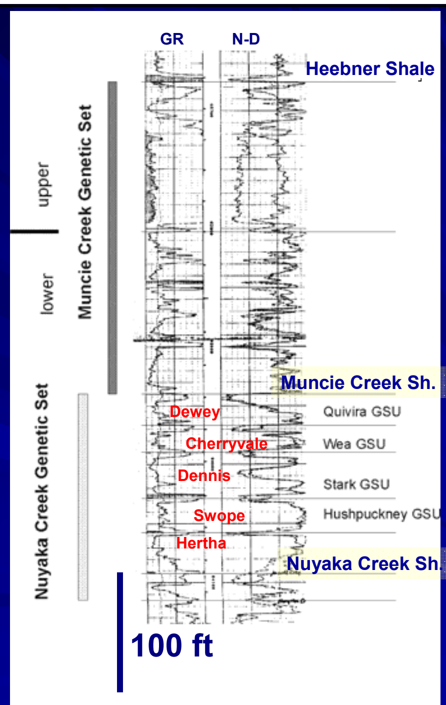
Saller et al. (2006)

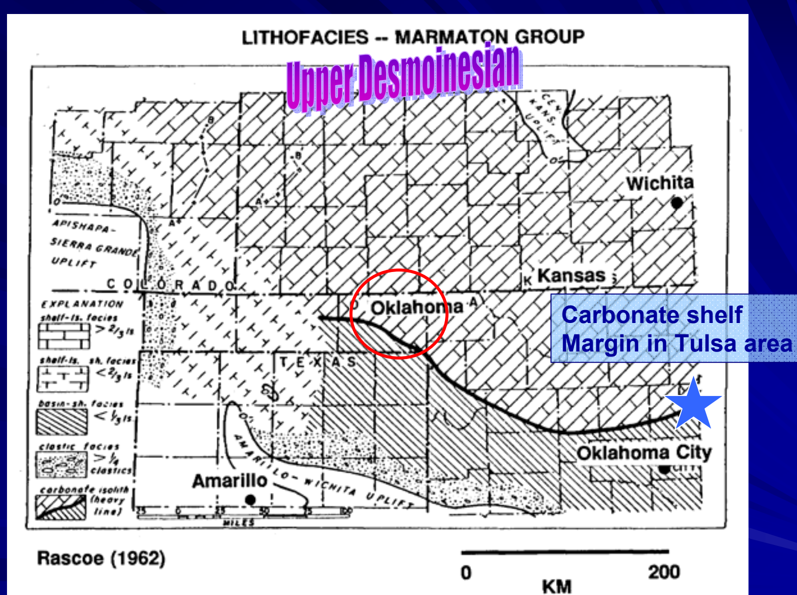
Conclusions (Continued)

- Porosity and permeability are continuous through the Reinecke reservoir, and hence the south dome acts as a single container.
- Reinecke production is typical of “reefal” -type reservoirs with water from an underlying aquifer pushing oil up into perforations at the top of the reservoir.
- This mechanism was so efficient that 50% of the OOIP was produced by primary recovery and injection of water below the oil-water contact.
- A crestal CO2 flood is currently underway and is feasible because of Reinecke's excellent reservoir continuity.
- The main value of the 3-D seismic surveys was to image the gross reservoir geometry in detail, which was essential for accurate volumetrics, successful reservoir simulation, and design of the crestal CO2 flood.

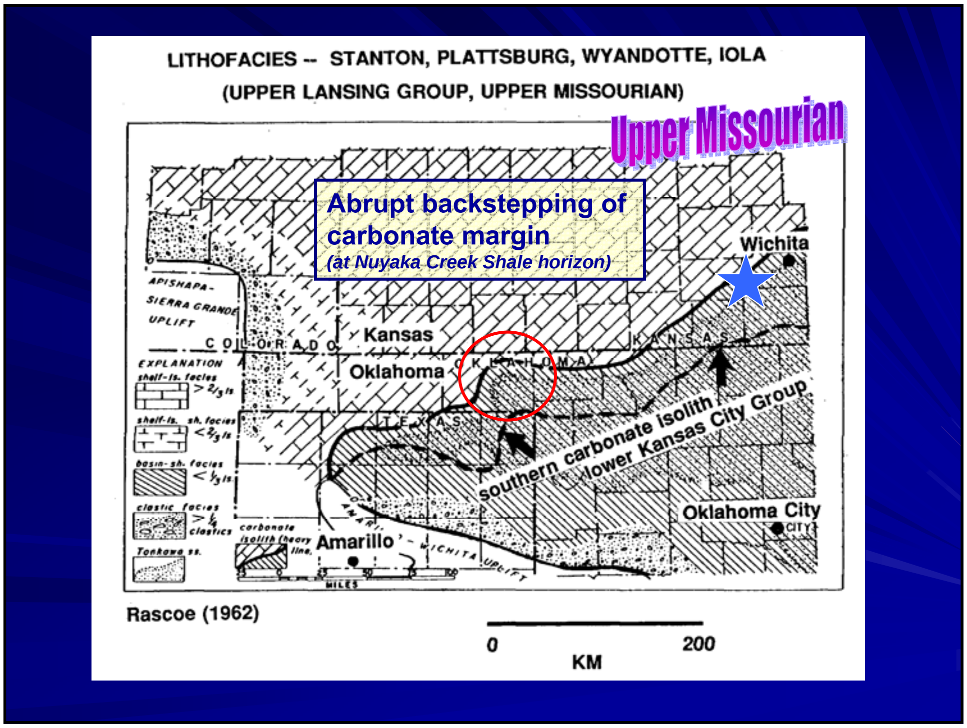
Type log of Missourian and Lower Virgilian strata on Kansas carbonate shelf

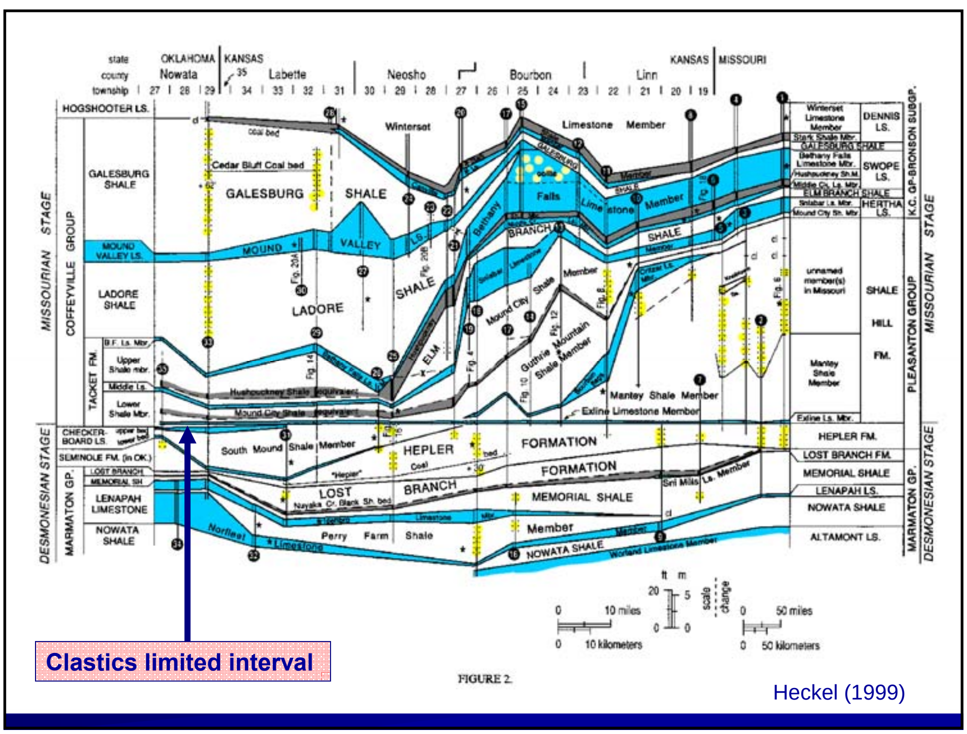
genetic stratigraphic units (GSUs) and depositional sequences

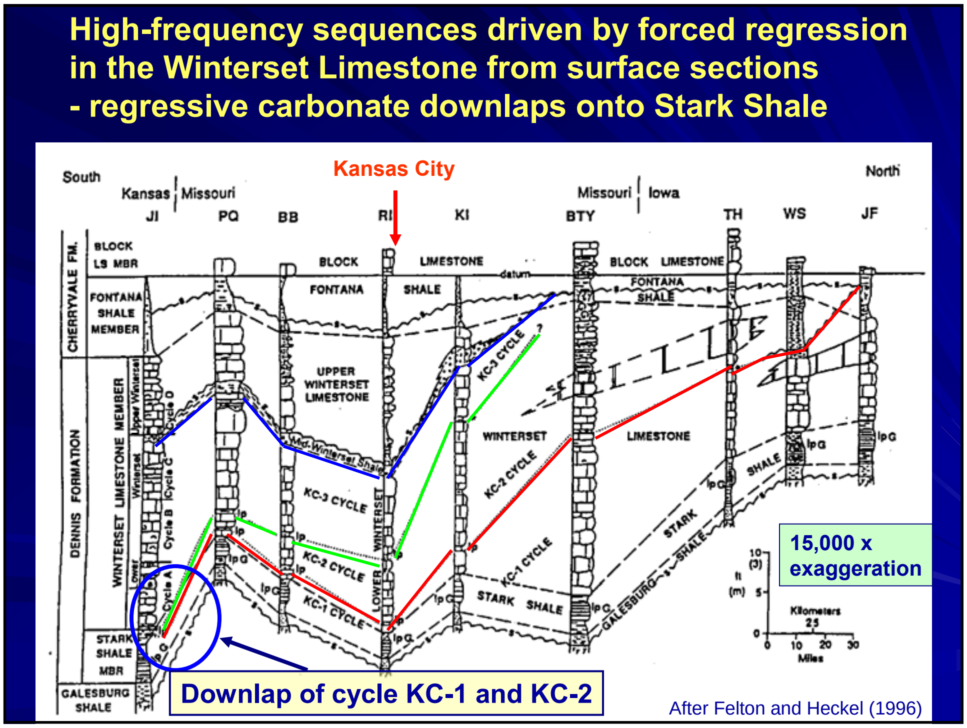


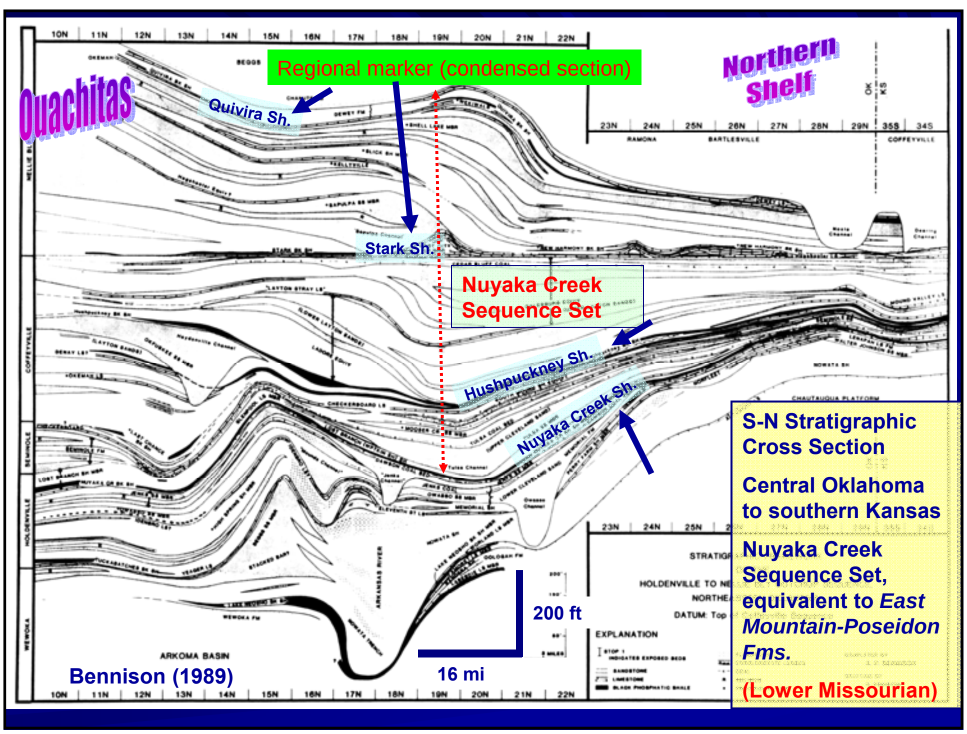


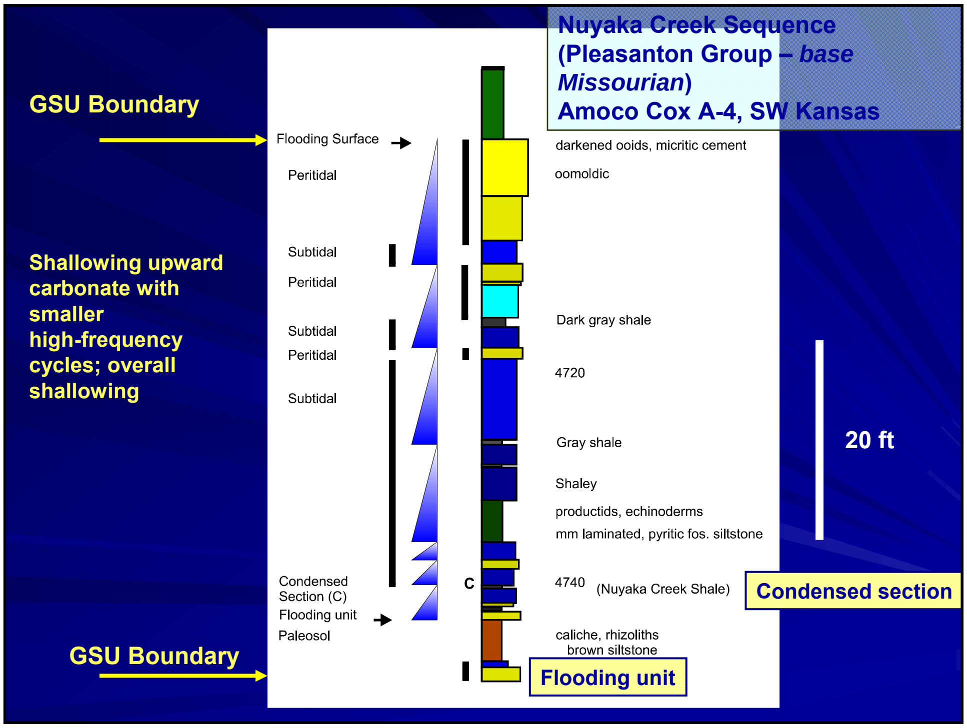
Carbonate shelf and sediment starved basin -- changes in elevation of depositional surface and rate of accumulation


LITHOFACIES -- STANTON, PLATTSBURG, WYANDOTTE, IOLA
(UPPER LANSING GROUP, UPPER MISSOURIAN)
Upper Missourian
Abrupt backstepping of carbonate margin
(at Nuyaka Creek Shale horizon)
Wichita
Kansas
Oklahoma
southern carbonate isolith
lower Kansas City Group
Oklahoma City
Amarillo
Rascoe (1962)
0
200
KM

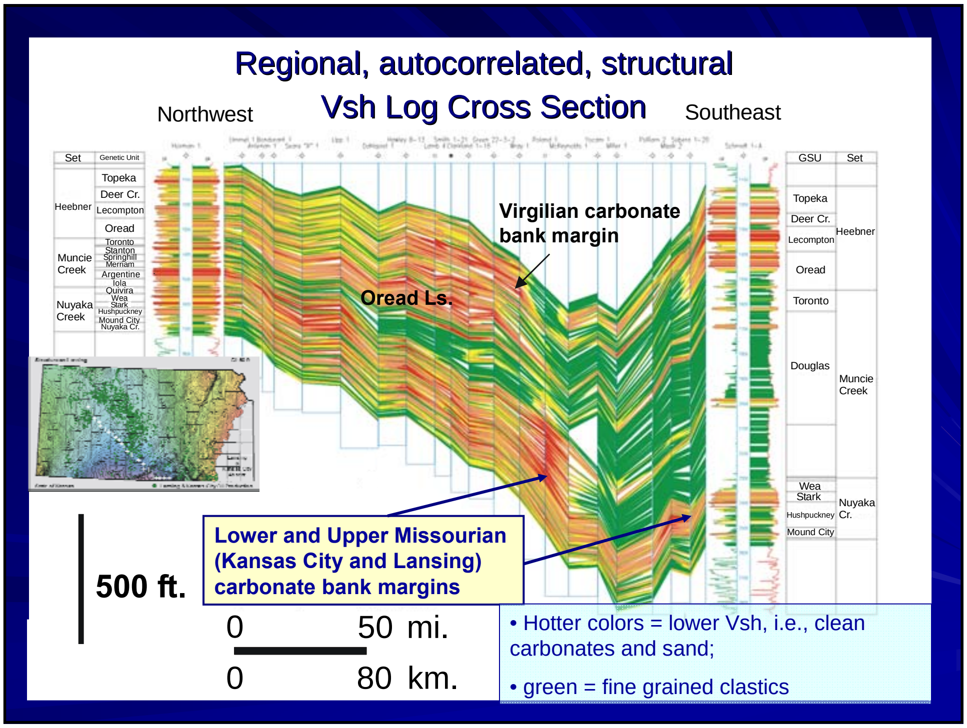

Clastics limited interval
FIGURE 2.
Heckel (1999)

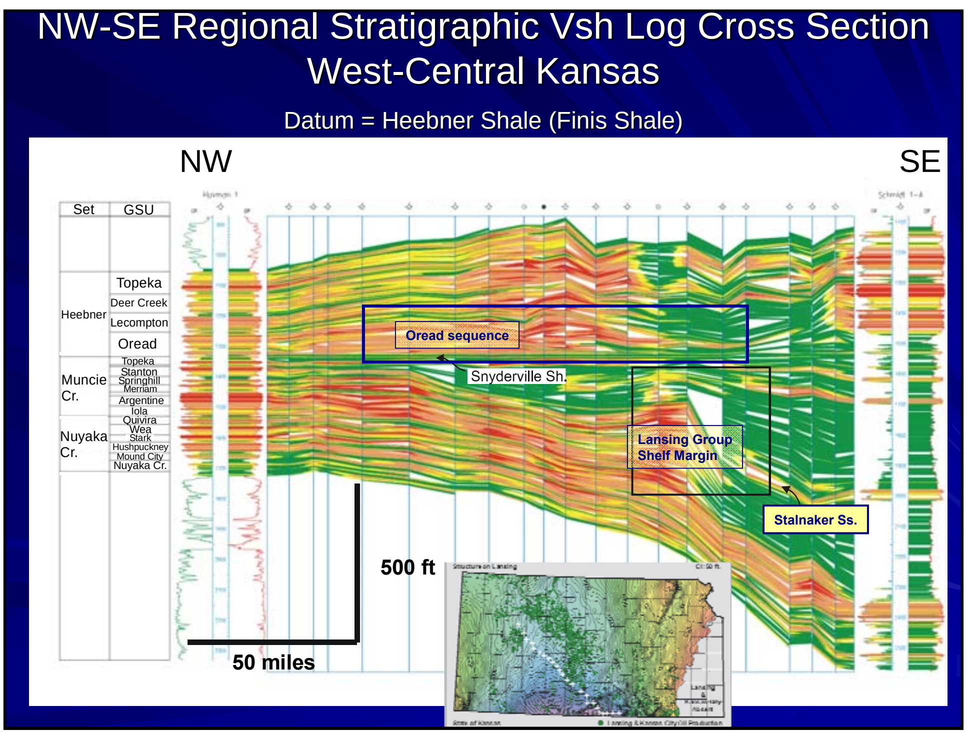

High-frequency sequences driven by forced regression in the Winterset Limestone from surface sections - regressive carbonate downlaps onto Stark Shale
Kansas City
South
North
Kansas
Missouri
Iowa
JI
PQ
BB
RI
KI
BTY
TH
WS
JF
CHERRYVALE FM.
BLOCK LS MBR
FONTANA SHALE MEMBER
DENNIS FORMATION
WINTERSET LIMESTONE MEMBER
STARK SHALE MBR
GALESBURG SHALE
BLOCK
LIMESTONE
FONTANA
SHALE
UPPER WINTERSET LIMESTONE
KC-3 CYCLE
KC-2 CYCLE
KC-1 CYCLE
WINTERSET
LIMESTONE
STARK SHALE
15,000 x exaggeration
Downlap of cycle KC-1 and KC-2
After Felton and Heckel (1996)


Ouachitas
Northern Shelf
Regional marker (condensed section)
Quivira Sh.
Stark Sh.
Nuyaka Creek Sequence Set
Hushpuckney Sh.
Nuyaka Creek Sh.
S-N Stratigraphic Cross Section
Central Oklahoma to southern Kansas
Nuyaka Creek Sequence Set, equivalent to East Mountain-Poseidon Fms.
(Lower Missourian)
200 ft
16 mi
Bennison (1989)
ARKOMA BASIN

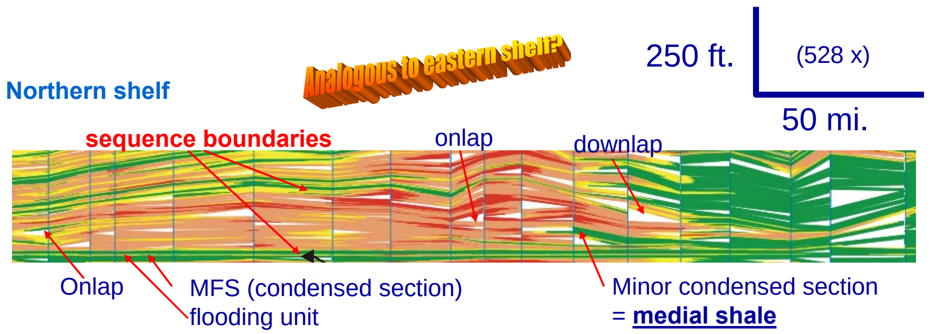

Nuyaka Creek Sequence
(Pleasanton Group – *base Missourian*)
Amoco Cox A-4, SW Kansas
GSU Boundary
Shallowing upward carbonate with smaller high-frequency cycles; overall shallowing
GSU Boundary
Flooding Surface
Peritidal
Subtidal
Peritidal
Subtidal
Peritidal
Subtidal
Condensed Section (C)
Flooding unit
Paleosol
C
darkened ooids, micritic cement
oomoldic
Dark gray shale
4720
Gray shale
Shaley
productids, echinoderms
mm laminated, pyritic fos. siltstone
4740
(Nuyaka Creek Shale)
caliche, rhizoliths
brown siltstone
20 ft
Condensed section
Flooding unit


Bounding surface between Missourian depositional sequences in the Kansas City area
Bethany Falls Ls. Mem. of Swope Ls. Fm.
Sequence boundary
Paleosol and underlying eroded Sniabar Limestone


Regional, autocorrelated, structural
Vsh Log Cross Section
Northwest
Southeast
Set
Genetic Unit
Heebner
Topeka
Deer Cr.
Lecompton
Oread
Muncie Creek
Toronto
Stanton
Springhill
Merriam
Argentine
Iola
Nuyaka Creek
Quivira
Wea
Stark
Hushpuckney
Mound City
Nuyaka Cr.
Virgilian carbonate bank margin
Oread Ls.
GSU
Douglas
Lower and Upper Missourian (Kansas City and Lansing) carbonate bank margins
500 ft.
0 50 mi.
0 80 km.
• Hotter colors = lower Vsh, i.e., clean carbonates and sand;
• green = fine grained clastics


NW-SE Regional Stratigraphic Vsh Log Cross Section
West-Central Kansas
Datum = Heebner Shale (Finis Shale)
NW
SE
Set
GSU
Topeka
Heebner
Deer Creek
Lecompton
Oread
Muncie Cr.
Topeka
Stanton
Springhill
Merriam
Argentine
Iola
Nuyaka Cr.
Quivira
Wea
Stark
Hushpuckney
Mound City
Nuyaka Cr.
Oread sequence
Snyderville Sh.
Lansing Group Shelf Margin
Stalnaker Ss.
500 ft
50 miles

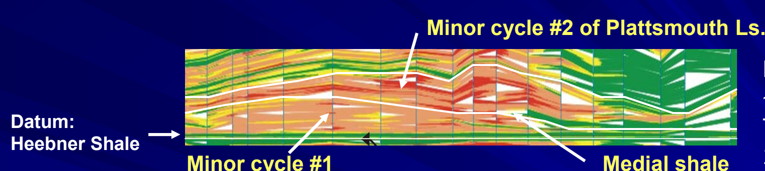
Regional Oread sequence development



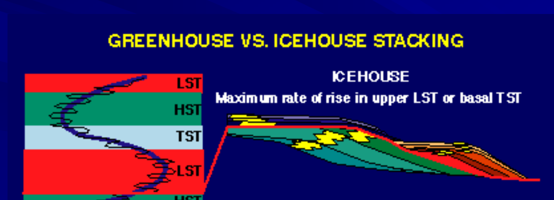
extracted from autocorrelated stratigraphic Vsh cross section

- generally shallowing upward, cleaner (lower Vsh) carbonate
- "slug-shaped" depositional sequence, highly extended along broad shelf to shelf margin
- thin transgressive limestone (Toronto Ls.), condensed section (Heebner Shale), regressive carbonate (Plattsmouth Ls.)
- Oread depositional sequence interrupted by high-frequency sequences
- "medial" shale and inferred downlap and onlap intervals do not correlate in adjoining wells
- cleaner (lower Vsh) carbonate buildup (grainstone and phylloid algal mounds) along shelf break
- clastics and carbonates progressive filling in embayment created by subsidence

Oread Sequence



Distance = ~150 miles
Thickness = 120 ft window



BEG-RCRL (1996)

Extracted from previous stratigraphic Vsh cross section

Northern shelf outside Lawrence, KS

Medial shale

Plattsmouth Limestone

Heebner Sh

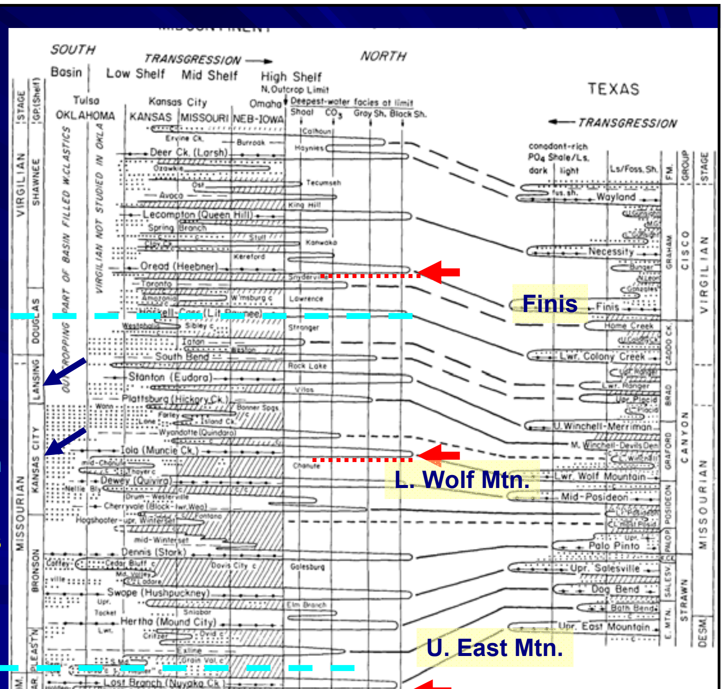
Leavenworth Ls.

Snyderville Shale

Ham Quarry, Perry, Ks

Correlation of Upper Pennsylvanian Cyclothems between KS and Texas

Boardman and Heckel (1989)

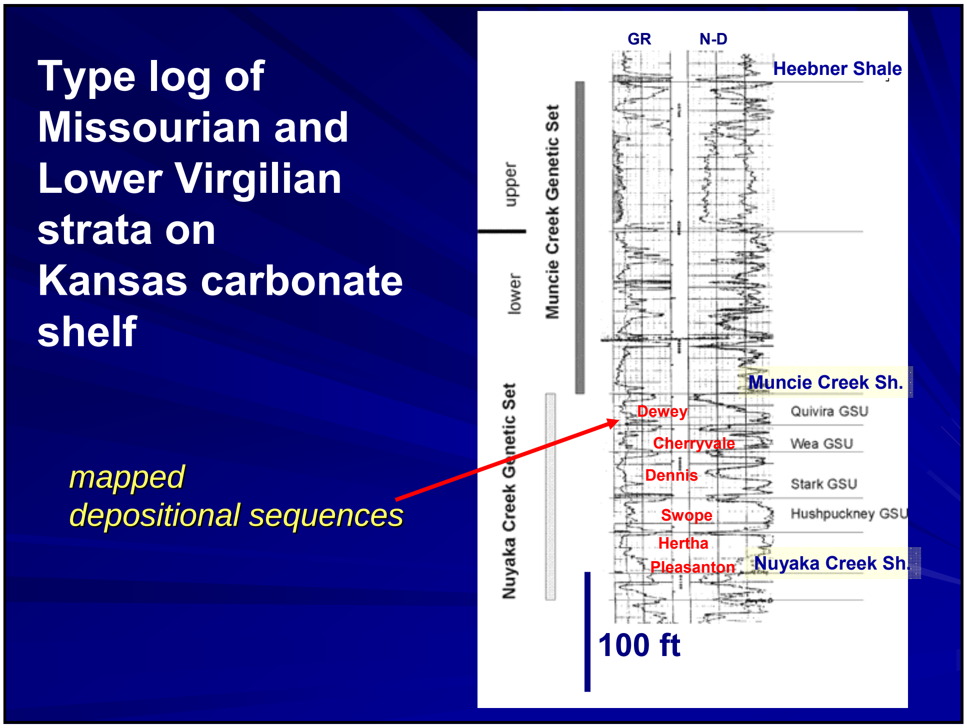


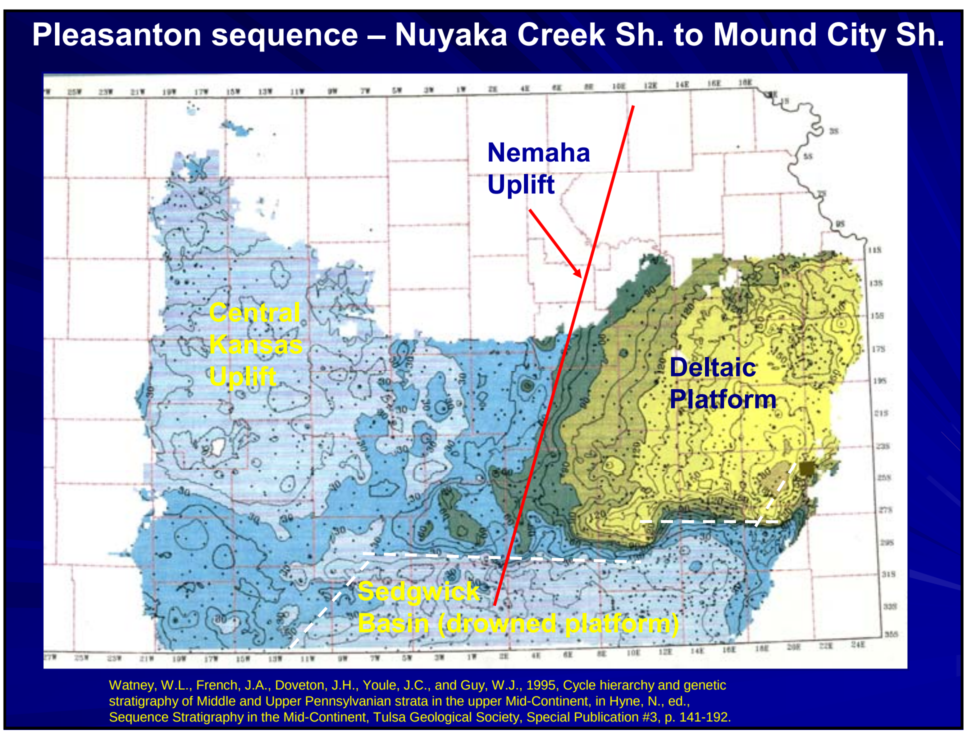
Cisco

Canyon

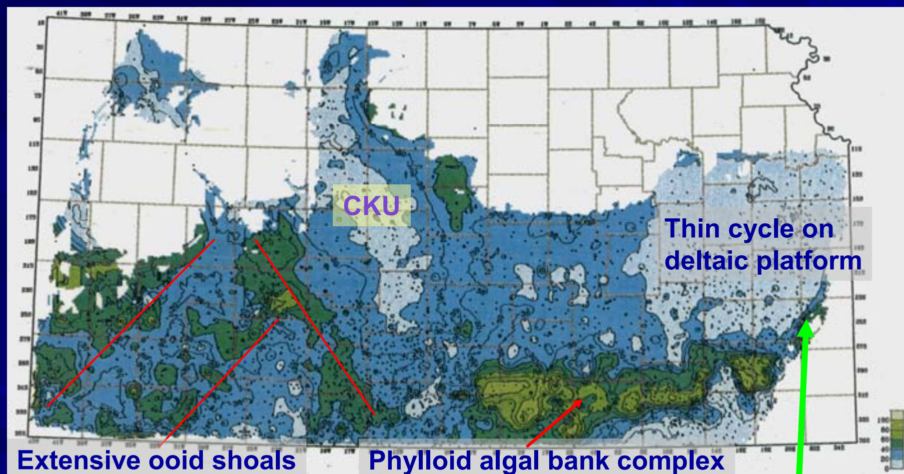
Boundaries of sequence sets

Strawn


Type log of Missourian and Lower Virgilian strata on Kansas carbonate shelf
mapped depositional sequences
GR
N-D
Heebner Shale
upper
lower
Muncie Creek Genetic Set
Nuyaka Creek Genetic Set
Muncie Creek Sh.
Dewey
Quivira GSU
Cherryvale
Wea GSU
Dennis
Stark GSU
Swope
Hushpuckney GSU
Hertha
Pleasanton
Nuyaka Creek Sh.
100 ft

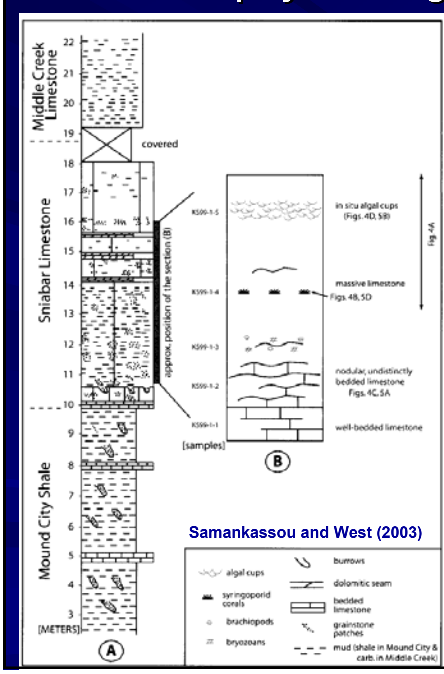

Pleasanton sequence – Nuyaka Creek Sh. to Mound City Sh.
Nemaha Uplift
Central Kansas Uplift
Deltaic Platform
Sedgwick Basin (drowned platform)
Watney, W.L., French, J.A., Doveton, J.H., Youle, J.C., and Guy, W.J., 1995, Cycle hierarchy and genetic stratigraphy of Middle and Upper Pennsylvanian strata in the upper Mid-Continent, in Hyne, N., ed., Sequence Stratigraphy in the Mid-Continent, Tulsa Geological Society, Special Publication #3, p. 141-192.

Hertha Sequence (Mound City Shale to Hushpuckney Shale)



Uniontown Sniabar phylloid algal bank exposure

Sniabar phylloid algal bank, Uniontown, KS

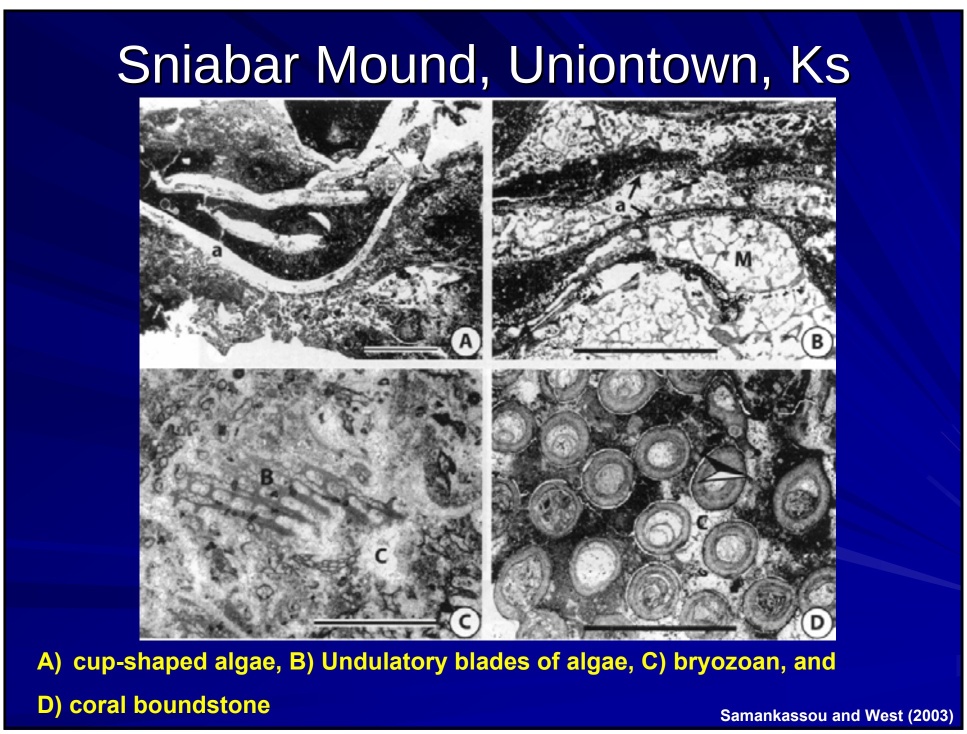


Samankassou and West (2003)

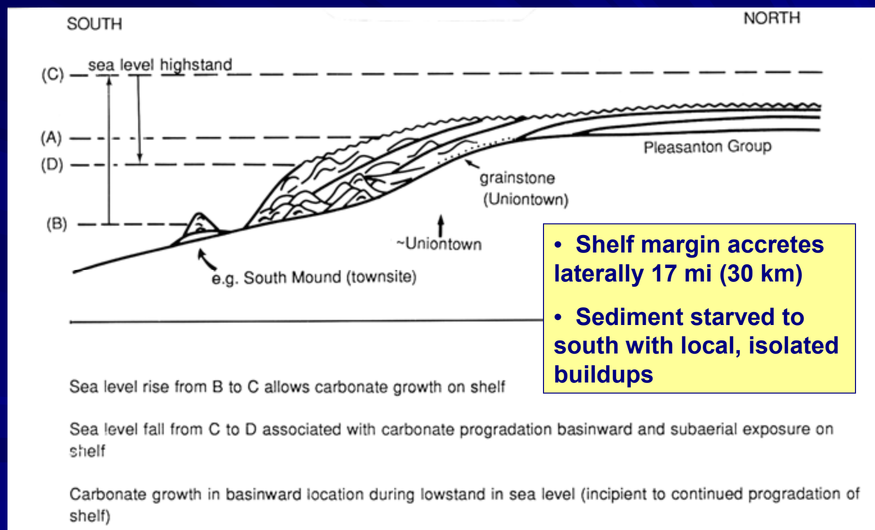
In situ algal cups

Samankassou and West (2003)


Sniabar Limestone
from Uniontown phylloid algal bank
Rugose coral
Pore space
w/partial fill
by silt
1 inch
Tabulate coral
Tabulate coral
bioturbation
Phylloid algae


Sniabar Mound, Uniontown, Ks
A) cup-shaped algae, B) Undulatory blades of algae, C) bryozoan, and
D) coral boundstone
Samankassou and West (2003)

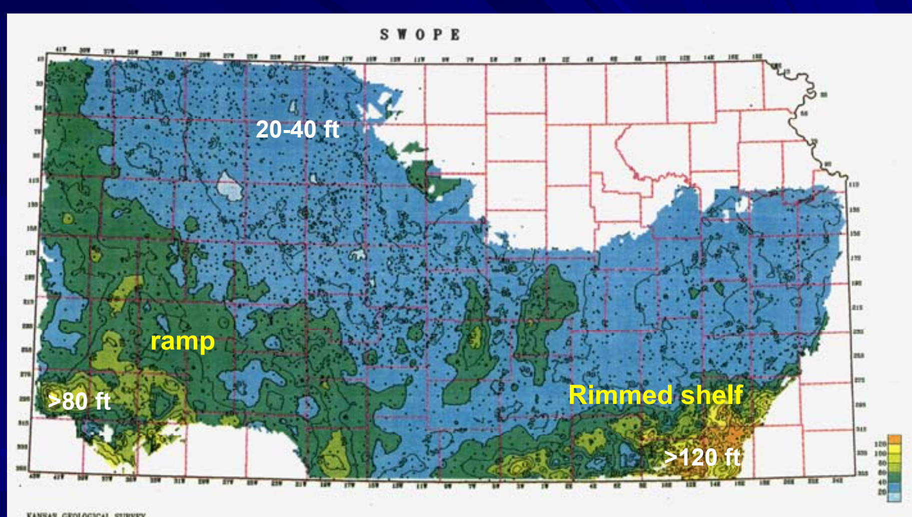
Hertha sequence in eastern Kansas, 100 ft thick on lower rimmed shelf margin



- **Shelf margin accretes laterally 17 mi (30 km)**
- **Sediment starved to south with local, isolated buildups**

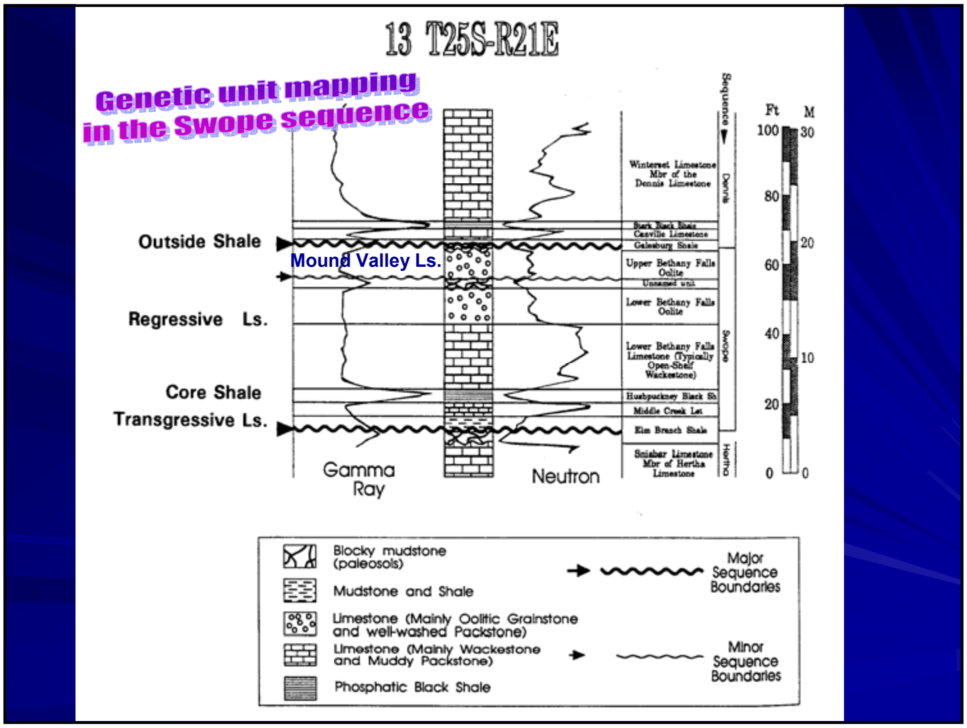
Watney et al. (1989)

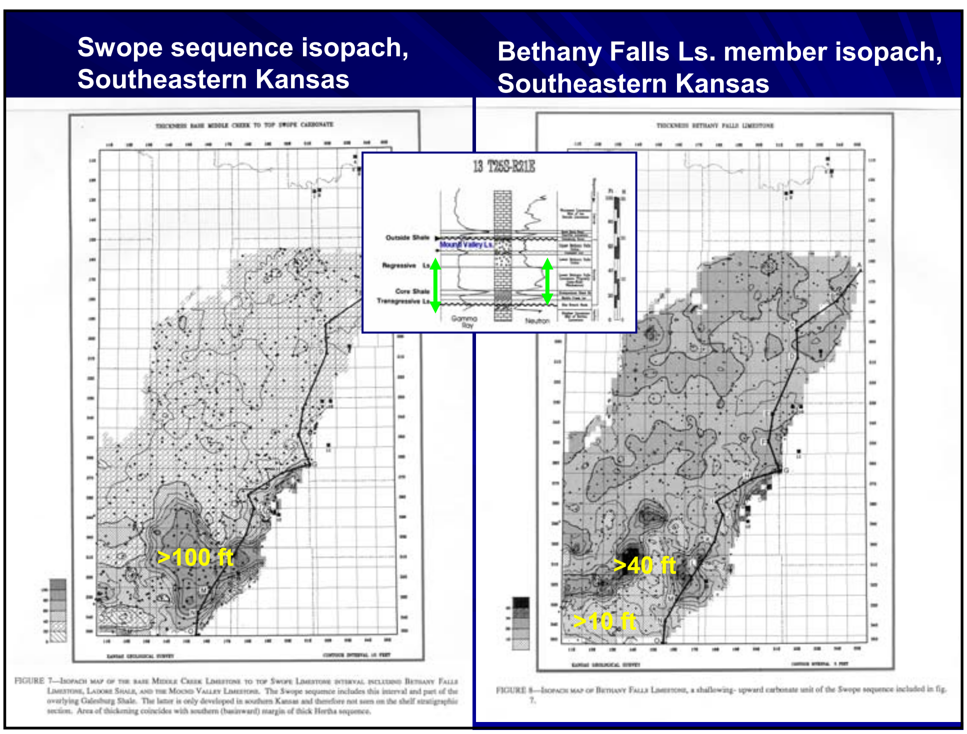
Swope sequence isopach (Hushpuckney Shale to Stark Shale)

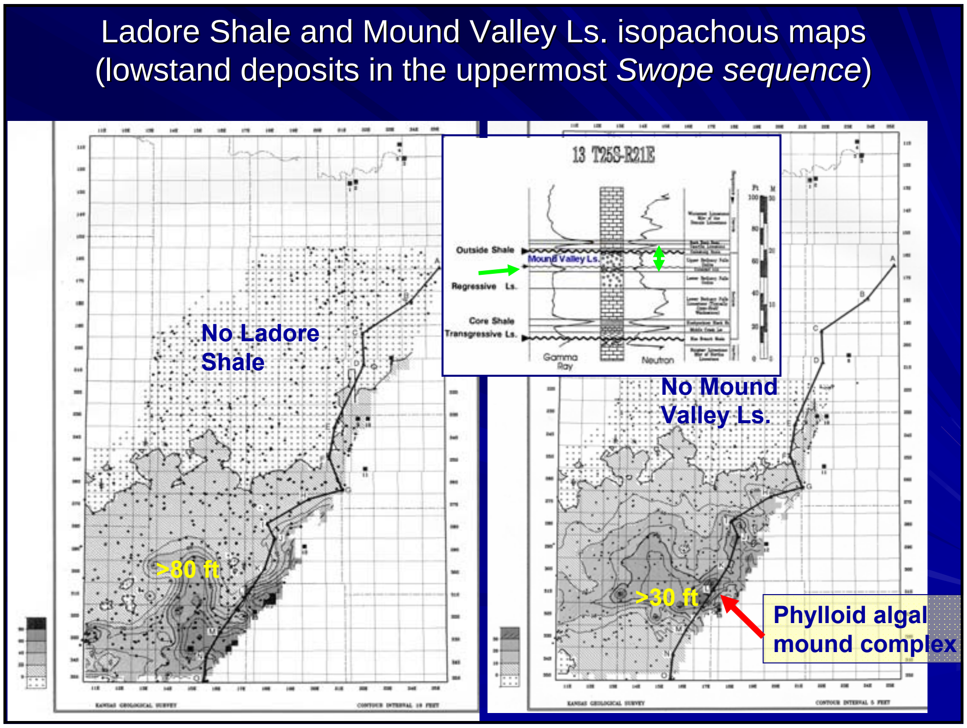


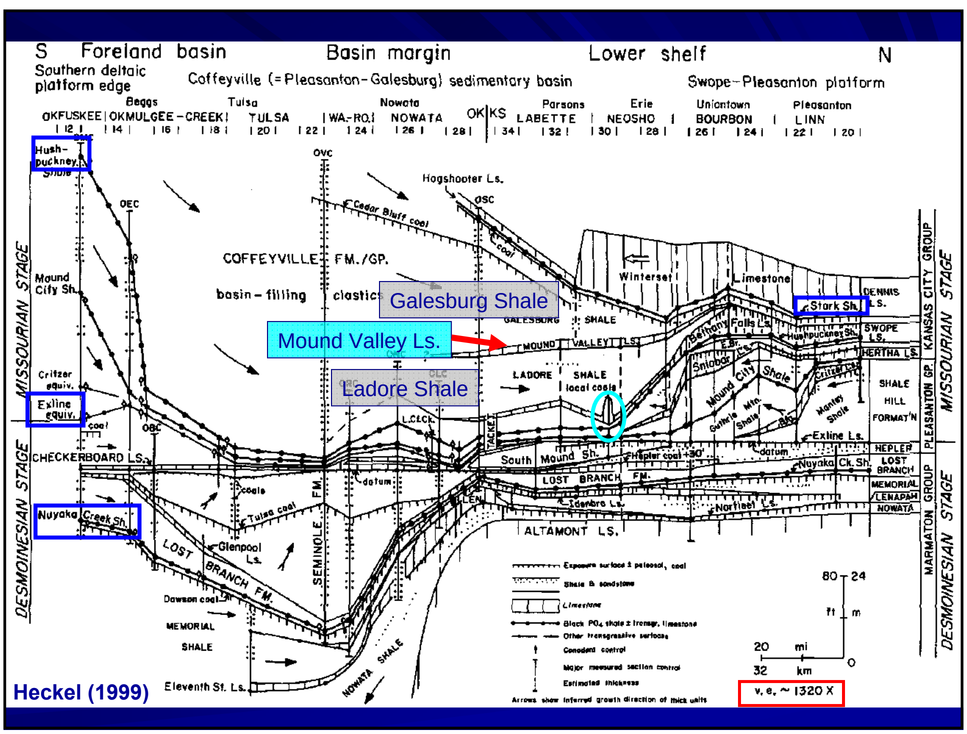
Rimmed shelf on east with narrow belt of *ooid shoals & lowstand clastics*

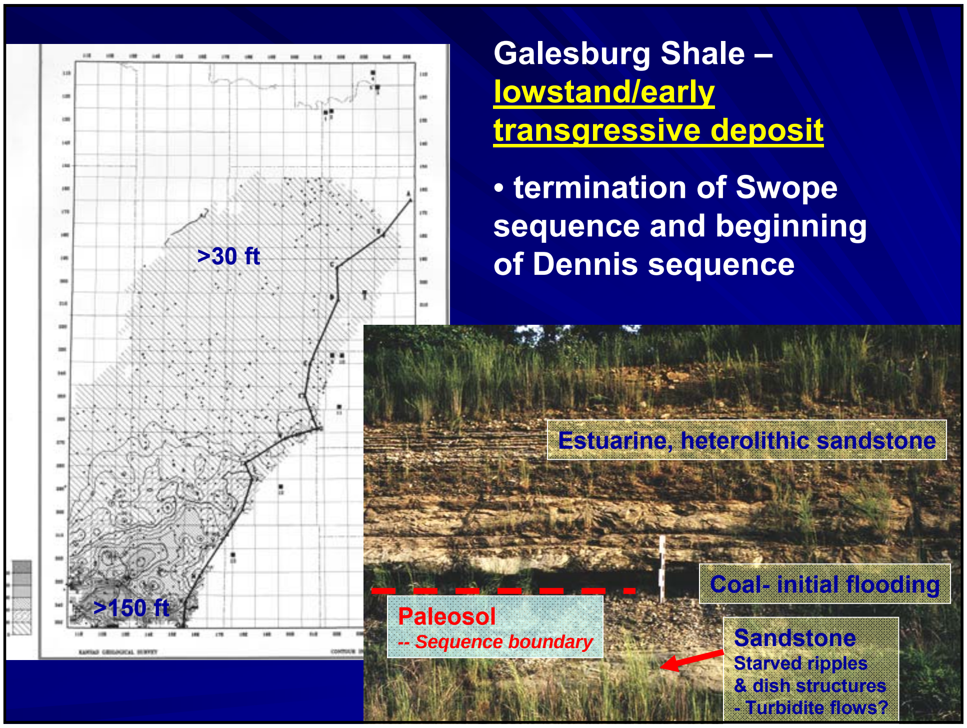
Ramp on west – *extensive tract of stacked ooid shoals (parasequence & minor cycles)*

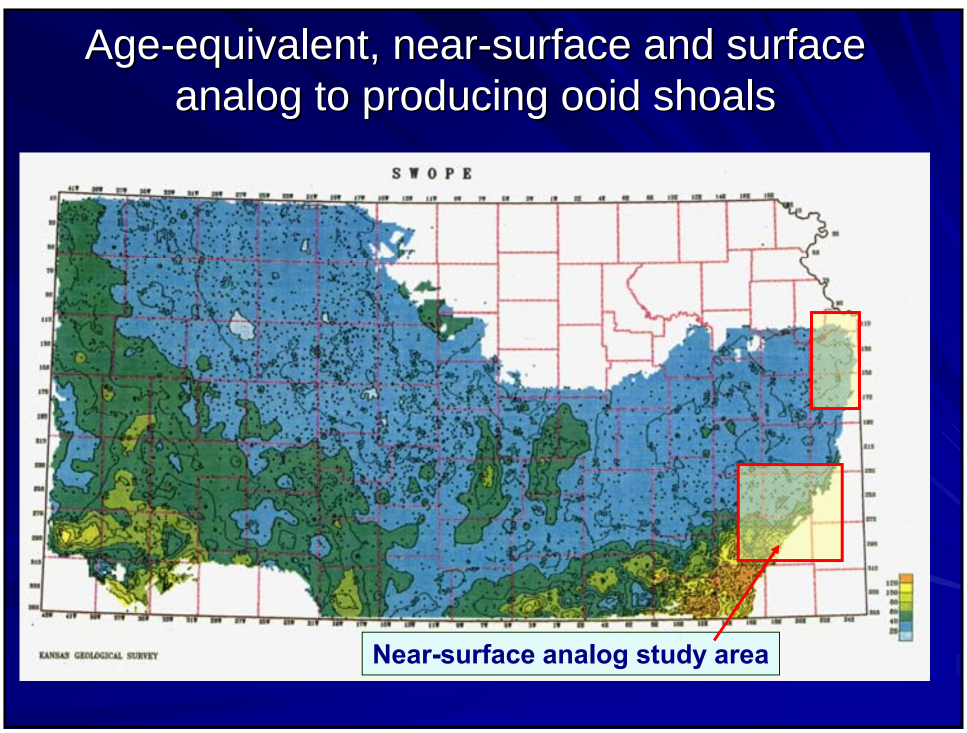

13 T25S-R21E
Genetic unit mapping
in the Swope sequence
Outside Shale
Mound Valley Ls.
Regressive Ls.
Core Shale
Transgressive Ls.
Gamma
Ray
Neutron
Sequence
Ft
M
Winterset Limestone Mbr of the Dennis Limestone
Dennis
Galesburg Shale
Upper Bethany Falls Oolite
Unnamed unit
Lower Bethany Falls Oolite
Swope
Lower Bethany Falls Limestone (Typically Open-Shelf Wackestone)
Hushpuckney Black Sh
Middle Creek Ls.
Elm Branch Shale
Sniabar Limestone Mbr of Hertha Limestone
Hertha
Blocky mudstone
(paleosols)
Mudstone and Shale
Limestone (Mainly Oolitic Grainstone and well-washed Packstone)
Limestone (Mainly Wackestone and Muddy Packstone)
Phosphatic Black Shale
Major
Sequence
Boundaries
Minor
Sequence
Boundaries

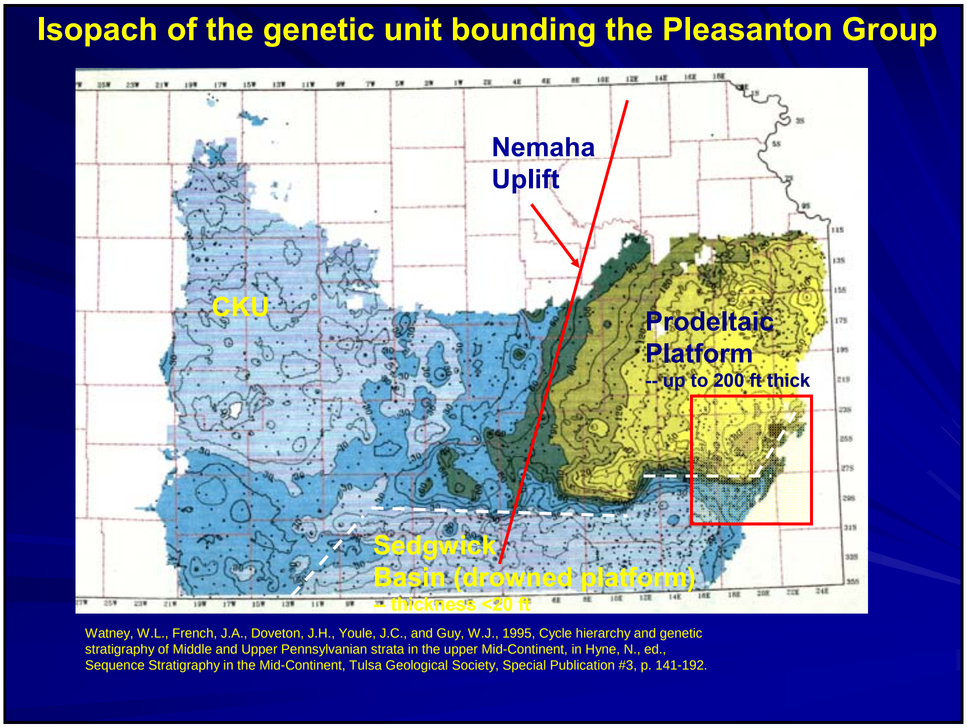

Swope sequence isopach,
Southeastern Kansas
Bethany Falls Ls. member isopach,
Southeastern Kansas
13 T25S-R21E
>100 ft
>40 ft
>10 ft


Ladore Shale and Mound Valley Ls. isopachous maps
(lowstand deposits in the uppermost *Swope sequence*)
No Ladore Shale
>80 ft
13 T25S-R21E
Outside Shale
Mound Valley Ls.
Regressive Ls.
Core Shale
Transgressive Ls.
Gamma Ray
Neutron
No Mound Valley Ls.
>30 ft
Phylloid algal mound complex

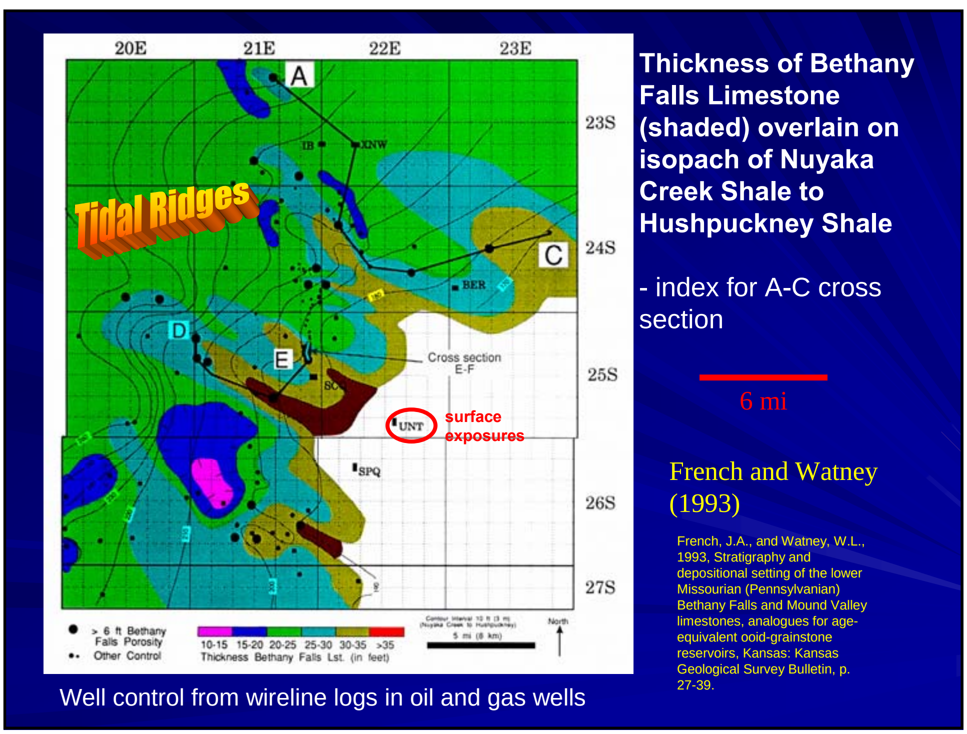

S
Foreland basin
Basin margin
Lower shelf
N
Southern deltaic platform edge
Coffeyville (=Pleasanton-Galesburg) sedimentary basin
Swope-Pleasanton platform
COFFEYVILLE FM./GP.
basin-filling clastics
Galesburg Shale
Mound Valley Ls.
Ladore Shale
Hogshooter Ls.
Hush-puckney Shale
Mound City Sh.
Exline equiv.
CHECKERBOARD LS.
Nuyaka Creek Sh.
LOST BRANCH FM.
SEMINOLE FM.
NOWATA SHALE
ALTAMONT LS.
MISSOURIAN STAGE
DESMOINESIAN STAGE
KANSAS CITY GROUP
PLEASANTON GP.
MARMATON GROUP
Heckel (1999)
v.e. ~ 1320 X


Galesburg Shale – lowstand/early transgressive deposit
• termination of Swope sequence and beginning of Dennis sequence
>30 ft
>150 ft
Estuarine, heterolithic sandstone
Coal- initial flooding
Paleosol
-- Sequence boundary
Sandstone
Starved ripples
& dish structures
- Turbidite flows?


Age-equivalent, near-surface and surface analog to producing ooid shoals
S W O P E
KANSAS GEOLOGICAL SURVEY
Near-surface analog study area

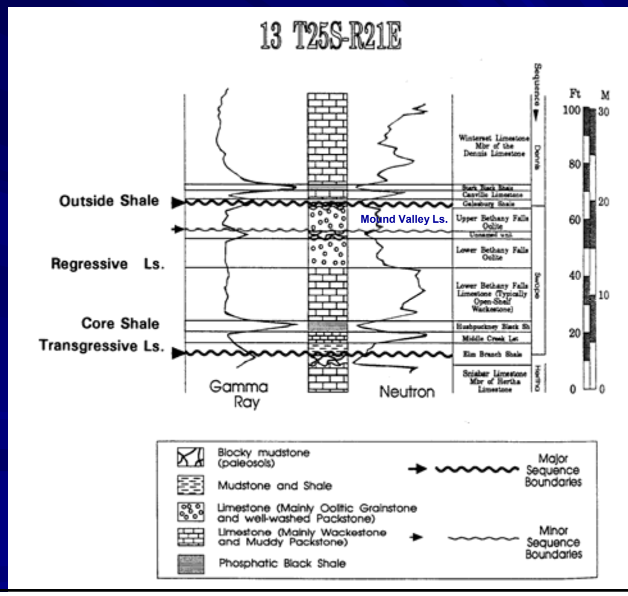


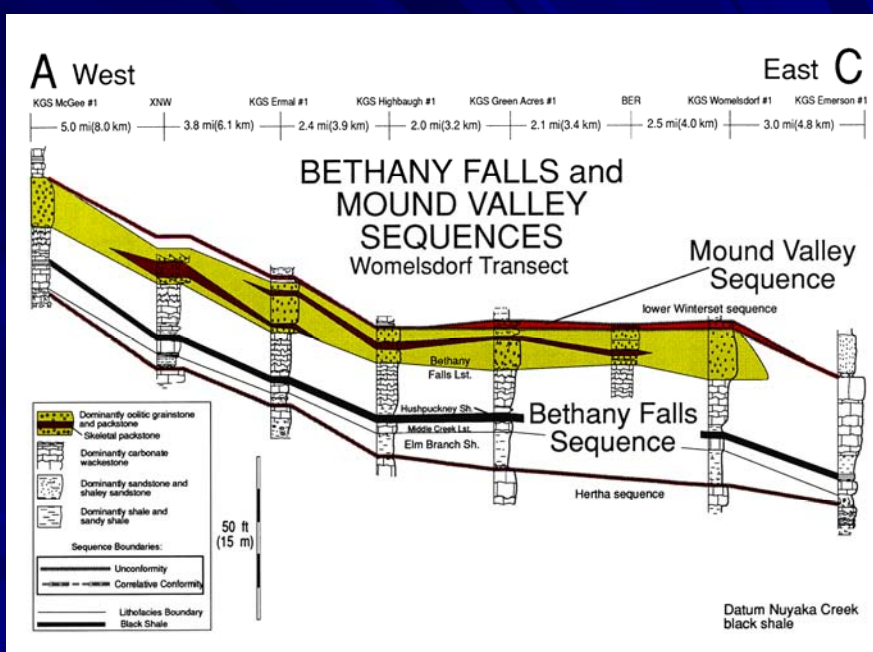
Isopach of the genetic unit bounding the Pleasanton Group
Nemaha Uplift
CKU
Prodeltaic Platform
-- up to 200 ft thick
Sedgwick Basin (drowned platform)
-- thickness <20 ft
Watney, W.L., French, J.A., Doveton, J.H., Youle, J.C., and Guy, W.J., 1995, Cycle hierarchy and genetic stratigraphy of Middle and Upper Pennsylvanian strata in the upper Mid-Continent, in Hyne, N., ed., Sequence Stratigraphy in the Mid-Continent, Tulsa Geological Society, Special Publication #3, p. 141-192.



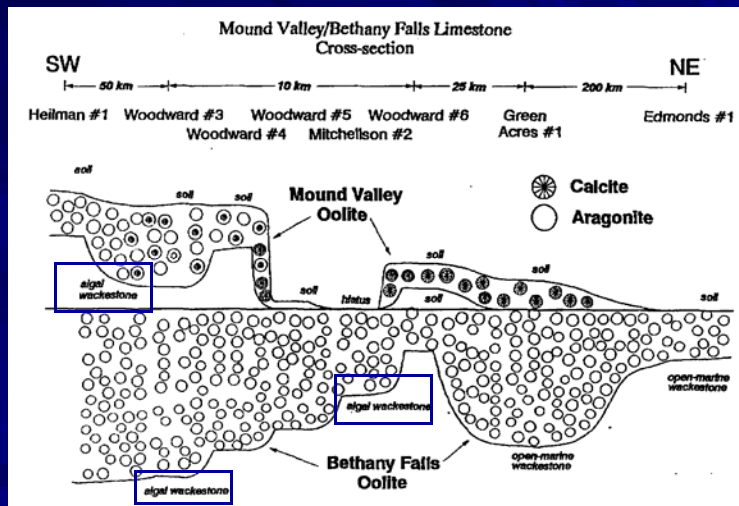
Thickness of Bethany Falls Limestone (shaded) overlain on isopach of Nuyaka Creek Shale to Hushpuckney Shale
- index for A-C cross section
6 mi
French and Watney (1993)
French, J.A., and Watney, W.L., 1993, Stratigraphy and depositional setting of the lower Missourian (Pennsylvanian) Bethany Falls and Mound Valley limestones, analogues for age-equivalent ooid-grainstone reservoirs, Kansas: Kansas Geological Survey Bulletin, p. 27-39.
20E
21E
22E
23E
23S
24S
25S
26S
27S
A
C
D
E
Tidal Ridges
Cross section E-F
surface exposures
UNT
SPQ
BER
> 6 ft Bethany Falls Porosity
Other Control
10-15 15-20 20-25 25-30 30-35 >35
Thickness Bethany Falls Lst. (in feet)
North
Well control from wireline logs in oil and gas wells

Woodward transect oolite shoal facies

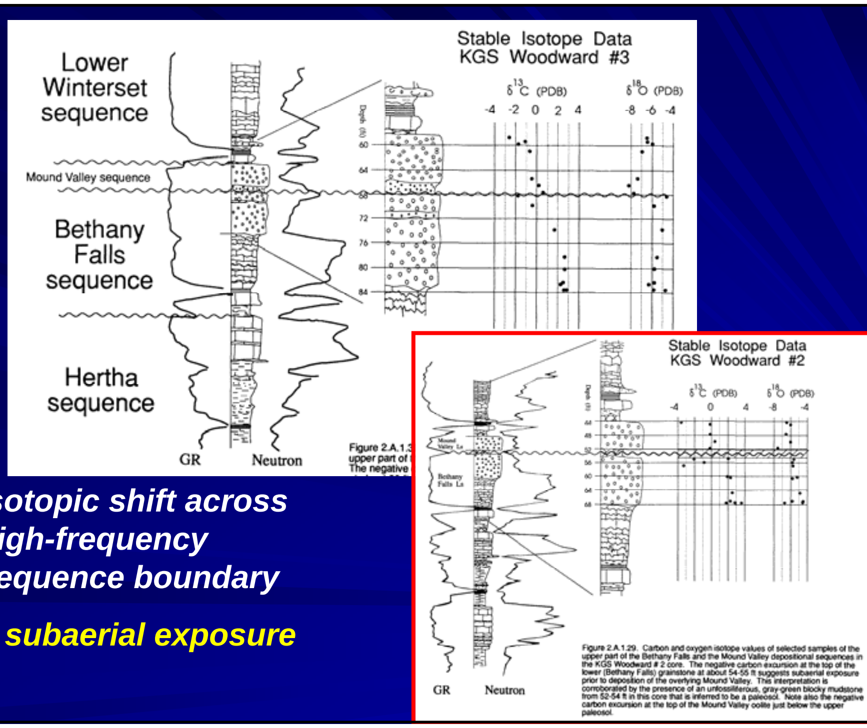




Swope sequence with two temporally oolites separated by paleosol

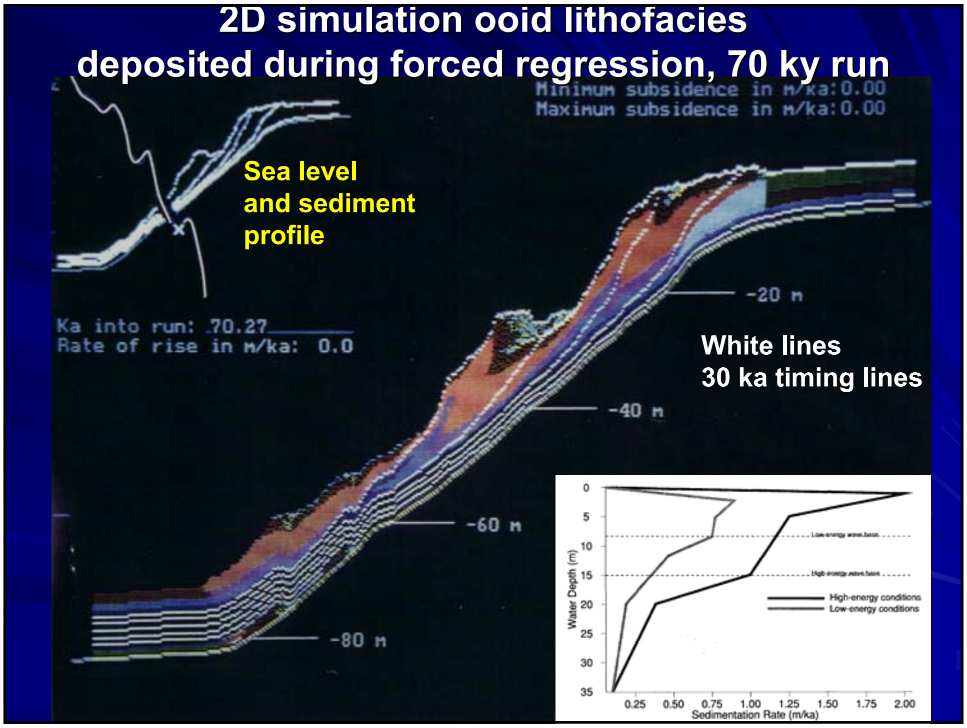


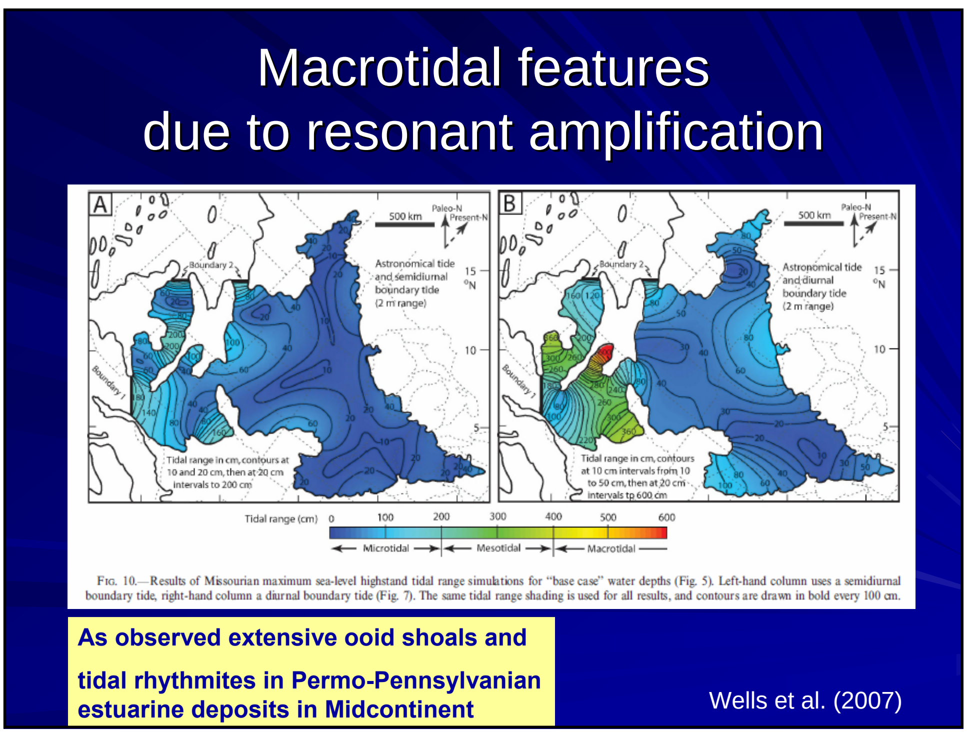
Watson (1997)

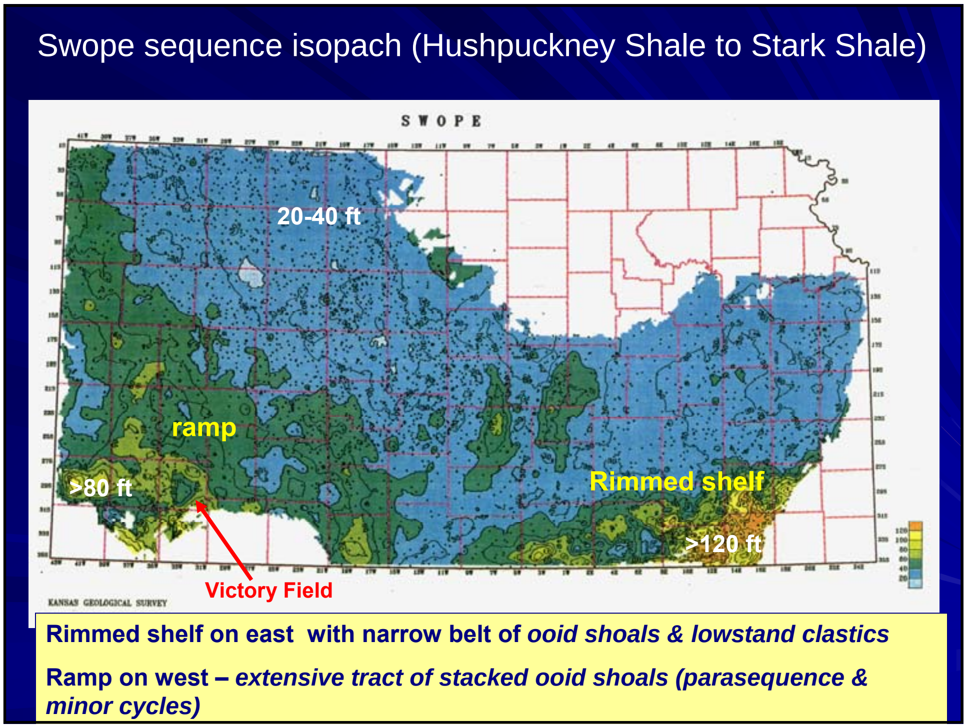


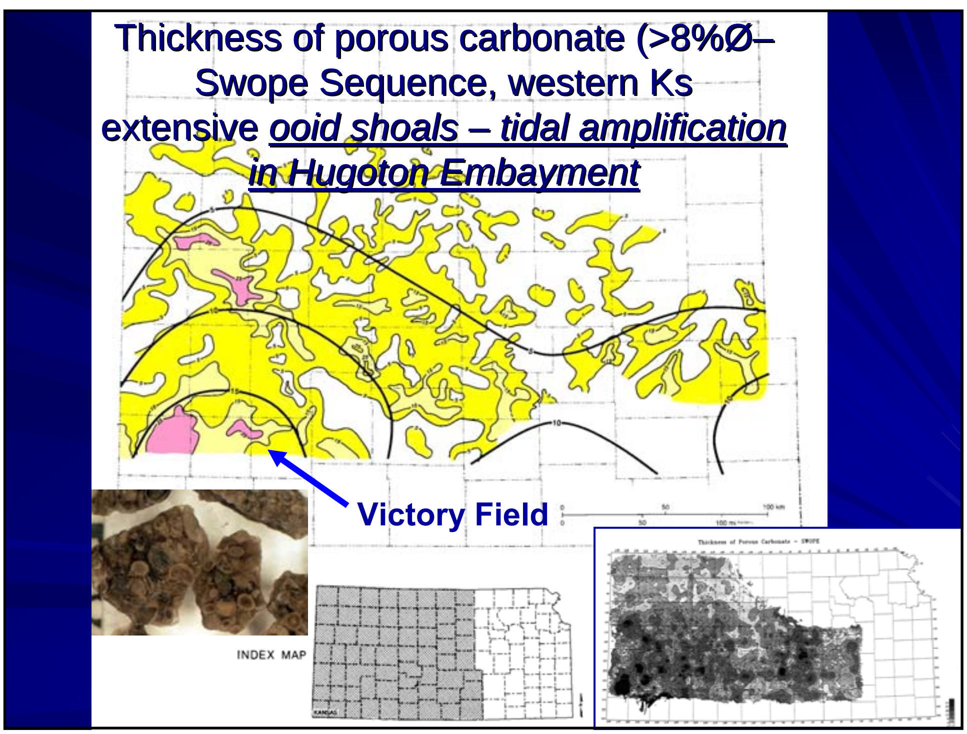
Isotopic shift across high-frequency sequence boundary

= subaerial exposure

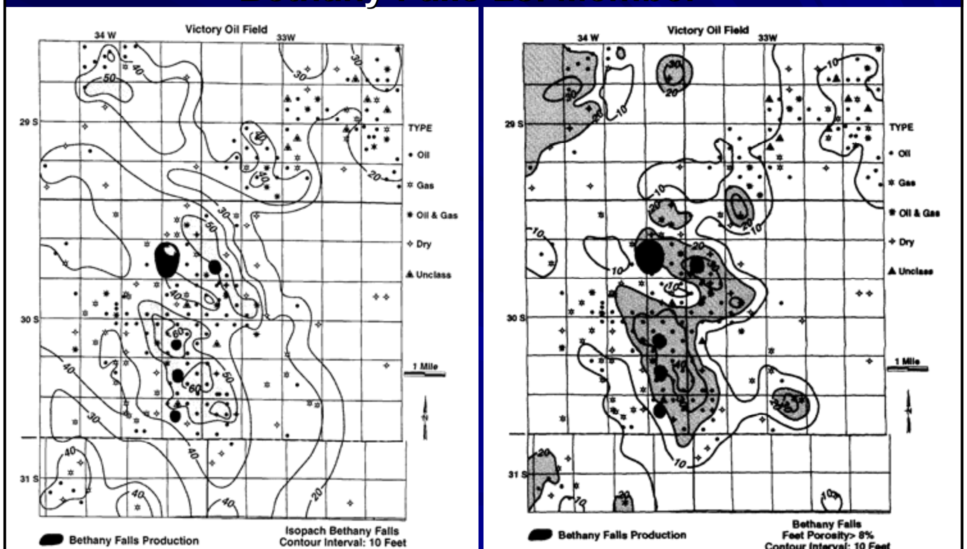

2D simulation ooid lithofacies
deposited during forced regression, 70 ky run
Minimum subsidence in m/ka: 0.00
Maximum subsidence in m/ka: 0.00
Sea level
and sediment
profile
Ka into run: 70.27
Rate of rise in m/ka: 0.0
-20 m
White lines
30 ka timing lines
-40 m
-60 m
-80 m
Water Depth (m)
Sedimentation Rate (m/ka)
Low-energy wave base
High-energy wave base
High-energy conditions
Low-energy conditions


Macrotidal features
due to resonant amplification
A
B
500 km
Paleo-N
Present-N
Boundary 2
Boundary 1
Astronomical tide and semidiurnal boundary tide (2 m range)
Astronomical tide and diurnal boundary tide (2 m range)
Tidal range in cm, contours at 10 and 20 cm, then at 20 cm intervals to 200 cm
Tidal range in cm, contours at 10 cm intervals from 10 to 50 cm, then at 20 cm intervals to 600 cm
Tidal range (cm)
Microtidal
Mesotidal
Macrotidal
FIG. 10.—Results of Missourian maximum sea-level highstand tidal range simulations for "base case" water depths (Fig. 5). Left-hand column uses a semidiurnal boundary tide, right-hand column a diurnal boundary tide (Fig. 7). The same tidal range shading is used for all results, and contours are drawn in bold every 100 cm.
As observed extensive ooid shoals and
tidal rhythmites in Permo-Pennsylvanian
estuarine deposits in Midcontinent
Wells et al. (2007)


Swope sequence isopach (Hushpuckney Shale to Stark Shale)
S W O P E
20-40 ft
ramp
>80 ft
Rimmed shelf
>120 ft
Victory Field
KANSAS GEOLOGICAL SURVEY
Rimmed shelf on east with narrow belt of *ooid shoals & lowstand clastics*
Ramp on west – *extensive tract of stacked ooid shoals (parasequence & minor cycles)*


Thickness of porous carbonate (>8%Ø– Swope Sequence, western Ks
extensive *ooid shoals – tidal amplification in Hugoton Embayment*
Victory Field
INDEX MAP

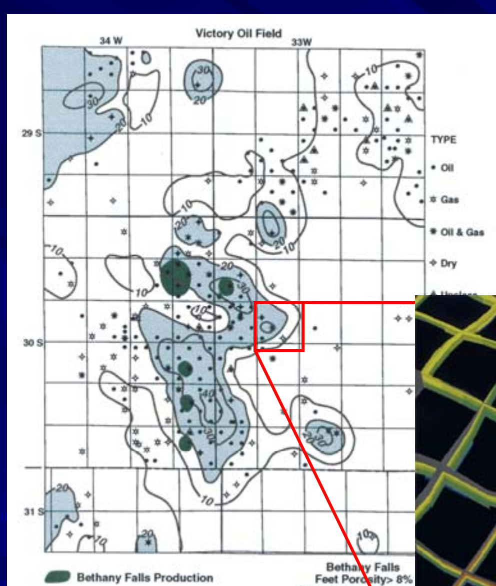
Victory Field – gross h, ft porosity in Bethany Falls Ls. Member



- Oolite buildup over crest of structure
- Effective pay in oomoldic reservoir difficult to evaluate, potential pay behind pipe

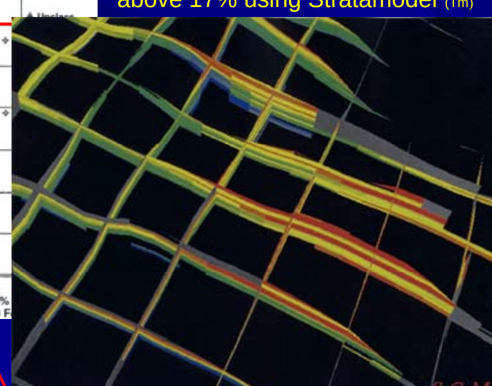
Victory Field
Bethany Falls Limestone

• Isolated production due to difficulty in evaluating pay in oomoldic porosity
• Most of interval behind pipe

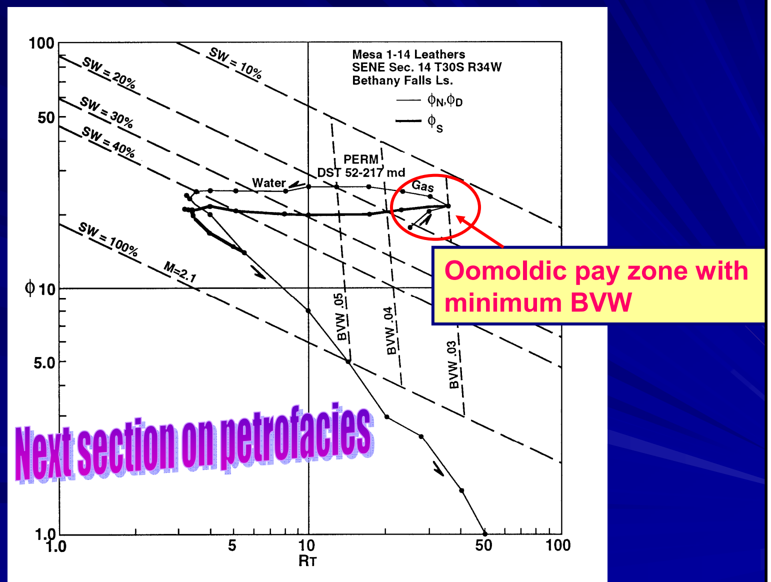


Watney, W.L., French, J.A., and Guy, W.J., 1996, Modeling of Petroleum Reservoirs in Pennsylvanian Strata of the Midcontinent, USA, in, Forester, A., and Merriam, D.F., eds., Spatial Modeling of Geologic Systems, Plenum Press, p. 43-77.

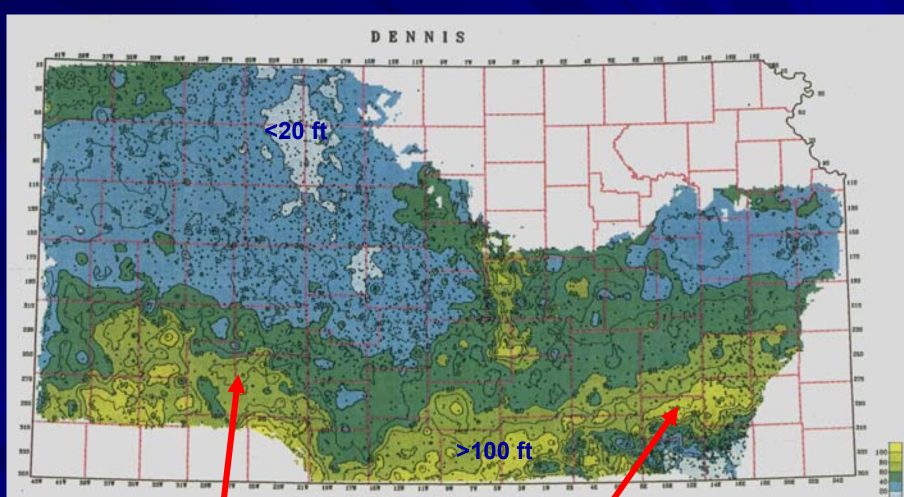
3-D visualization of porosity above 17% using Stratamodel (Tm)



Super Pickett crossplot – pore typing and petrophysical modeling of oomoldic pay



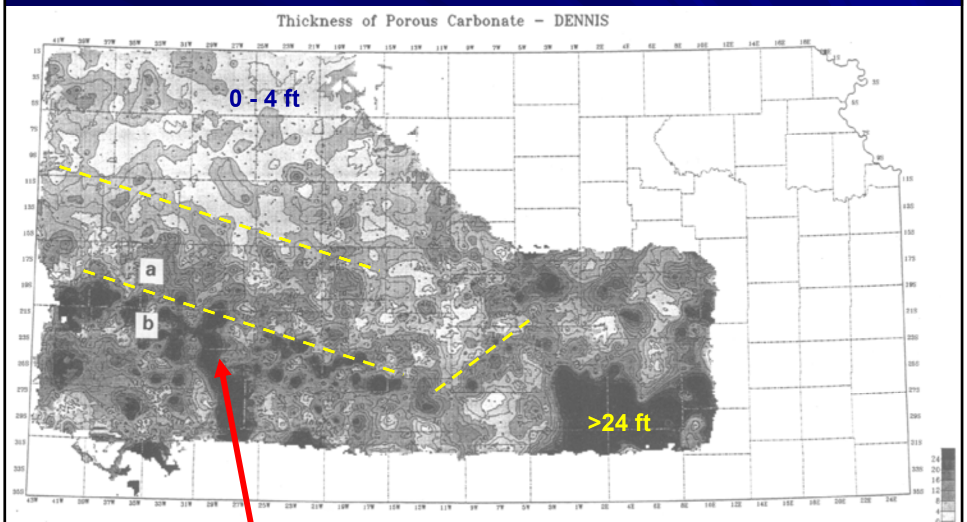
Dennis sequence thickness (Stark Shale – base Cherryvale Fm.)



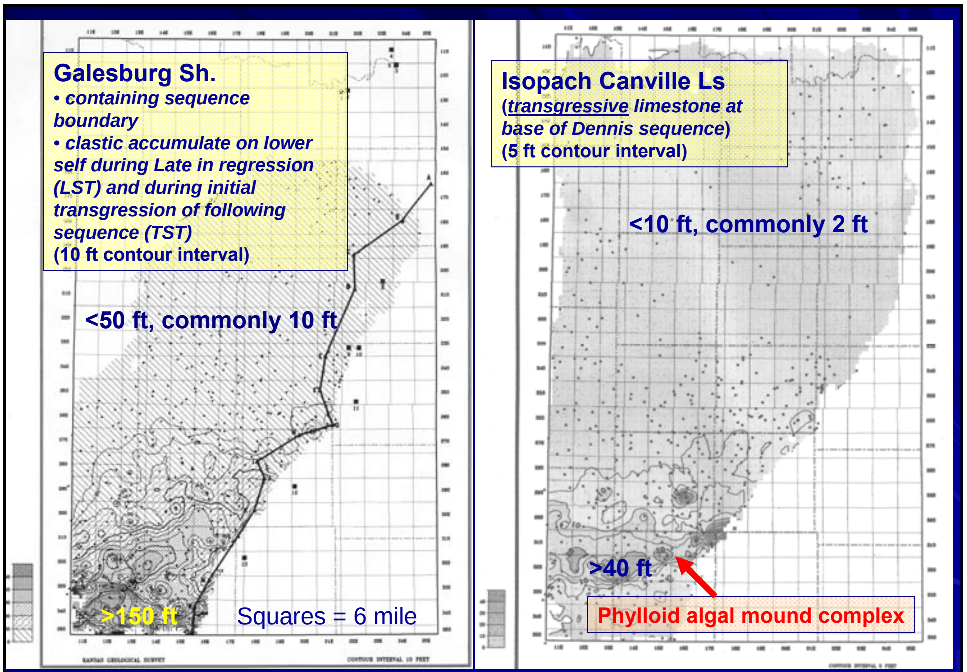
Shallow lithofacies predominately oolitic -- embayment with tidal amplification

Predominantly phylloid algal mounds and some oolite

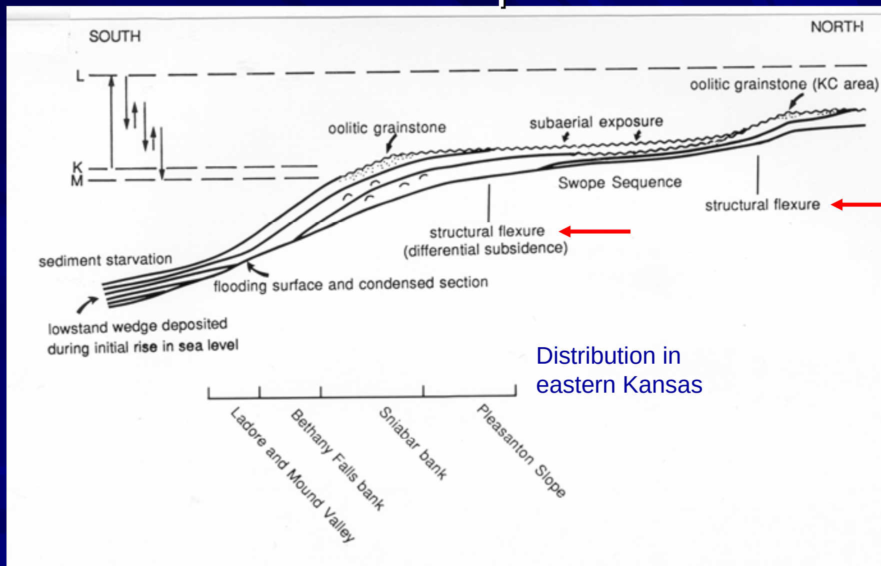
Dennis Sequence, thickness of porous carbonate >8% Ø



Predominately oolitic (cluster of shoals along break in slope along shelf)
-- embayment with tidal amplification



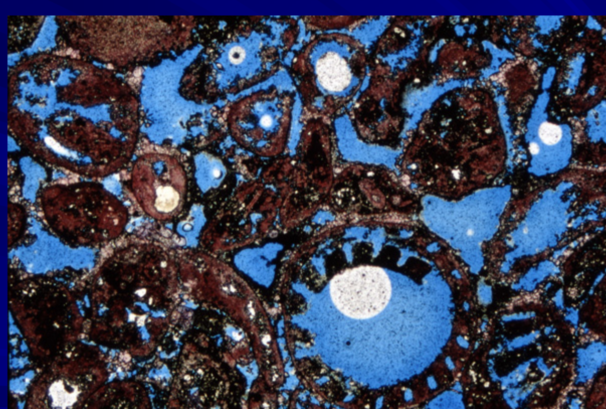
Dennis sequence

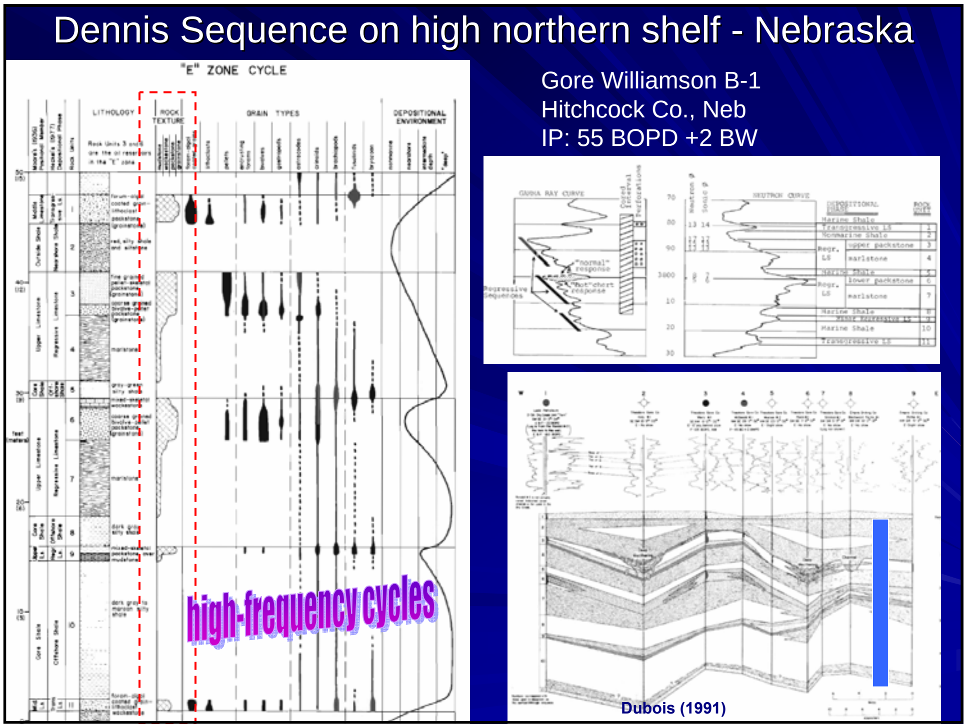


Sea level rise K to L - major marine inundation with major shelfward shift in carbonate deposition; renewed subsidence results in northward backstepping of shelf margin. Sea level fall from L to M with minor oscillations results in basinward progradation of carbonates.

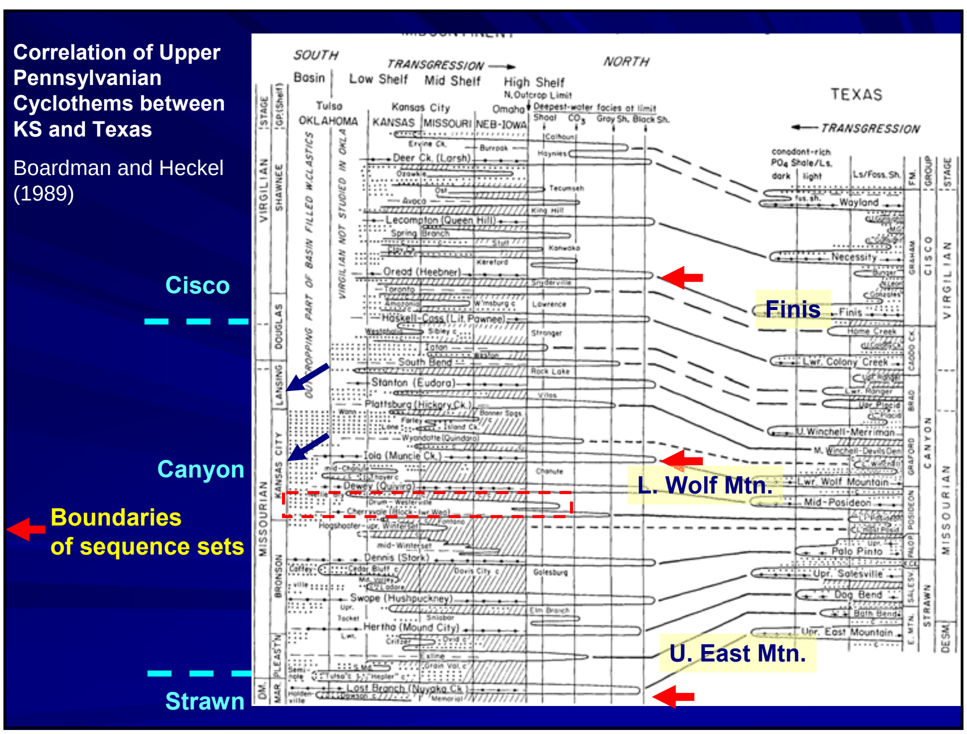
Watney et al. (1989)

Dennis Sequence - High shelf Hitchcock County, Nebraska

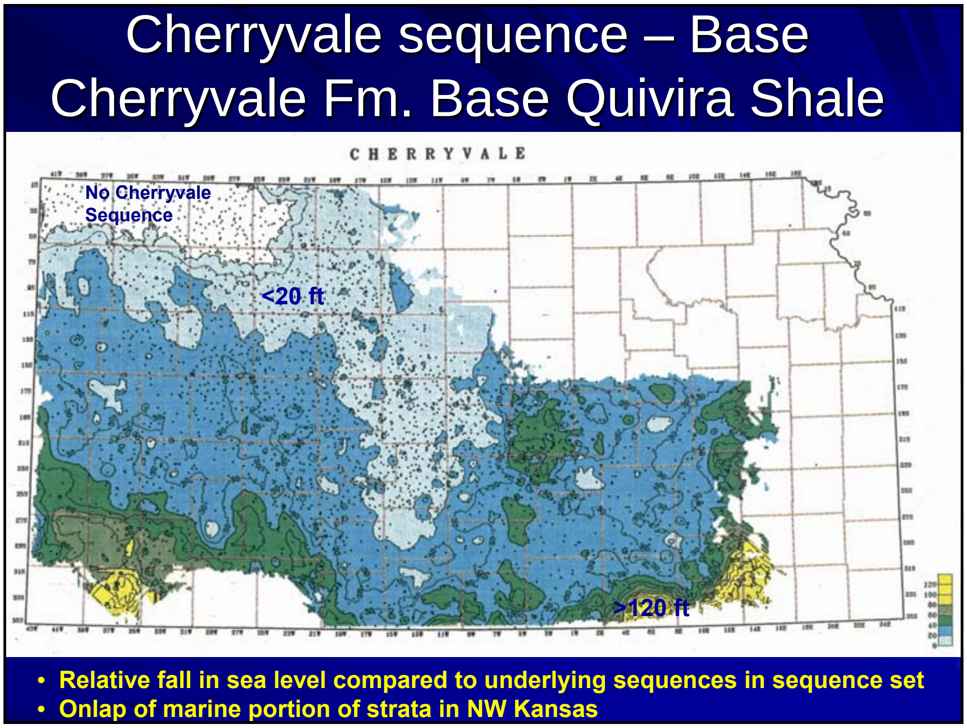


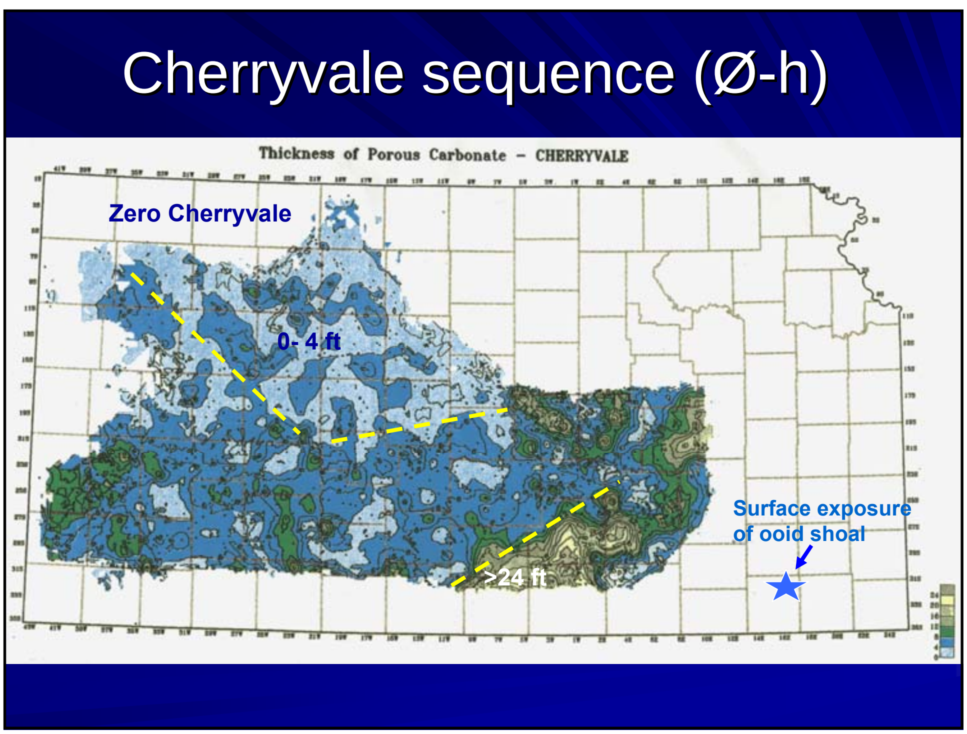


Dennis Sequence on high northern shelf - Nebraska
"E" ZONE CYCLE
LITHOLOGY
ROCK TEXTURE
GRAIN TYPES
DEPOSITIONAL ENVIRONMENT
high-frequency cycles
Gore Williamson B-1
Hitchcock Co., Neb
IP: 55 BOPD +2 BW
GAMMA RAY CURVE
NEUTRON CURVE
Dubois (1991)

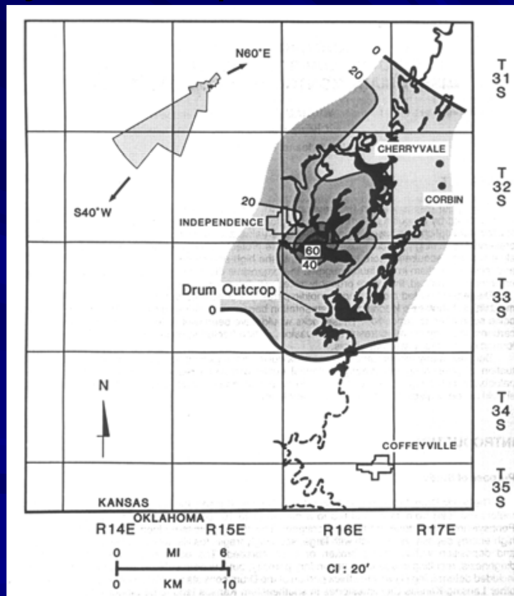


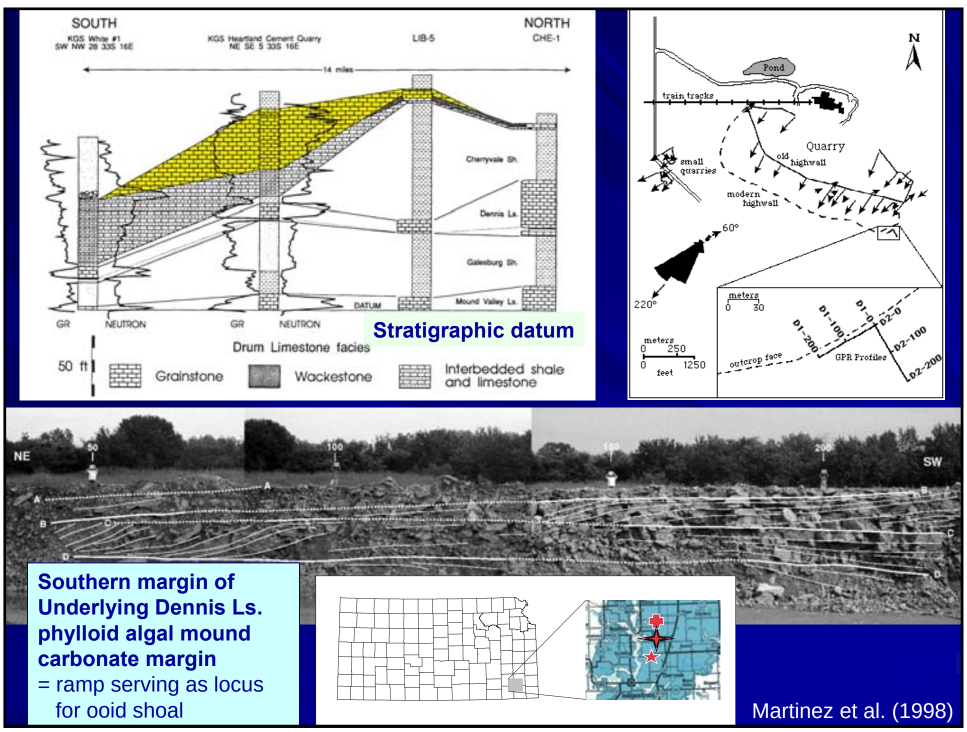
Correlation of Upper Pennsylvanian Cyclothems between KS and Texas
Boardman and Heckel (1989)
Cisco
Canyon
Boundaries of sequence sets
Strawn
SOUTH
TRANSGRESSION
NORTH
Basin
Low Shelf
Mid Shelf
High Shelf
OKLAHOMA
KANSAS
MISSOURI
NEB-IOWA
TEXAS
TRANSGRESSION
VIRGILIAN
MISSOURIAN
Finis
L. Wolf Mtn.
U. East Mtn.


Cherryvale sequence – Base
Cherryvale Fm. Base Quivira Shale
CHERRYVALE
No Cherryvale
Sequence
<20 ft
>120 ft
• Relative fall in sea level compared to underlying sequences in sequence set
• Onlap of marine portion of strata in NW Kansas


Cherryvale sequence (Ø-h)
Thickness of Porous Carbonate – CHERRYVALE
Zero Cherryvale
0- 4 ft
>24 ft
Surface exposure
of ooid shoal

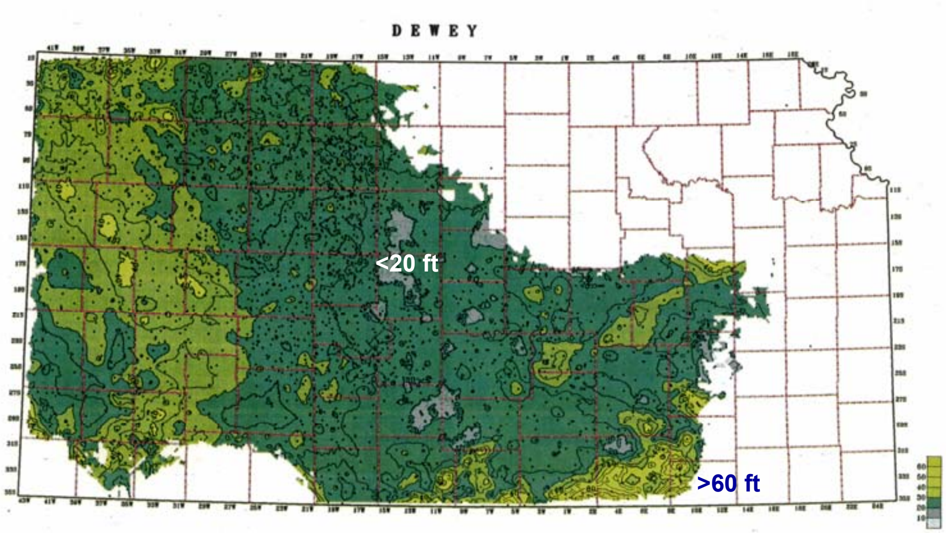
Local development of thick ooid shoal in Cherryvale sequence in SE Kansas





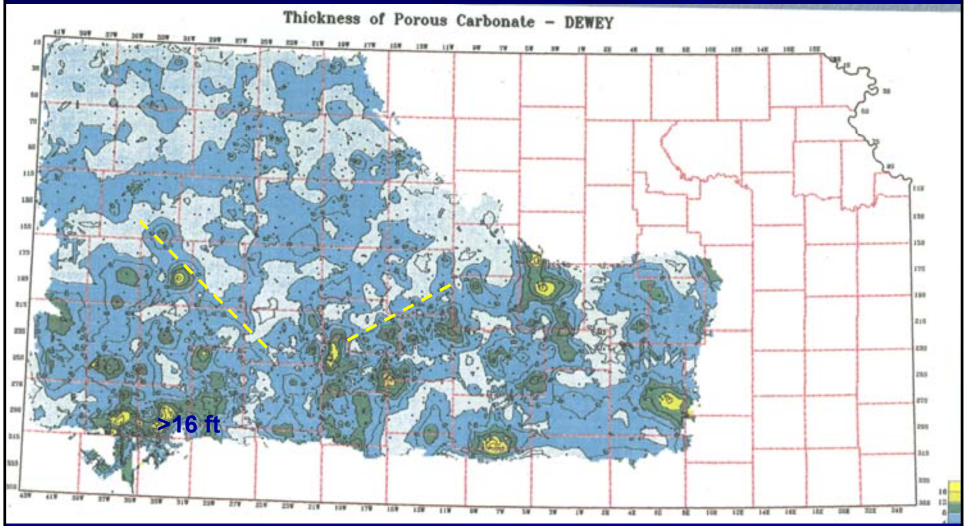
Cherryvale Sequence

Dewey sequence – Quivira Shale to Muncie Creek Shale

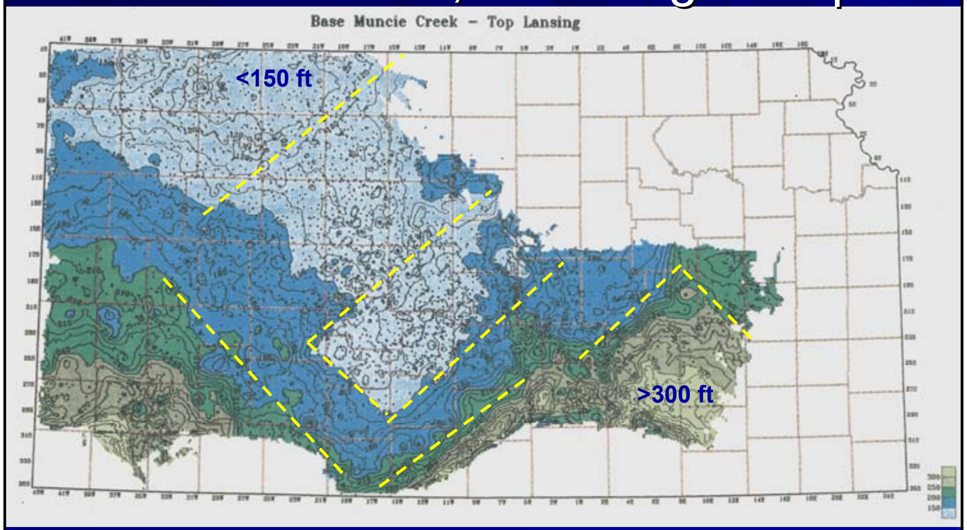


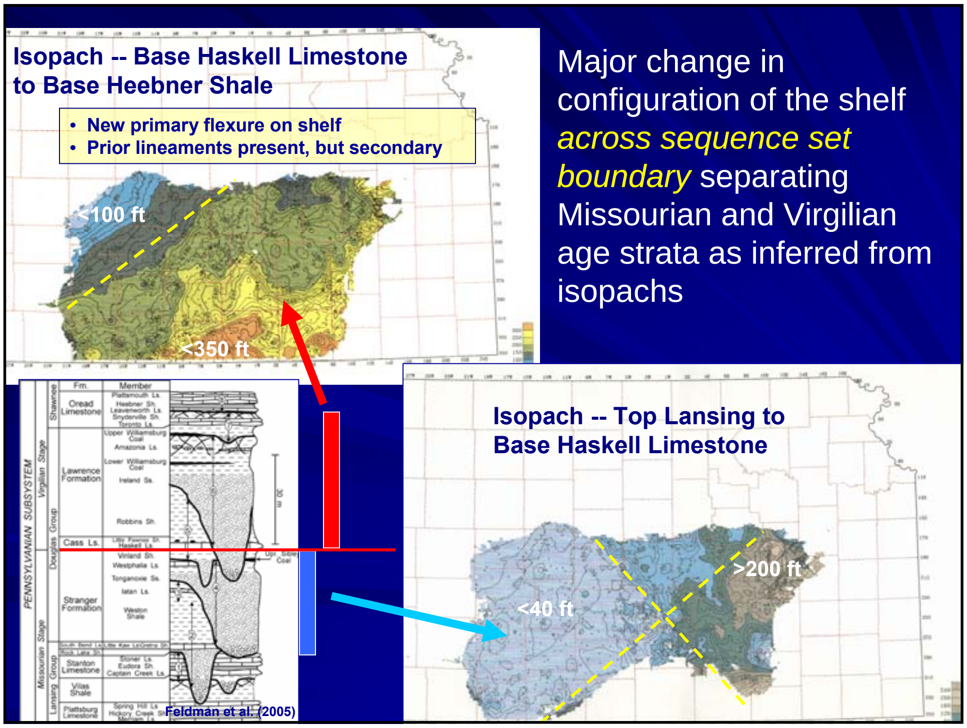
- Generally lower accommodation across shelf except in SE proximal to shelf margin
- Also shelf rather flat and high-energy shoals limited to local shelf flexure

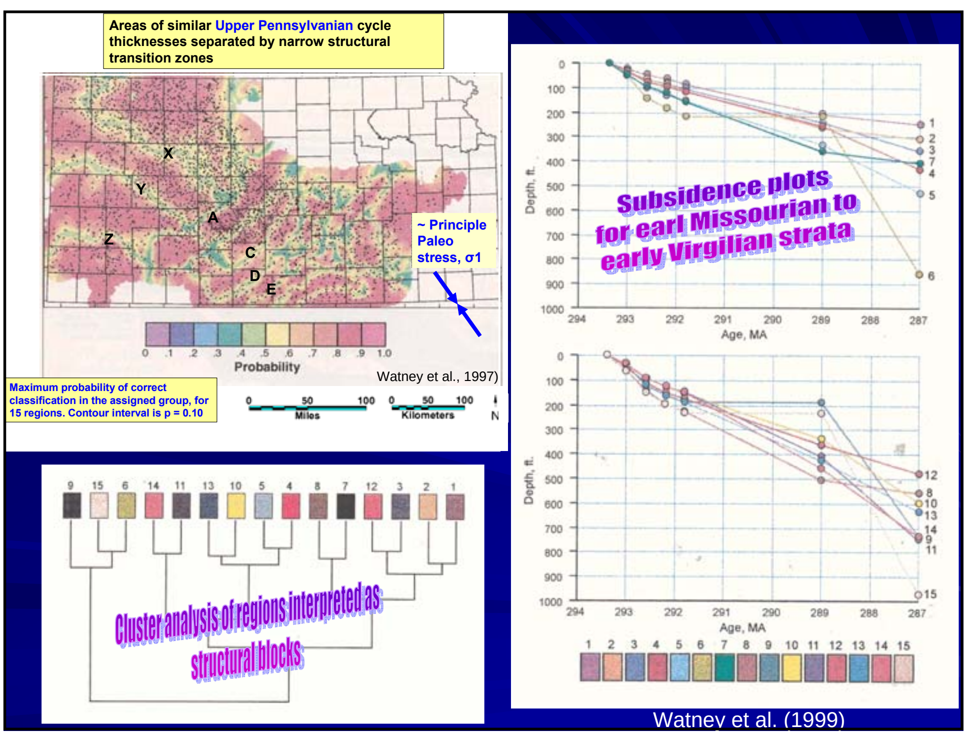
Dewey Sequence – thickness of porous carbonate,> 8% Ø

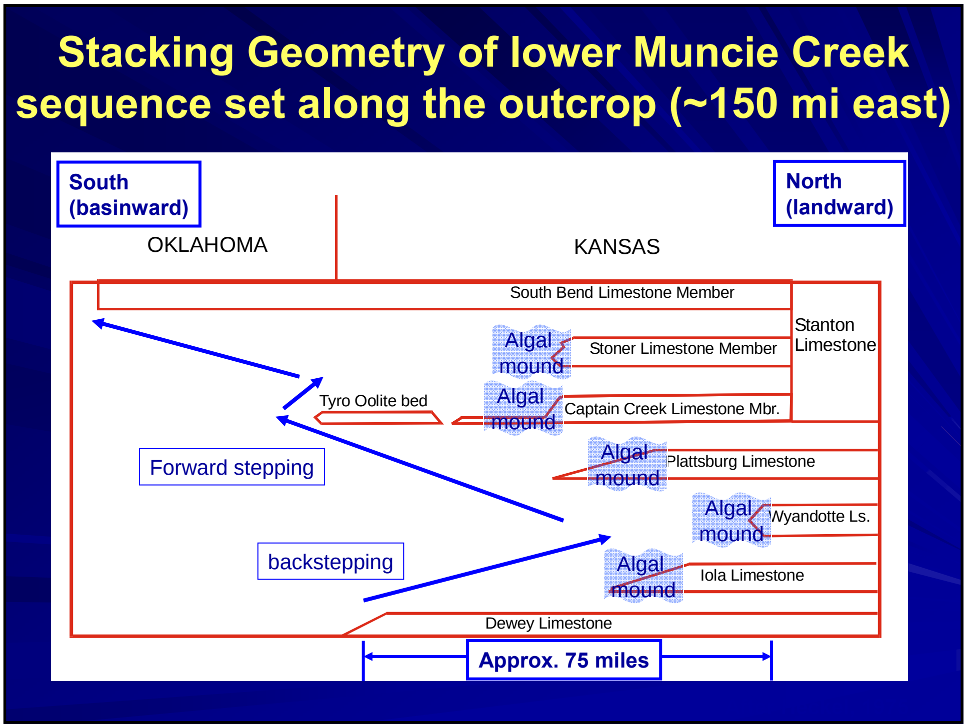


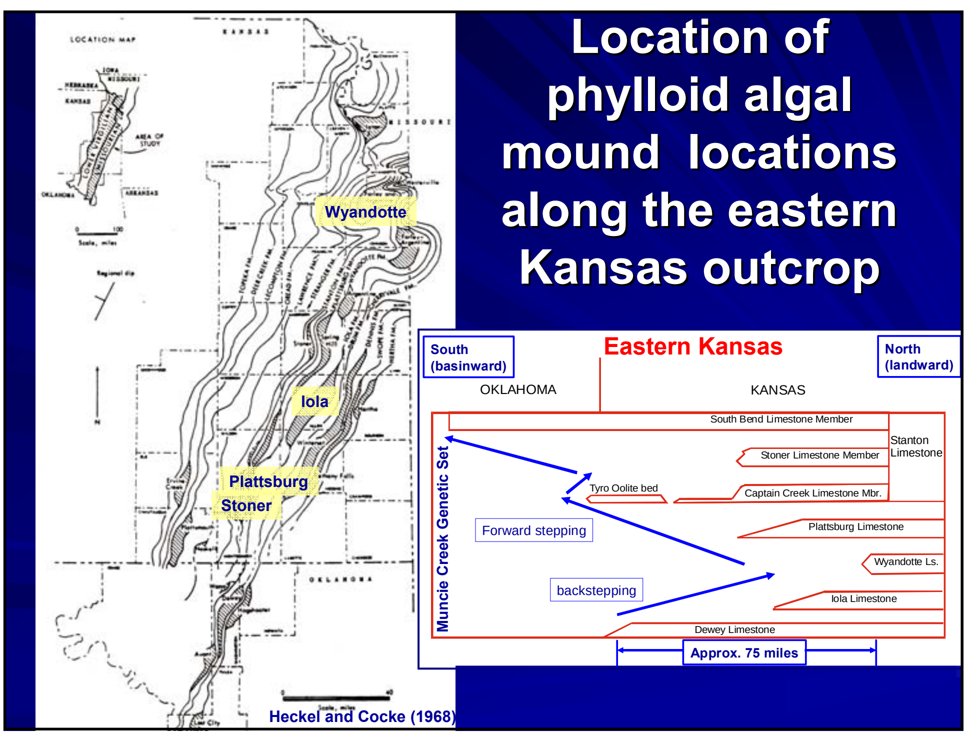
Muncie Creek Sequence Set Late Missourian, ~Lansing Group



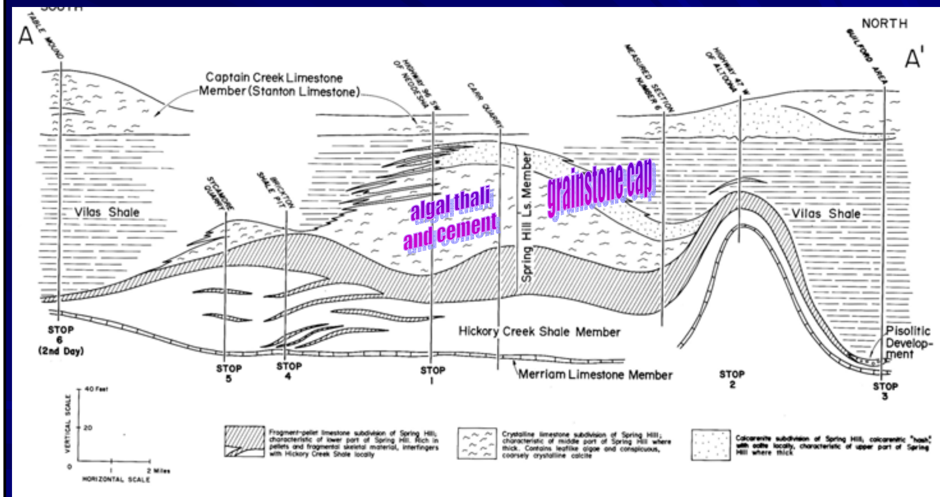

Isopach -- Base Haskell Limestone to Base Heebner Shale
• New primary flexure on shelf
• Prior lineaments present, but secondary
<100 ft
<350 ft
Major change in configuration of the shelf across sequence set boundary separating Missourian and Virgilian age strata as inferred from isopachs
Isopach -- Top Lansing to Base Haskell Limestone
>200 ft
<40 ft
PENNSYLVANIAN SUBSYSTEM
Virgilian Stage
Missourian Stage
Shawnee
Douglas Group
Lansing Group
Fm.
Member
Oread Limestone
Lawrence Formation
Cass Ls.
Stranger Formation
Stanton Limestone
Vilas Shale
Plattsburg Limestone
Feldman et al. (2005)


Areas of similar Upper Pennsylvanian cycle thicknesses separated by narrow structural transition zones
X
Y
Z
A
C
D
E
~ Principle Paleo stress, σ1
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0
Probability
Watney et al., 1997)
Maximum probability of correct classification in the assigned group, for 15 regions. Contour interval is p = 0.10
Miles
Kilometers
9 15 6 14 11 13 10 5 4 8 7 12 3 2 1
Cluster analysis of regions interpreted as structural blocks
Subsidence plots for earl Missourian to early Virgilian strata
Depth, ft.
Age, MA
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Watney et al. (1999)

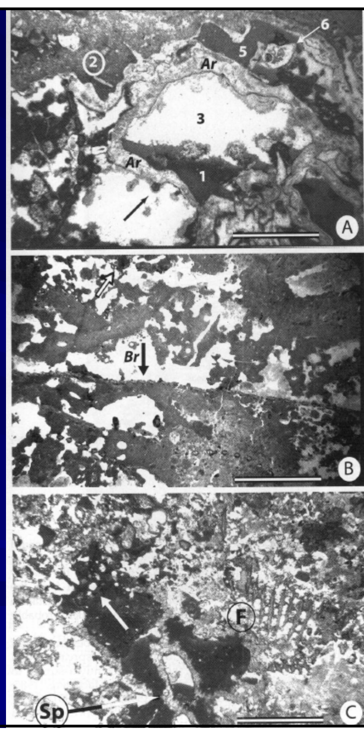

Stacking Geometry of lower Muncie Creek sequence set along the outcrop (~150 mi east)
South (basinward)
North (landward)
OKLAHOMA
KANSAS
South Bend Limestone Member
Stanton Limestone
Algal mound
Stoner Limestone Member
Tyro Oolite bed
Algal mound
Captain Creek Limestone Mbr.
Forward stepping
Algal mound
Plattsburg Limestone
Algal mound
Wyandotte Ls.
backstepping
Algal mound
Iola Limestone
Dewey Limestone
Approx. 75 miles

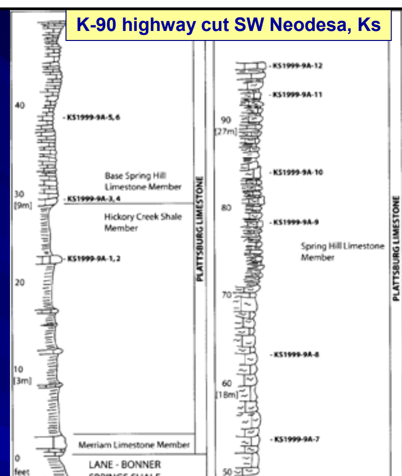

Location of phylloid algal mound locations along the eastern Kansas outcrop
LOCATION MAP
KANSAS
MISSOURI
OKLAHOMA
Wyandotte
Iola
Plattsburg
Stoner
Heckel and Cocke (1968)
Eastern Kansas
South (basinward)
North (landward)
OKLAHOMA
KANSAS
Muncie Creek Genetic Set
South Bend Limestone Member
Stanton Limestone
Stoner Limestone Member
Tyro Oolite bed
Captain Creek Limestone Mbr.
Forward stepping
Plattsburg Limestone
Wyandotte Ls.
backstepping
Iola Limestone
Dewey Limestone
Approx. 75 miles

Plattsburg Bank, SE Kansas



Harbaugh (1959)





A) *Archaeolithophyllum* red algal boundstone from 30 ft level

B) *Archaeolithophyllum*-bryozoan boundstone from 30 ft level, intertwined

C) Bryozoan boundstone from 90 ft level

Samankassou and West (2003)

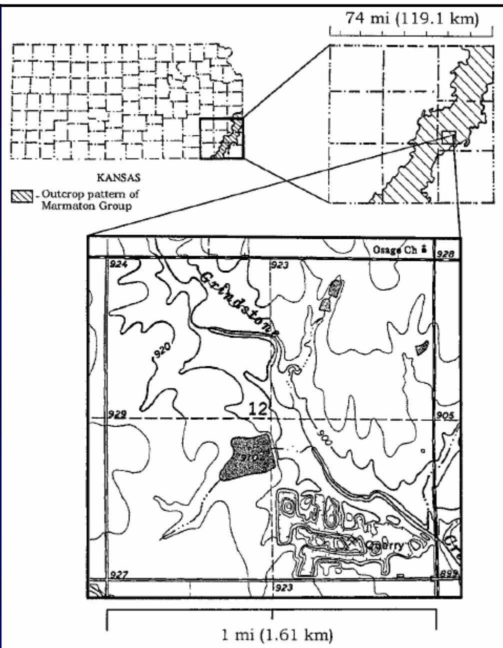


FIGURE 1—Location map. Quarry is in SE 1/4, sec. 12, T30S, R22E, USGS Grindstone Creek 7.5′ quadrangle, Crawford County, Kansas (outcrop pattern from Jewett, 1964).

Parasequences in the Lower Marmaton, Middle Desmoinesian Fort Scott Limestone sequence

(Chaetetid buildups on lower shelf)

SE Kansas

Suchy and West (2001)

WESTPHALIAN CHAETETID BUILDUPS 427

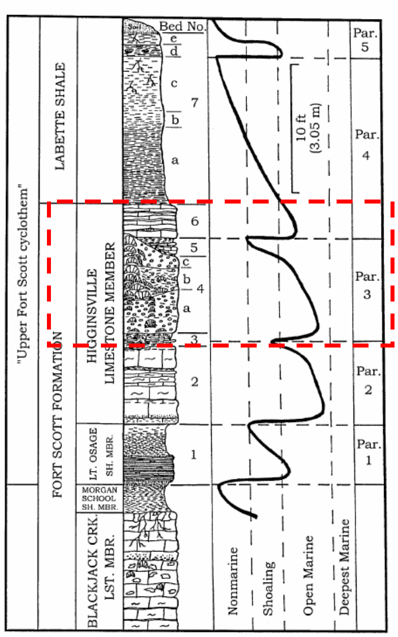


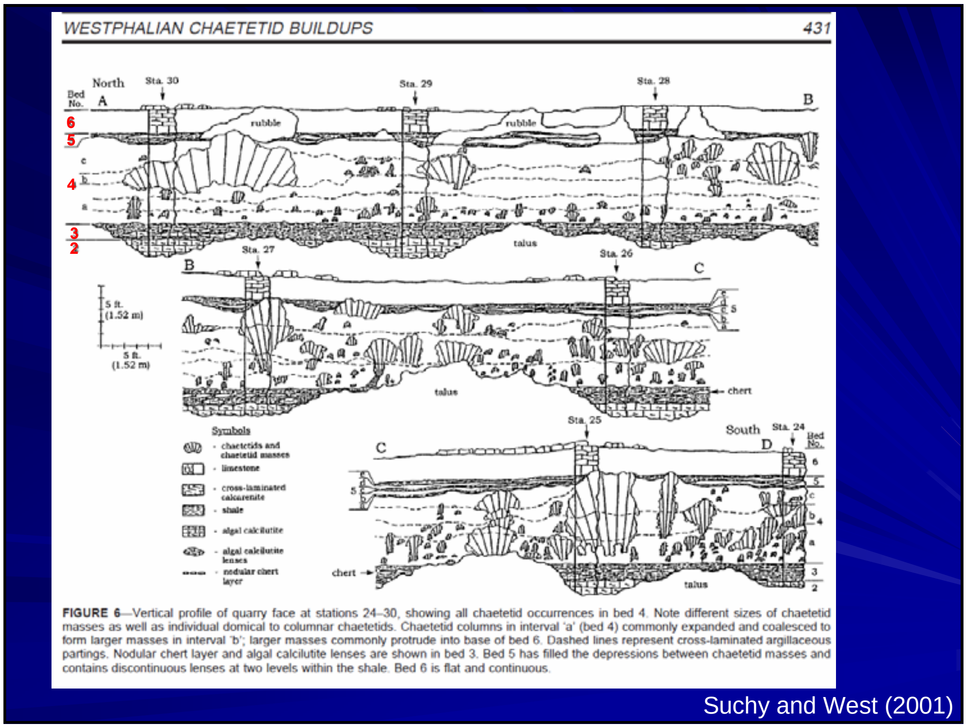
FIGURE 3—Stratigraphic column from the study area, showing sea-level curve based on recognized parasequences ("Par." = parasequence). This composite stratigraphic section is based on exposures of the Higginsville Limestone and Labette Shale at stations 11, 11a, and 32 within the quarry (see Fig. 4), and on exposures of the Little Osage Shale Member and Blackjack Creek Limestone Member at a locality 13.5 miles (21.7 km) south-southwest of the quarry. Bed numbers and intervals within those beds also are shown (modified from Suchy and West, 1991).

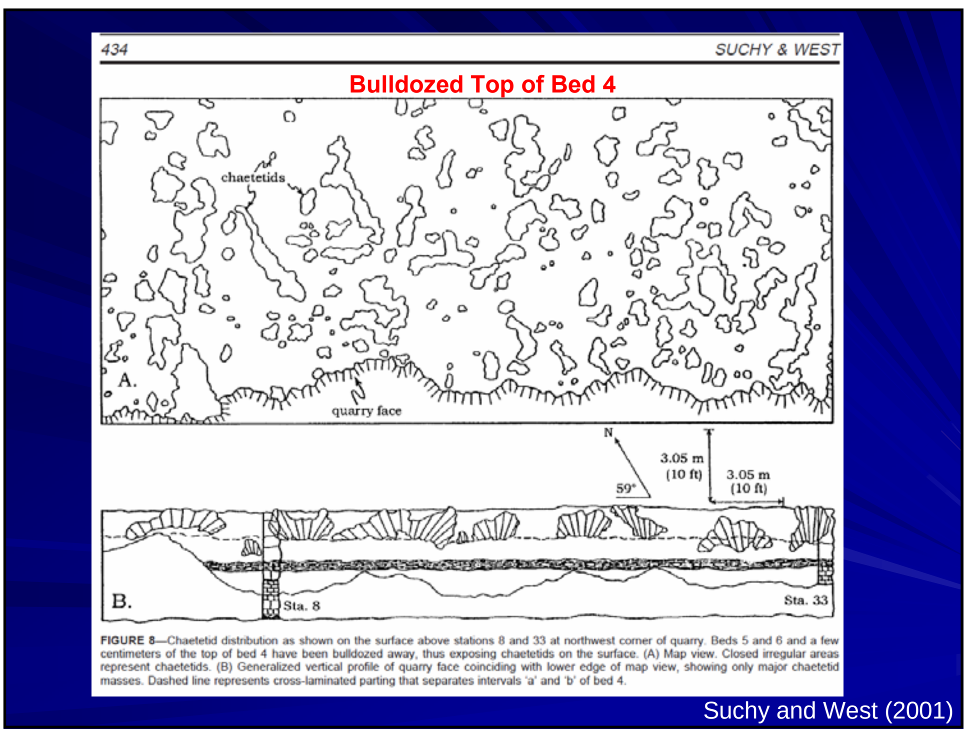
Parasequences **in the Lower Marmaton, Middle Desmoinesian Fort Scott Limestone sequence**

(Chaetetid buildups on lower shelf)

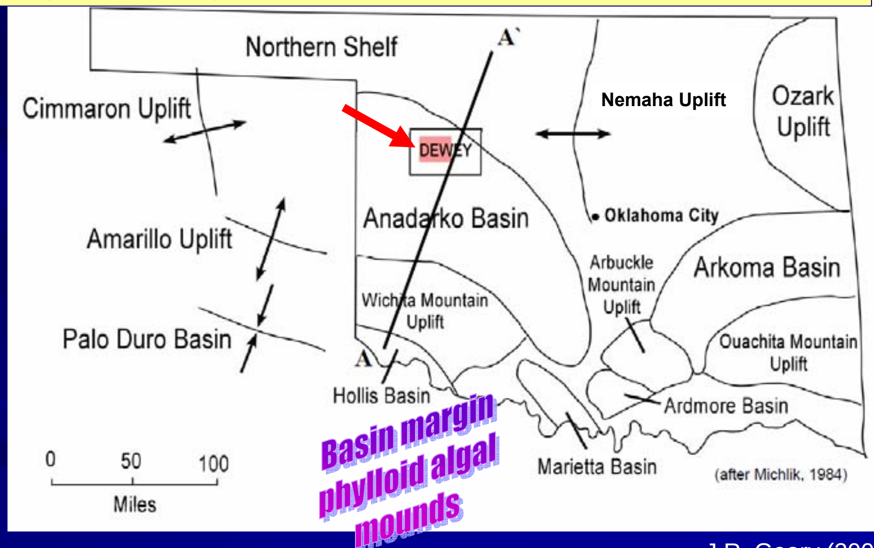
SE Kansas

Suchy and West (2001)

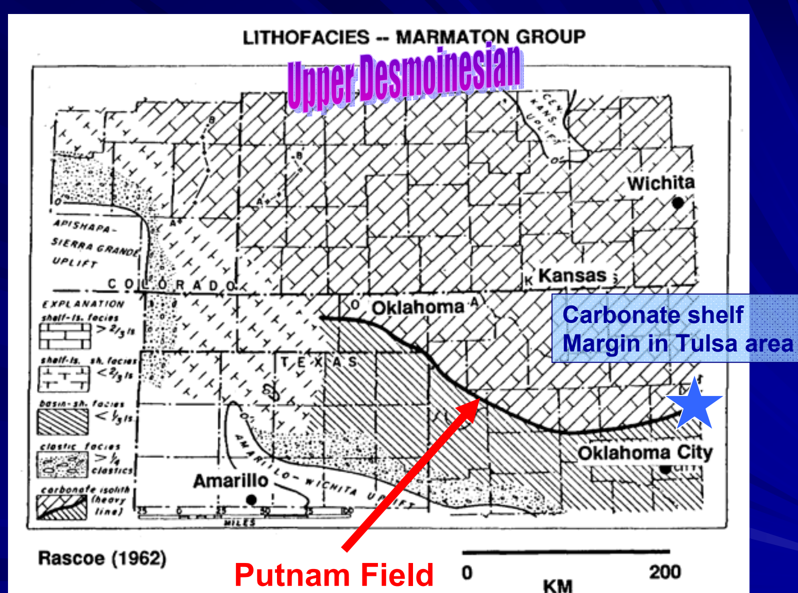

WESTPHALIAN CHAETETID BUILDUPS
431
North
Sta. 30
Sta. 29
Sta. 28
Bed No.
A
B
rubble
talus
Sta. 27
Sta. 26
C
5 ft. (1.52 m)
chert
Symbols
- chaetetids and chaetetid masses
- limestone
- cross-laminated calcarenite
- shale
- algal calcilutite
- algal calcilutite lenses
- nodular chert layer
Sta. 25
South
Sta. 24
D
FIGURE 6—Vertical profile of quarry face at stations 24–30, showing all chaetetid occurrences in bed 4. Note different sizes of chaetetid masses as well as individual domical to columnar chaetetids. Chaetetid columns in interval 'a' (bed 4) commonly expanded and coalesced to form larger masses in interval 'b'; larger masses commonly protrude into base of bed 6. Dashed lines represent cross-laminated argillaceous partings. Nodular chert layer and algal calcilutite lenses are shown in bed 3. Bed 5 has filled the depressions between chaetetid masses and contains discontinuous lenses at two levels within the shale. Bed 6 is flat and continuous.
Suchy and West (2001)


434
SUCHY & WEST
Bulldozed Top of Bed 4
chaetetids
A.
quarry face
N
59°
3.05 m (10 ft)
3.05 m (10 ft)
B.
Sta. 8
Sta. 33
FIGURE 8—Chaetetid distribution as shown on the surface above stations 8 and 33 at northwest corner of quarry. Beds 5 and 6 and a few centimeters of the top of bed 4 have been bulldozed away, thus exposing chaetetids on the surface. (A) Map view. Closed irregular areas represent chaetetids. (B) Generalized vertical profile of quarry face coinciding with lower edge of map view, showing only major chaetetid masses. Dashed line represents cross-laminated parting that separates intervals 'a' and 'b' of bed 4.
Suchy and West (2001)

Controls on Hydrocarbon Entrapment and Reservoir Distribution: the Pennsylvanian Big Lime and Oswego Limestone in the Putnam Field Area, Anadarko Basin, Oklahoma
– equivalent in age to shelfal Chaetetid mound in SE Kansas

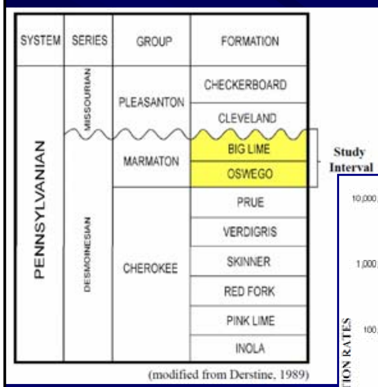


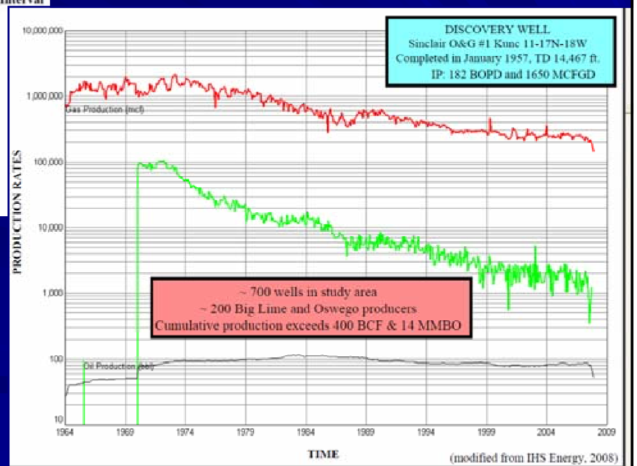
J.R. Geary (2008)



Carbonate shelf and sediment starved basin -- changes in elevation of depositional surface and rate of accumulation

Marmaton has six major sequences in Kansas and are incorporated in two formations at this location

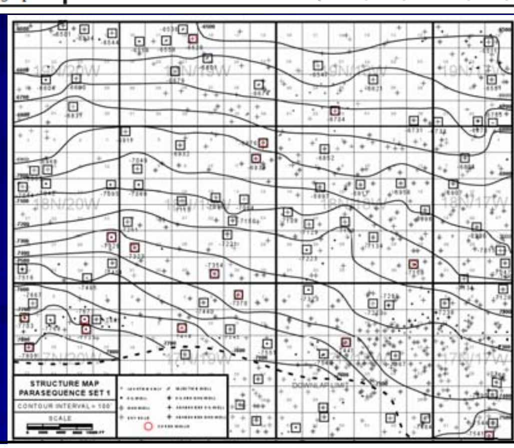




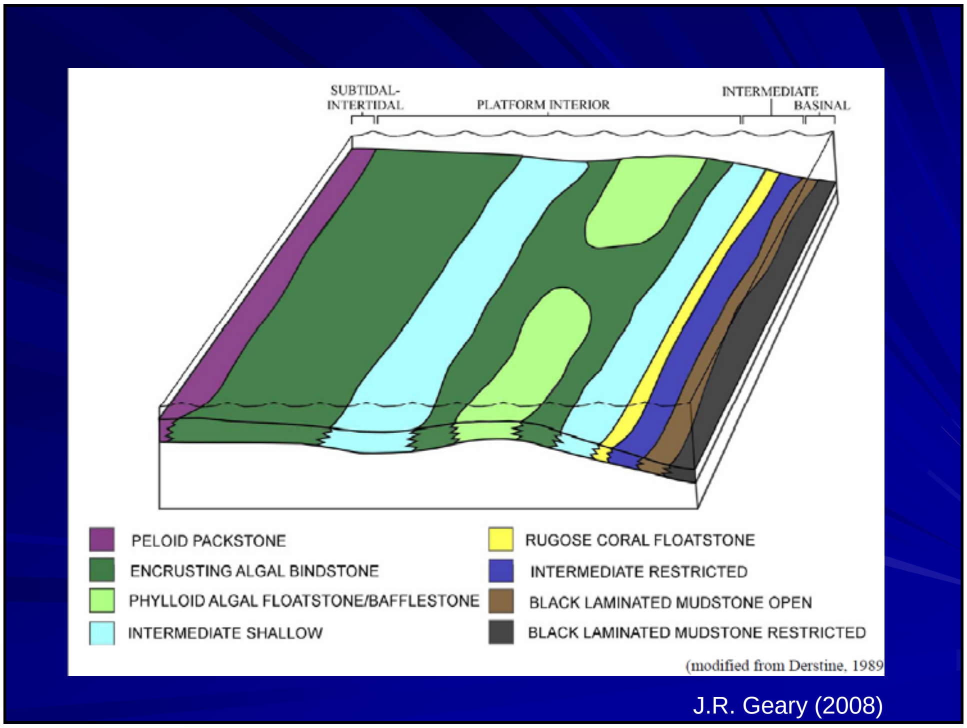
J.R. Geary (2008)

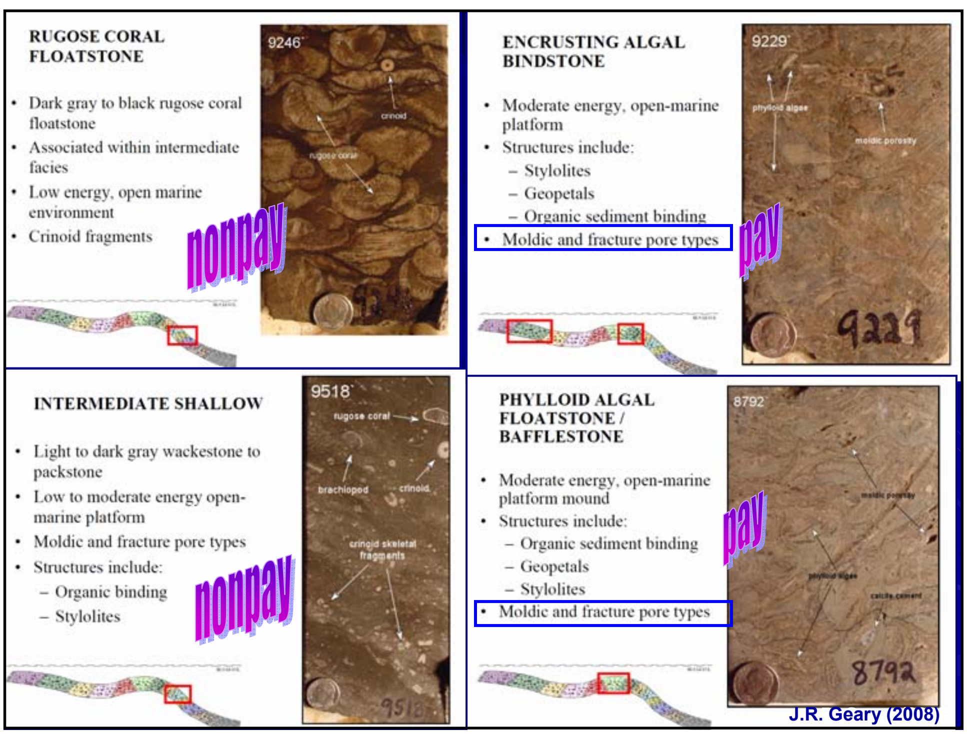
Discovery Information	Parameters	Reservoir Characteristics	Parameters	Production Information	Parameters
Year discovered	1957	Depth to reservoir	8120-9926 feet	Study area	201600 acres, 315 mi²
Initial producer	1650 MCFD, 182 BOD	Average gross interval	123 feet	Estimated well count	700
Average elevation	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 Sw	30%	Expansion factor	0.0038
Drive mechanism	Gravity			Cumulative production (as of 5/02)	
Reservoir Pressure	4500 psi			Big Lime	239 MBO, 12 Bcf
Reservoir Temperature	160 °F			Oswego	13MMBO, 395 Bcf
Trap	Stratigraphic				

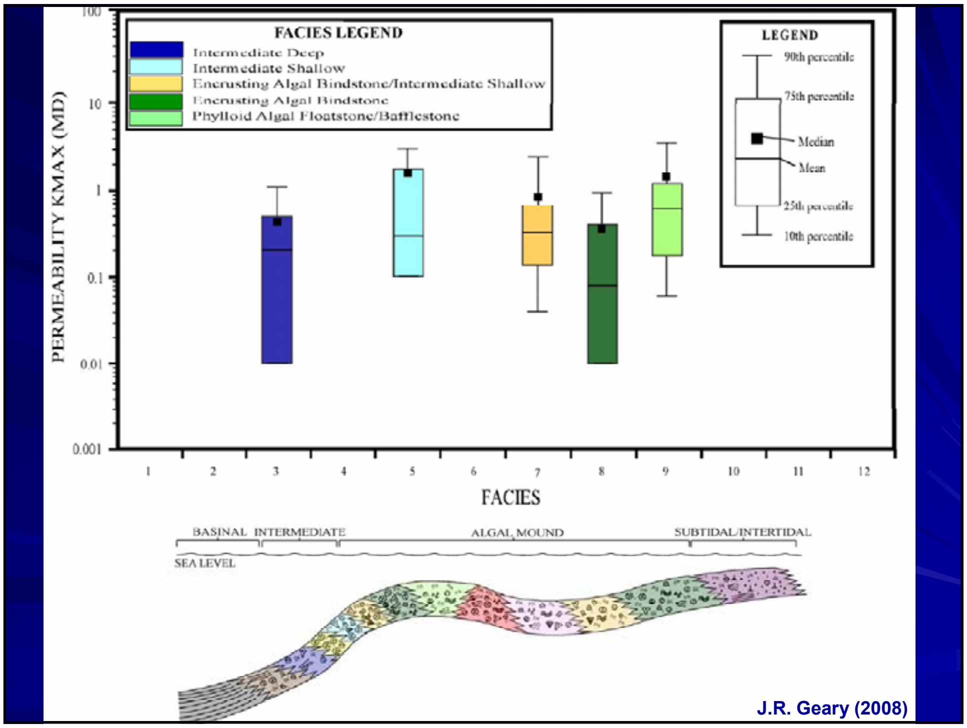
(Brown, 1963; Swanson, 1967;Zagaar, 1965; and IHS Energy)

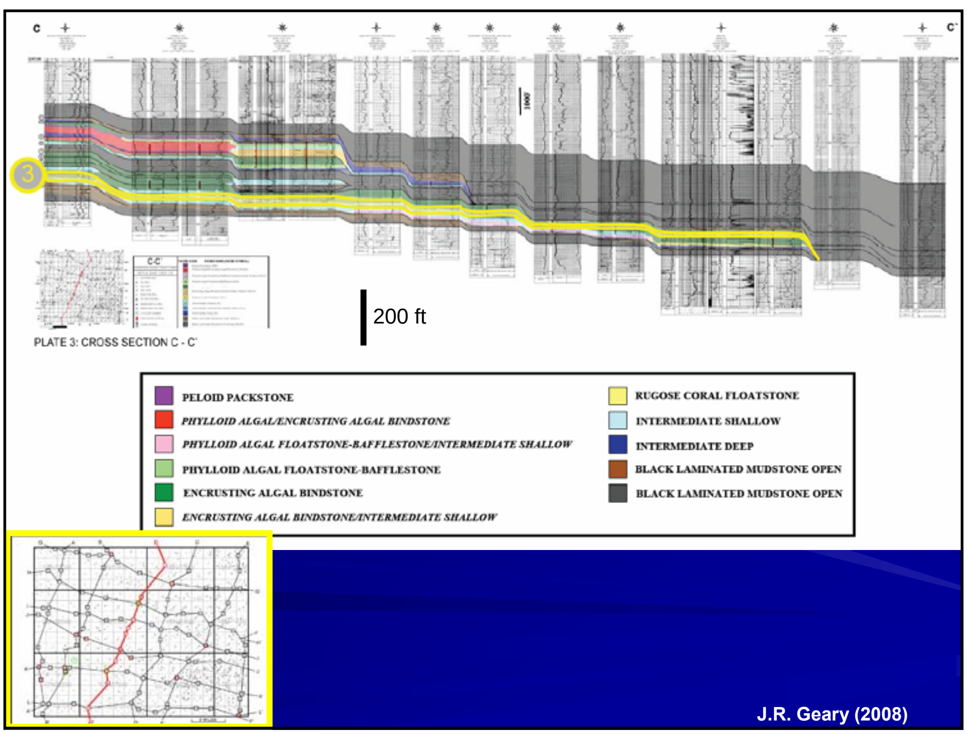


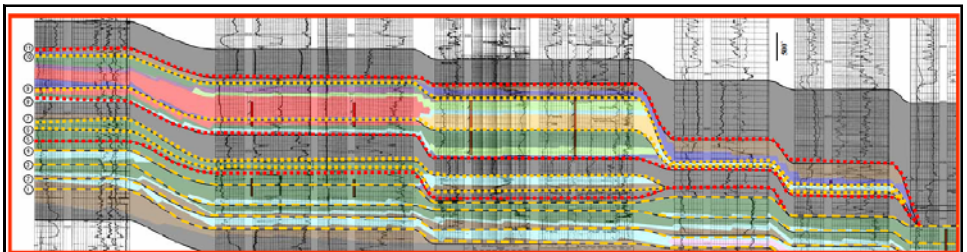
J.R. Geary (2008)


SUBTIDAL-INTERTIDAL
PLATFORM INTERIOR
INTERMEDIATE
BASINAL
PELOID PACKSTONE
ENCRUSTING ALGAL BINDSTONE
PHYLLOID ALGAL FLOATSTONE/BAFFLESTONE
INTERMEDIATE SHALLOW
RUGOSE CORAL FLOATSTONE
INTERMEDIATE RESTRICTED
BLACK LAMINATED MUDSTONE OPEN
BLACK LAMINATED MUDSTONE RESTRICTED
(modified from Derstine, 1989
J.R. Geary (2008)


RUGOSE CORAL FLOATSTONE
• Dark gray to black rugose coral floatstone
• Associated within intermediate facies
• Low energy, open marine environment
• Crinoid fragments
nonpay
9246
ENCRUSTING ALGAL BINDSTONE
• Moderate energy, open-marine platform
• Structures include:
– Stylolites
– Geopetals
– Organic sediment binding
• Moldic and fracture pore types
pay
9229
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
nonpay
9518
PHYLLOID ALGAL FLOATSTONE / BAFFLESTONE
• Moderate energy, open-marine platform mound
• Structures include:
– Organic sediment binding
– Geopetals
– Stylolites
• Moldic and fracture pore types
pay
8792
J.R. Geary (2008)


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)
FACIES
BASINAL
INTERMEDIATE
ALGAL MOUND
SUBTIDAL/INTERTIDAL
SEA LEVEL
J.R. Geary (2008)


C
C'
3
200 ft
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
J.R. Geary (2008)



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

100 ft

- 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

Message: high-frequency stack of lithofacies tied to varying shelf elevation

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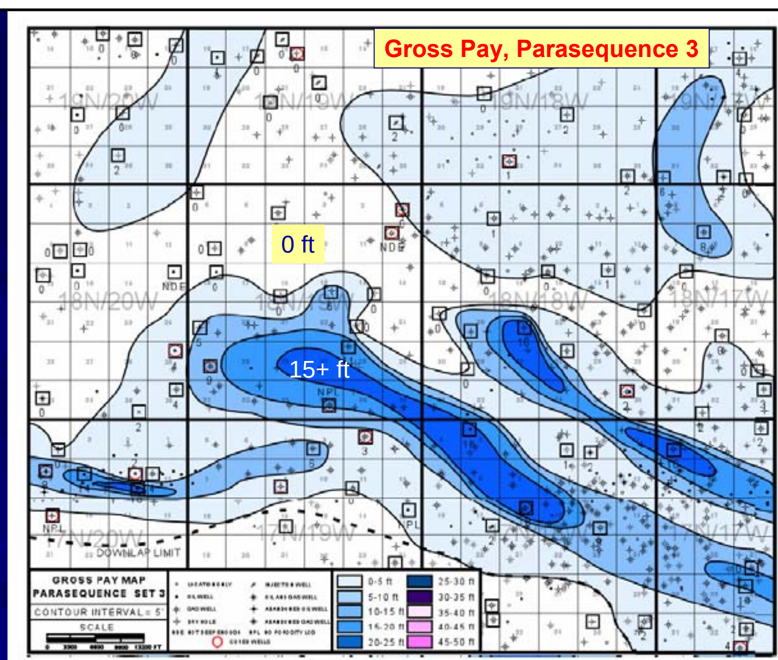

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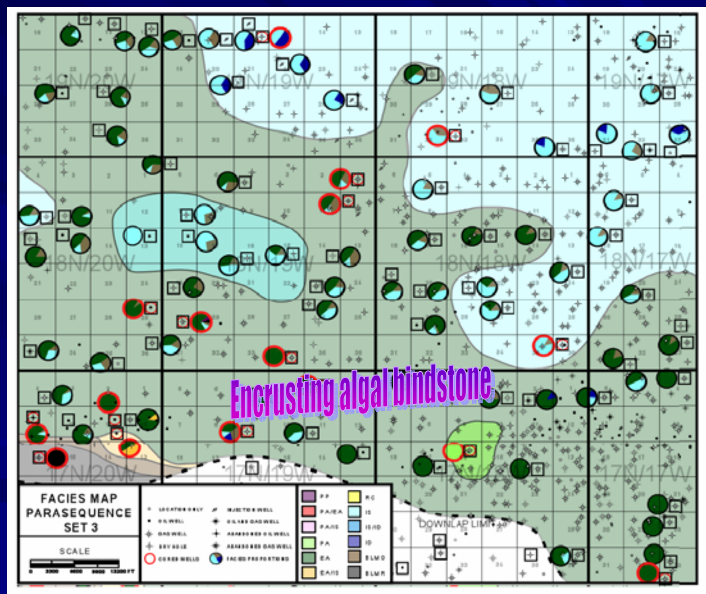
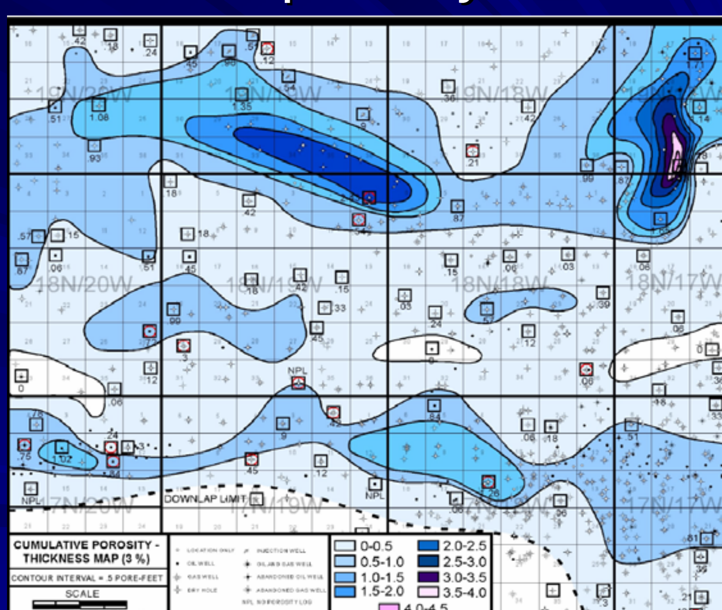
Prorated production to facies



Cumulative porosity thickness



J.R. Geary (2008)

Outcrop-based reservoir characterization: A composite phylloid-algal mound, western Orogrande basin (New Mexico) -- Patrick D. Doherty, Gerilyn S. Soreghan, and John P. Castagna

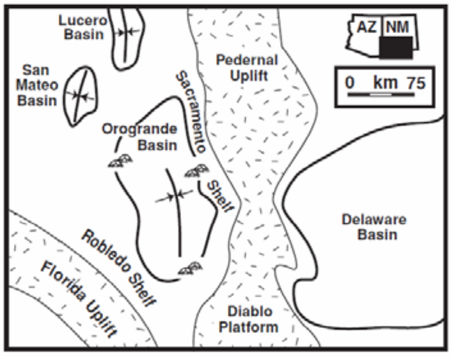


Figure 2. Pennsylvanian–Permian paleogeography of the Orogrande basin showing basins and highlands (stippled). Modified from Algeo et al. (1991) and Soreghan and Giles (1999a).

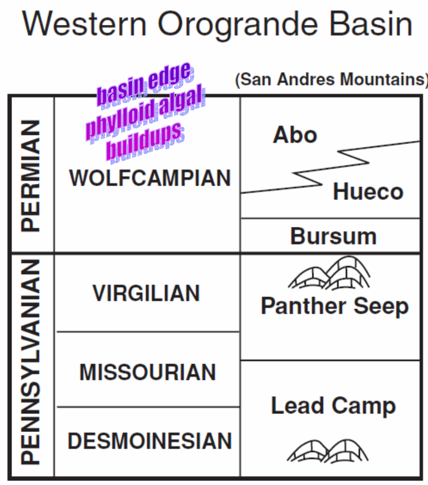


Figure 3. Pennsylvanian–Permian stratigraphy of the western margin (San Andres Mountains) of the Orogrande basin. Studied mounds are from the Panther Seep Formation and are of middle Virgilian–earliest Wolfcampian age (Kottlowski et al., 1956).

Doherty et al. (2002)

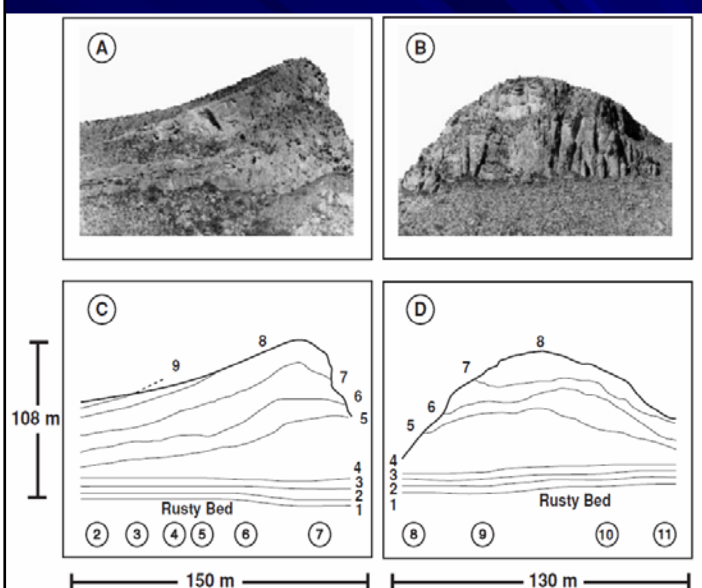


Figure 4. (A) Photograph showing studied mound as seen from the southwest, illustrating mound core and flanking strata (sections 2–7). (B) Photograph showing studied mound as seen from the southeast, illustrating mound core and flanking strata (sections 8–11). (C) Traced high-frequency sequence boundaries from photo (A). (D) Traced high-frequency sequence boundaries from photo (B).

Doherty et al. (2002)

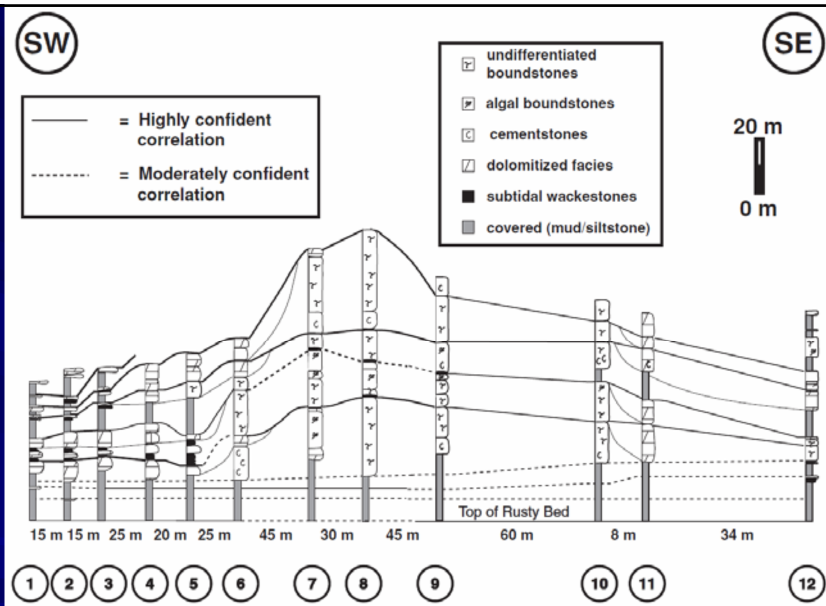


Figure 5. Correlated measured sections showing generalized facies types and high-frequency sequence boundaries. Highly confident correlation surfaces were accessible and sampled. Moderately confident correlation surfaces were inaccessible. Inaccessible cliff surfaces were traced remotely using binoculars, and covered surfaces were estimated using regional dip angles.

Doherty et al. (2002)

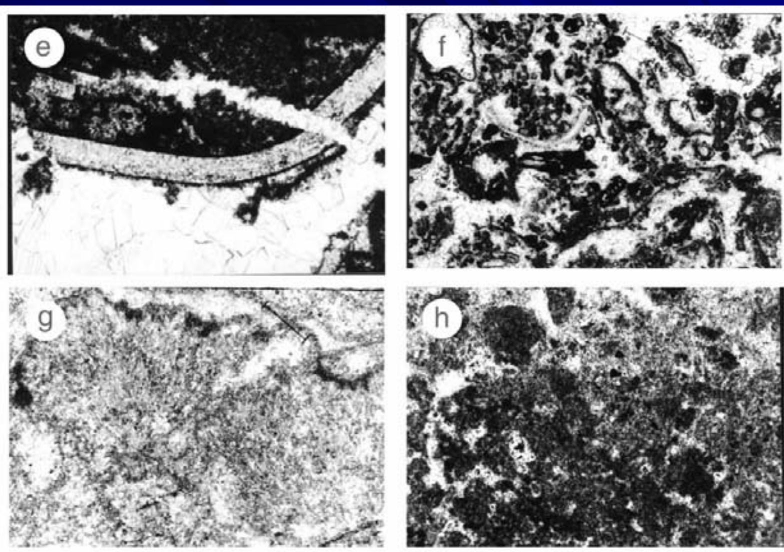


Figure 7. Facies photomicrographs (horizontal dimension is 10 mm): (a) peloid-rich packstone, (b) skeletal packstone, (c) lithoclastic packstone, (d) skeletal wackestone, (e) phylloid-algal boundstone, (f) foram-algal boundstone, (g) cementstone, (h) dolomitized

Doherty et al. (2002)

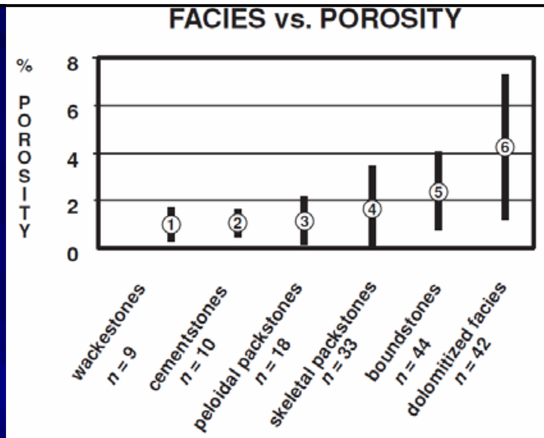


Figure 8. Porosity variation among different facies; error bars represent one standard deviation. Facies 1 and 2 demonstrate the relatively low porosity of wackestones and cementstones, respectively. Packstones (3 and 4) exhibit slightly higher porosities and more variation. Boundstones contain two porosity types (interparticle and vuggy) and are slightly more porous relative to facies 1–4. Average porosity of dolomitized facies are a statistically unique population exhibiting higher porosity compared to undolomitized depositional facies. The numerical data used to construct Figure 8 appear in Table 2.

Doherty et al. (2002)

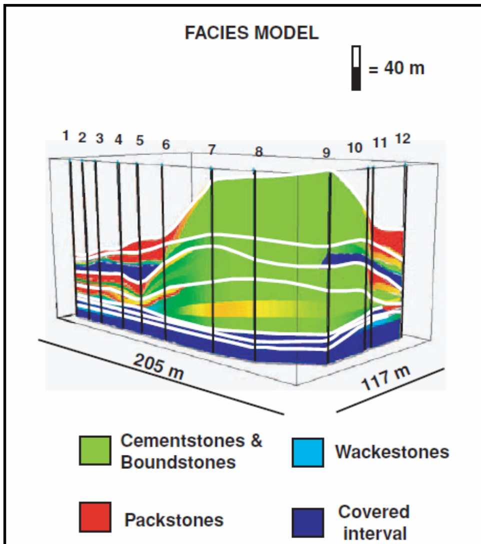


Figure 10. Deterministic geocellular model as viewed from the south-southeast. Data are derived from the facies data contained in twelve pseudowells (measured stratigraphic sections). The model uses layer equivalence and onlap with 20 proportional layers per sequence, a power factor of 2, and a 100 m search radius. Distribution of boundstones, flanking packstone facies, covered intervals, and wackestone facies are illustrated in the model.

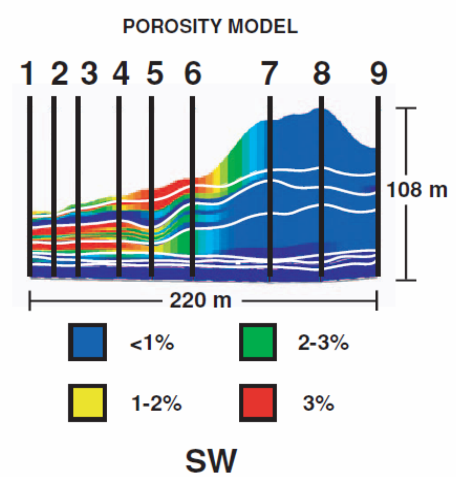
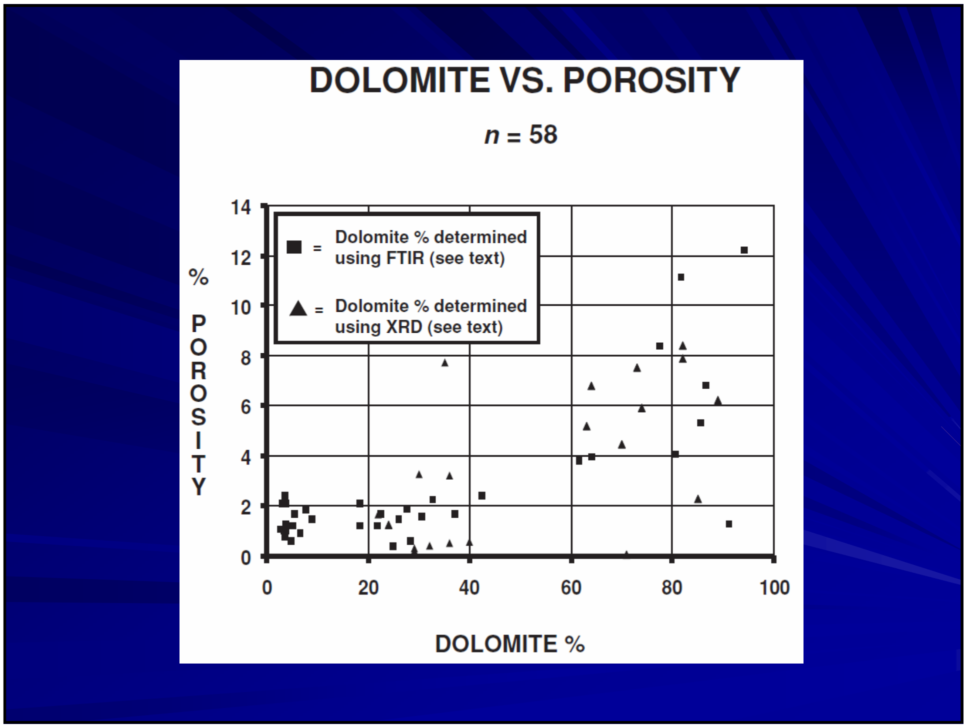
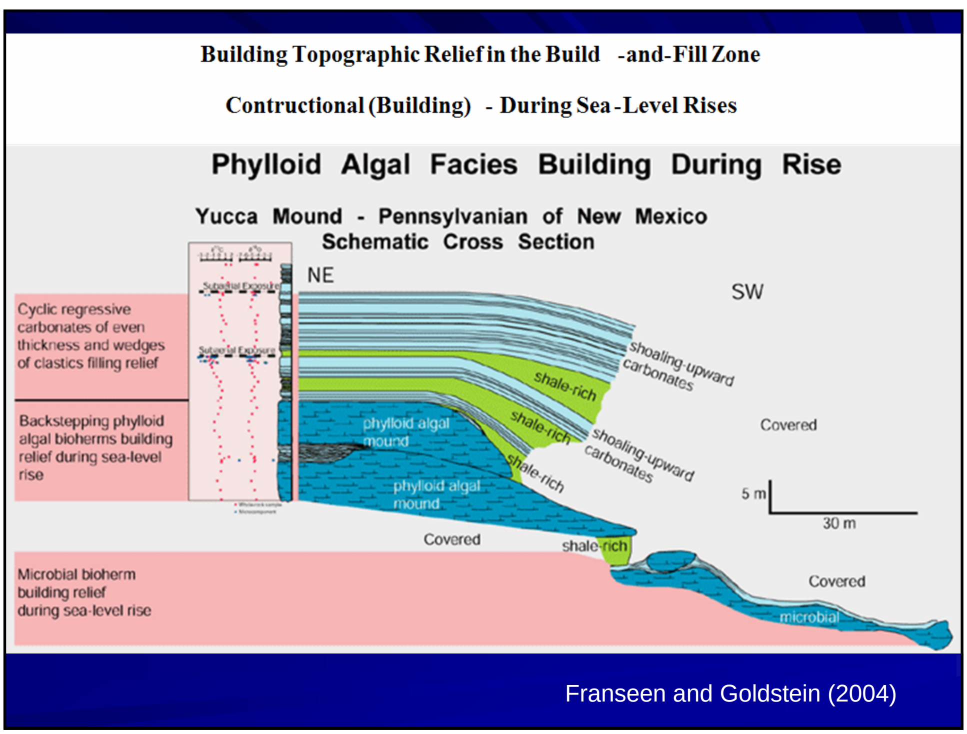
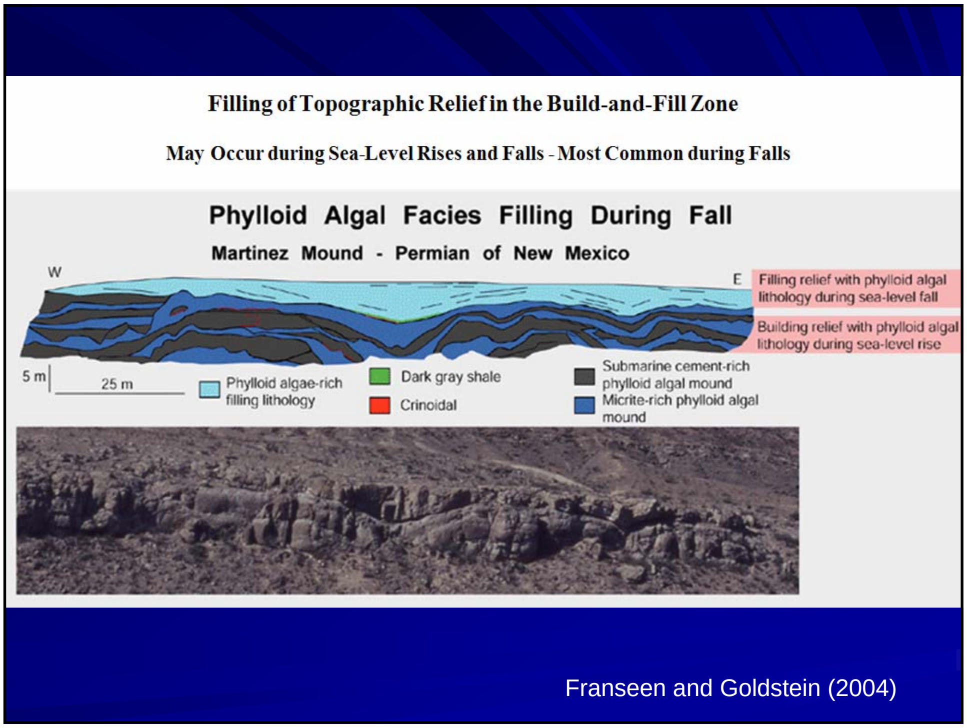


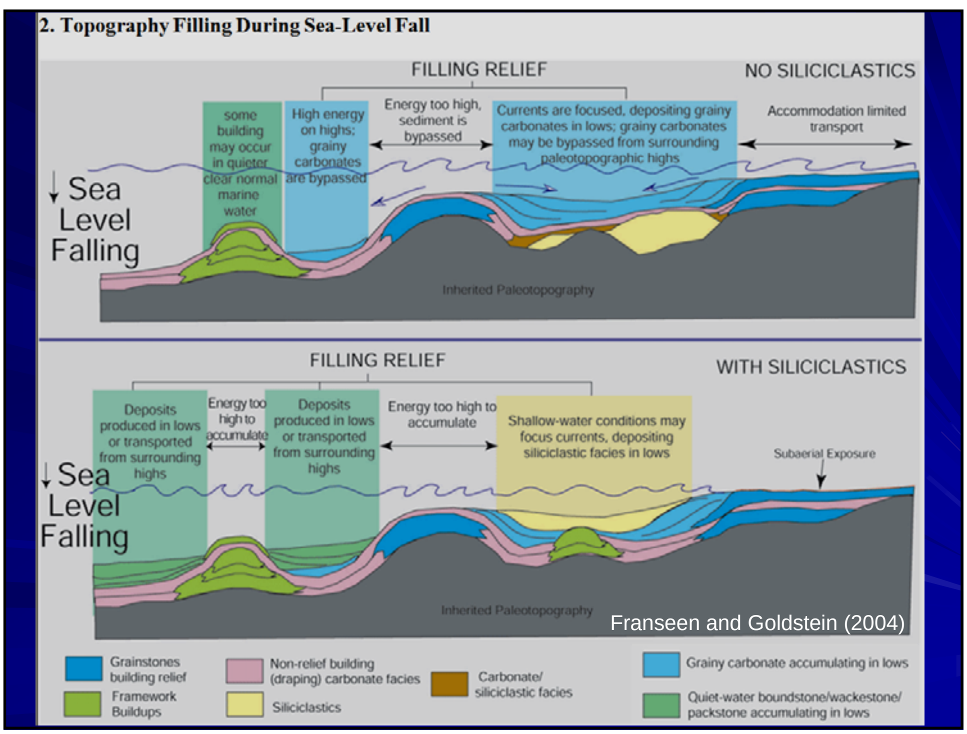
Figure 11. Deterministic porosity model as viewed from the southwest using a power factor of 1 and a 50 m search radius. The model illustrates the stratiform porosity distribution within the dolomitized facies of the mound-flank strata (between wells 1 and 6). Porosity values within the mound core are essentially tight, because of the prevalence of cementstones.

Doherty et al. (2002)


DOLOMITE VS. POROSITY
n = 58
% POROSITY
DOLOMITE %
Dolomite % determined using FTIR (see text)
Dolomite % determined using XRD (see text)
0
2
4
6
8
10
12
14
20
40
60
80
100

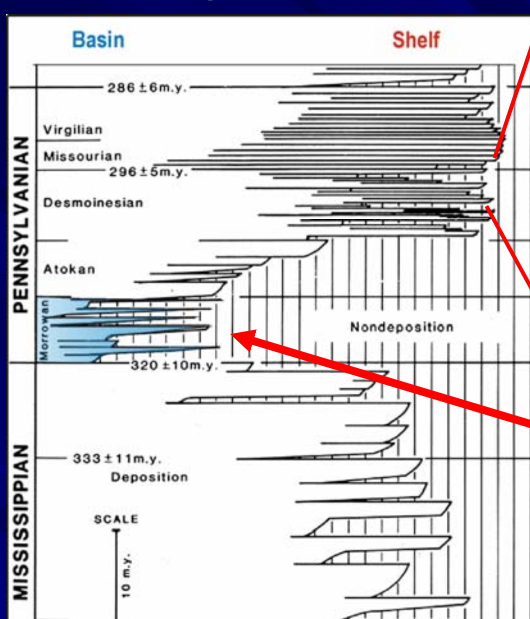

Building Topographic Relief in the Build -and-Fill Zone
Contructional (Building) - During Sea-Level Rises
Phylloid Algal Facies Building During Rise
Yucca Mound - Pennsylvanian of New Mexico
Schematic Cross Section
NE
SW
Cyclic regressive carbonates of even thickness and wedges of clastics filling relief
Backstepping phylloid algal bioherms building relief during sea-level rise
Microbial bioherm building relief during sea-level rise
Shoaling-upward carbonates
shale-rich
phylloid algal mound
Covered
5 m
30 m
microbial
Franseen and Goldstein (2004)

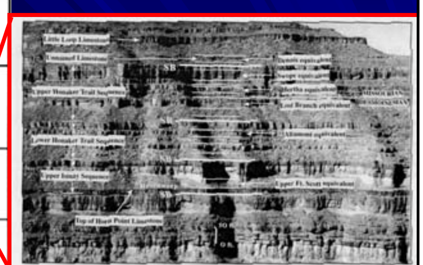

Filling of Topographic Relief in the Build-and-Fill Zone
May Occur during Sea-Level Rises and Falls - Most Common during Falls
Phylloid Algal Facies Filling During Fall
Martinez Mound - Permian of New Mexico
W
E
Filling relief with phylloid algal lithology during sea-level fall
Building relief with phylloid algal lithology during sea-level rise
5 m
25 m
Phylloid algae-rich filling lithology
Dark gray shale
Crinoidal
Submarine cement-rich phylloid algal mound
Micrite-rich phylloid algal mound
Franseen and Goldstein (2004)


2. Topography Filling During Sea-Level Fall
FILLING RELIEF
NO SILICICLASTICS
some building may occur in quieter clear normal marine water
High energy on highs; grainy carbonates are bypassed
Energy too high, sediment is bypassed
Currents are focused, depositing grainy carbonates in lows; grainy carbonates may be bypassed from surrounding paleotopographic highs
Accommodation limited transport
Sea Level Falling
Inherited Paleotopography
FILLING RELIEF
WITH SILICICLASTICS
Deposits produced in lows or transported from surrounding highs
Energy too high to accumulate
Deposits produced in lows or transported from surrounding highs
Energy too high to accumulate
Shallow-water conditions may focus currents, depositing siliciclastic facies in lows
Subaerial Exposure
Sea Level Falling
Inherited Paleotopography
Franseen and Goldstein (2004)
Grainstones building relief
Framework Buildups
Non-relief building (draping) carbonate facies
Siliciclastics
Carbonate/ siliciclastic facies
Grainy carbonate accumulating in lows
Quiet-water boundstone/wackestone/ packstone accumulating in lows

Additional resources for Part 3 – Sequence Stratigraphy

Coastal onlap curve of Ross and Ross (1987)



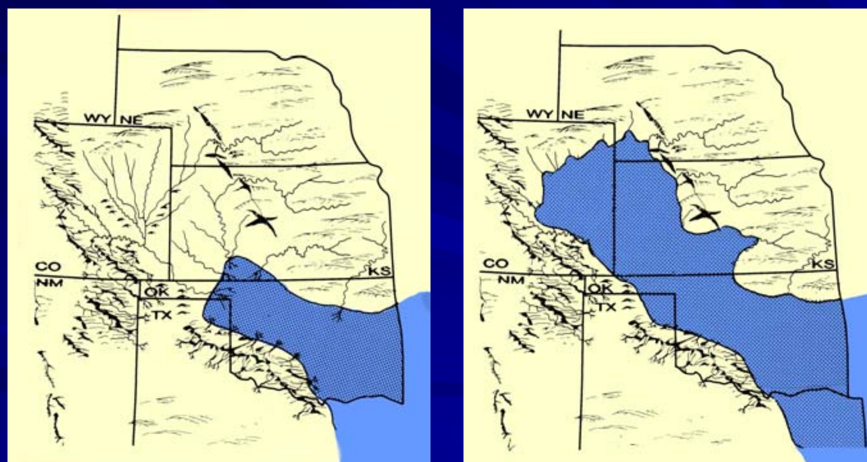


Middle and Upper Pennsylvanian Honaker Trail, Utah

IVF systems prominent in Upper Midcontinent during the Morrowan

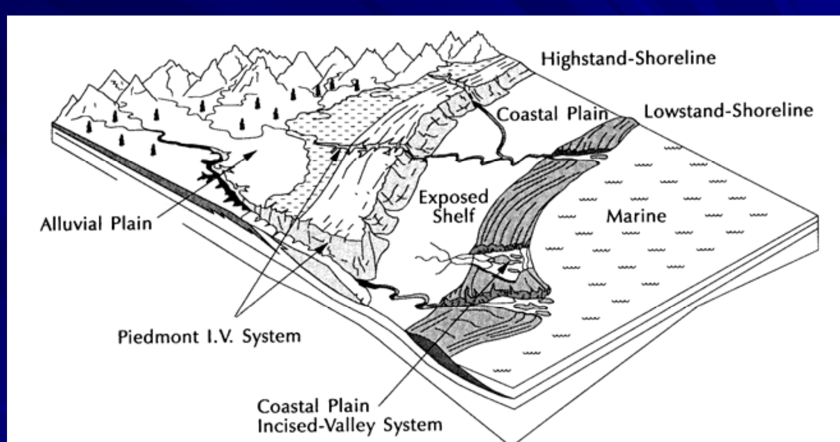
Paleogeography during Morrowan Upper Midcontinent

Lowstand exposed shelf incisement **Highstand inundated shelf**



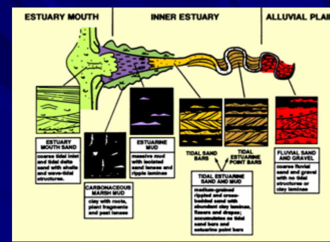
(after Kristinik and Blakeley, 1990)

Coastal zone showing distinction between piedmont and coastal-plain incised valley



From Zaitlin et al. (1994)

Development of incised valley fill system



Processes → **Responses**

Climate — Tectonics
Eustacy

rates, duration, magnitudes
(relative to sedimentation)

Accommodation

Sedimentation

Erosion
Deposition
(and autocyclic variations)

- sediment supply
- grain size
- stream discharge

Development and Preservation of IVF Systems

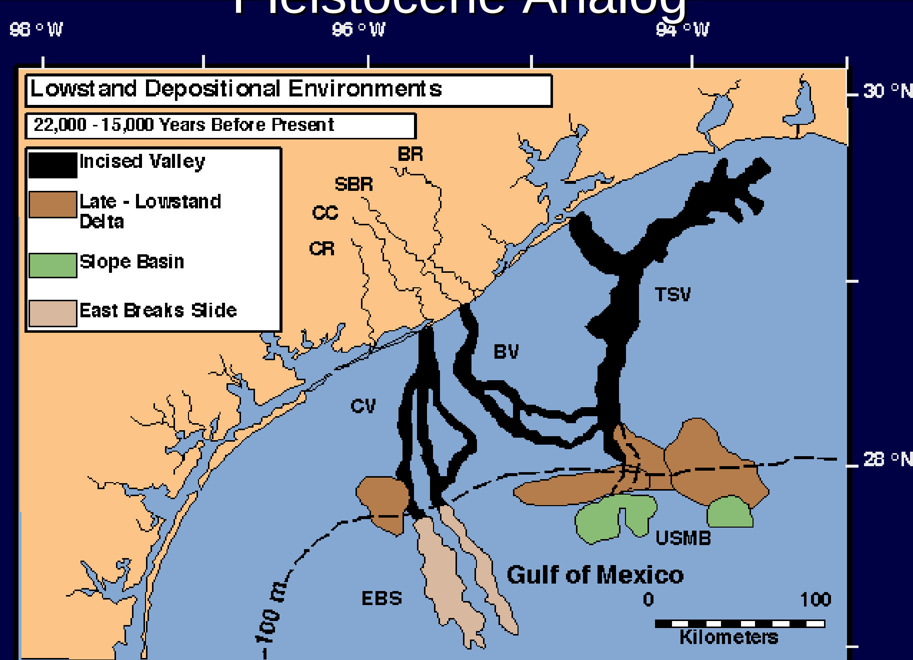
- *Why place and time are important*

- ***Lower, longer stands of relative sea level***
  - more time on shelf to create more extensive incision through drainage network
  - focus drainage to lower, through going portions of shelf
  - subsequent highstand would be larger to cover and preserve IVF's
- ***Wetter climate***
  - increased discharge to erode and transport sediment to encourage incision
- ***Longer, slower rate of transgression***
  - facilitate nearshore processes to work in "funnel" (tidal ravinement)
- ***Basin/uplift geometries***
  - focus stream runoff and increase discharge from hinterland
  - slope changes and knickpoints developed due to differential subsidence and uplift

Depositional sequences and incised valley fill analogs in the Quaternary

- *Duration and magnitude of Quaternary-age eustacy are very similar to the Pennsylvanian:*
  - Eustatic amplitudes are very close...
    - minimum of 80 meters and probably in excess of 100 meters for Upper Pennsylvanian (Soreghan and Giles, 1999; and other authors); compared to ~100 meters dominate for Quaternary.
  - Average duration of eustatic cycles are similar...
    - 143 +- 64 kiloyears minimum to ~400 kiloyears (Milankovitch eccentricity) for Upper Pennsylvanian and Lower Permian (Rasbury et al., 1998) compared to 100 kilo-years for Late Pleistocene.
- *Good examples Quaternary <u>coastal-plain IVS</u> in literature*

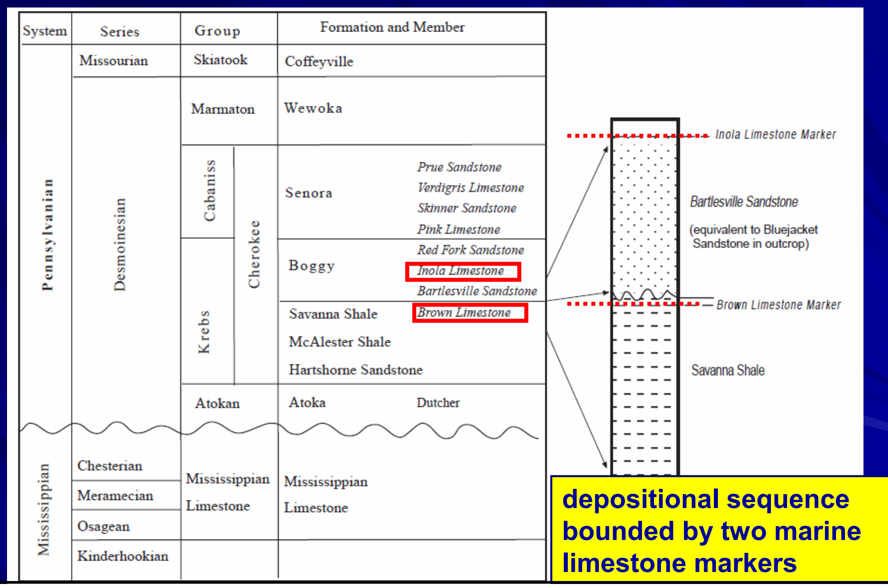
Pleistocene Analog



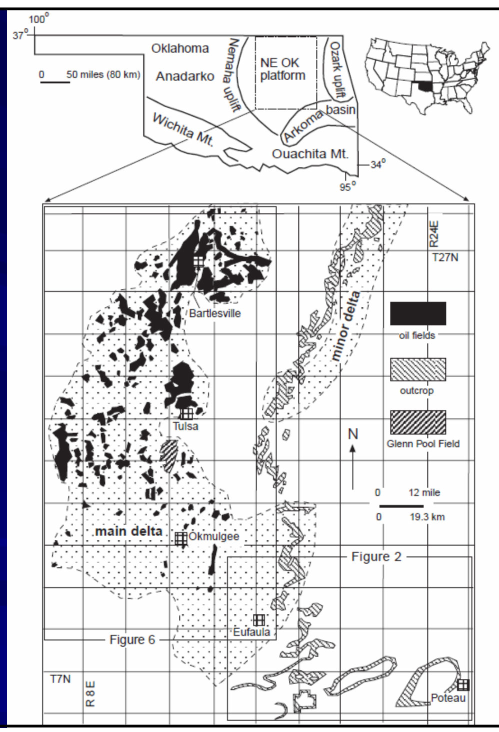
Anderson and Rodriguez (1999)

Sequence Stratigraphy of the Middle Pennsylvanian Bartlesville Sandstone, Northeastern Oklahoma:
A Case of an Underfilled Incised Valley

-- Liangmiao (Scott) Ye and Dennis Kerr (2000)

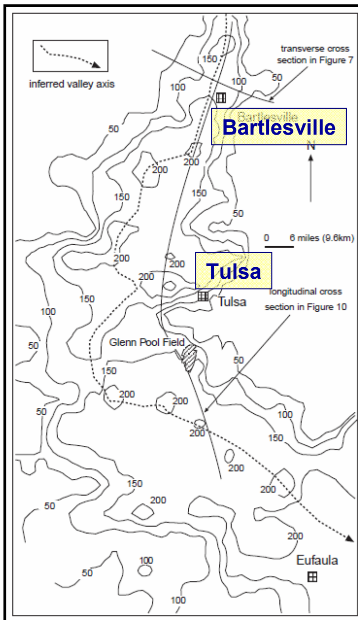


depositional sequence bounded by two marine limestone markers



- Desmoinesian platform "delta" complex
- Rapid subsidence adjoining Arkoma Basin
- "High fidelity" sedimentation
- Refined sequence stratigraphic interpretation
- Prominent oil production and opportunity for IOR

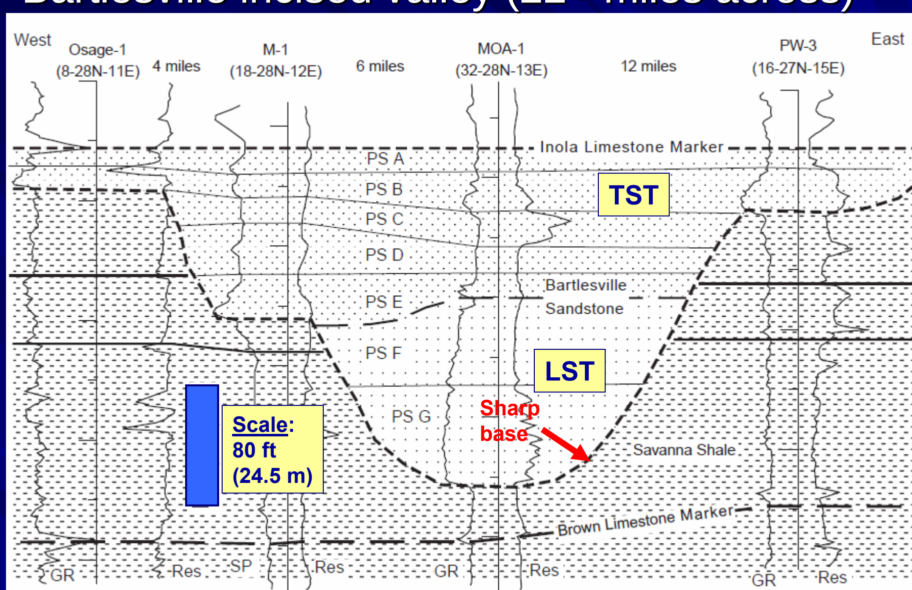
Ye and Kerr (2000)



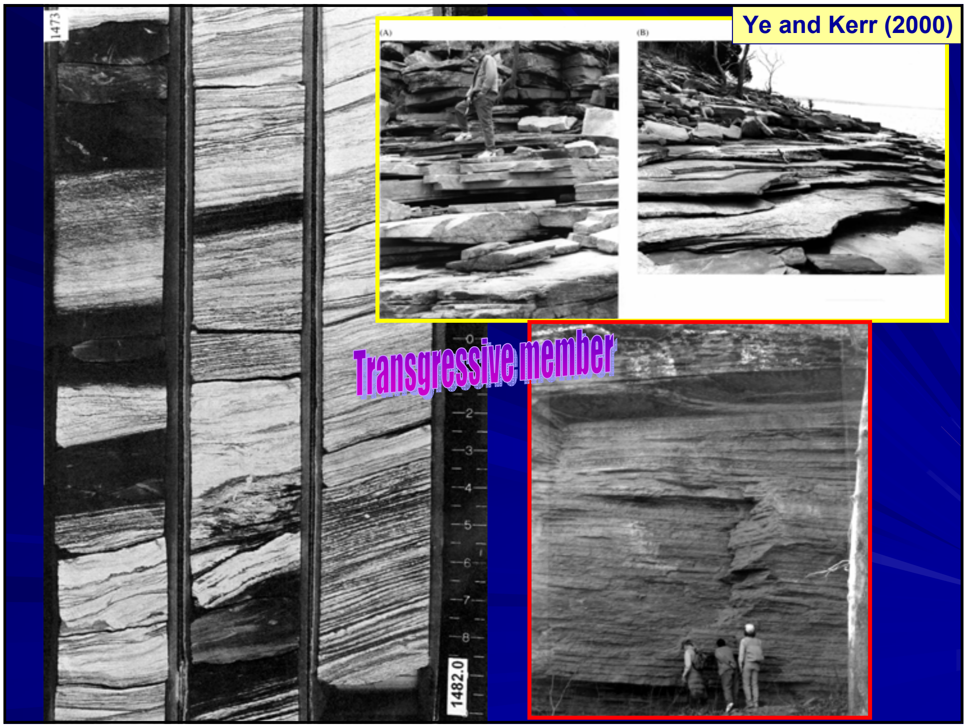
- Regional Bartlesville sandstone gross-interval isopach
- Main fairway from 50 to 250 feet thick
- Large paleovalley

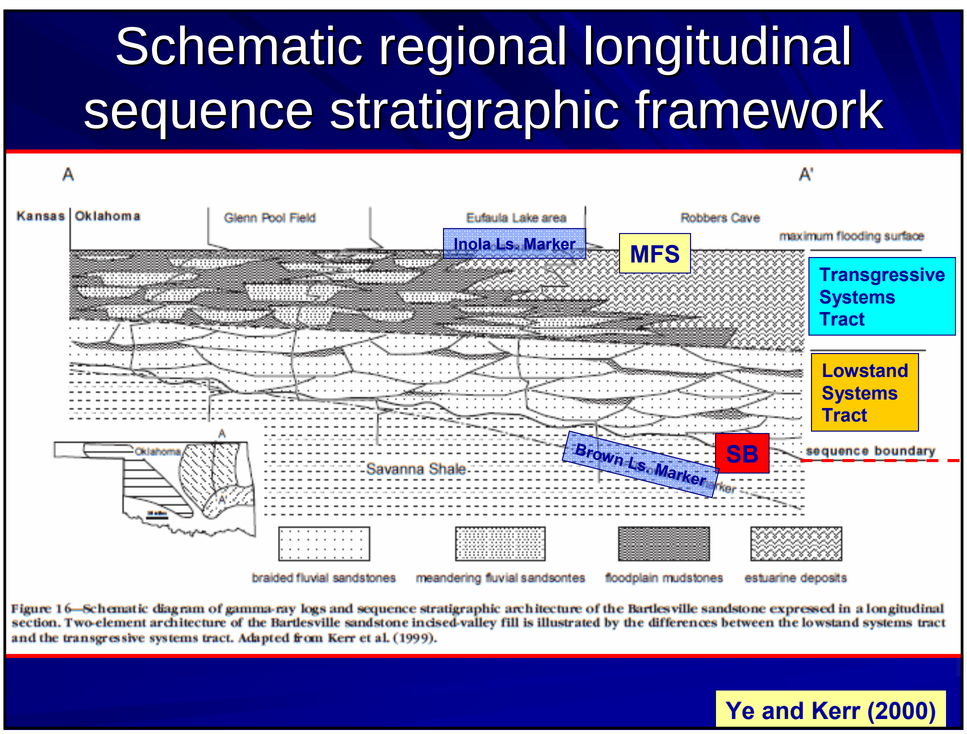
Ye and Kerr (2000)

Regional transverse cross section of Bartlesville incised valley (22+ miles across)



Ye and Kerr (2000)


Ye and Kerr (2000)
Transgressive member
1473
1482.0

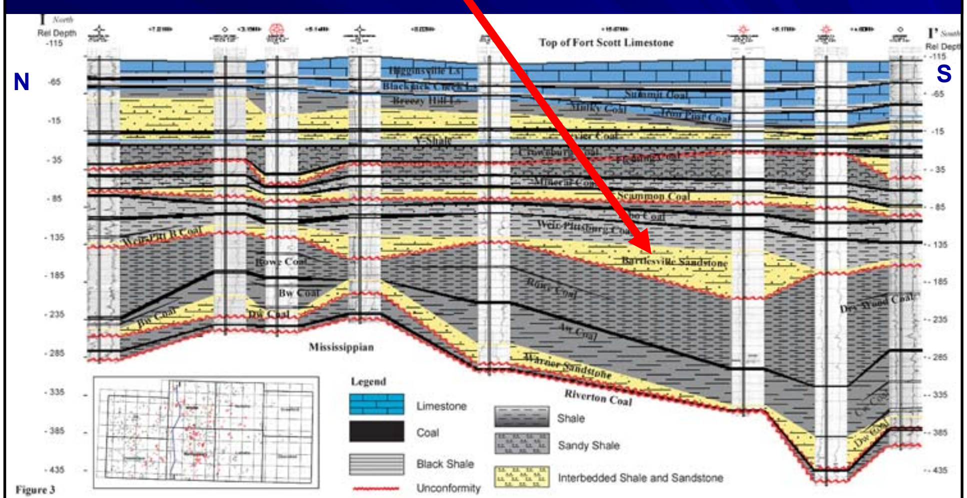

Schematic regional longitudinal sequence stratigraphic framework
A
A'
Kansas
Oklahoma
Glenn Pool Field
Eufaula Lake area
Robbers Cave
maximum flooding surface
Inola Ls. Marker
MFS
Transgressive Systems Tract
Lowstand Systems Tract
SB
sequence boundary
Brown Ls. Marker
Savanna Shale
braided fluvial sandstones
meandering fluvial sandsontes
floodplain mudstones
estuarine deposits
Figure 16—Schematic diagram of gamma-ray logs and sequence stratigraphic architecture of the Bartlesville sandstone expressed in a longitudinal section. Two-element architecture of the Bartlesville sandstone incised-valley fill is illustrated by the differences between the lowstand systems tract and the transgressive systems tract. Adapted from Kerr et al. (1999).
Ye and Kerr (2000)

Conclusions

- The Bartlesville sandstone is a fluvial-dominated, incised-valley fill deposited above a type 1 sequence boundary.
- Two sequence architectural elements constitute the valley fill: the lower Bartlesville lowstand systems tract characterized by braided-fluvial deposits, and the upper Bartlesville transgressive systems tract dominated by meandering-fluvial, grading-upward to tidally influenced, meandering-fluvial facies and downvalley to tidally dominated estuarine facies.
- The Inola Limestone Member marker, capping the Bartlesville sandstone interval, represents the condensed section within the type 1 sequence.
- Bartlesville sandstone is an underfilled incised valley the Bartlesville paleovalley was mainly filled during rising stages of relative sea level.
- The Bartlesville sequence stratigraphic architecture has a strong influence on reservoir characteristics and petroleum resource distribution.
- The lowstand systems tract contains high-quality reservoir sandstones that contain about two-thirds of the total original oil in place.
- The transgressive systems tract, which is much more heterogeneous and less developed by comparison, offers the main potential for future development.

Ye and Kerr (2000)

Example of a N-S stratigraphic cross section from SE Kansas shelf, illustrating stratigraphy in equivalent Bartlesville Sandstone interval along higher shelf position

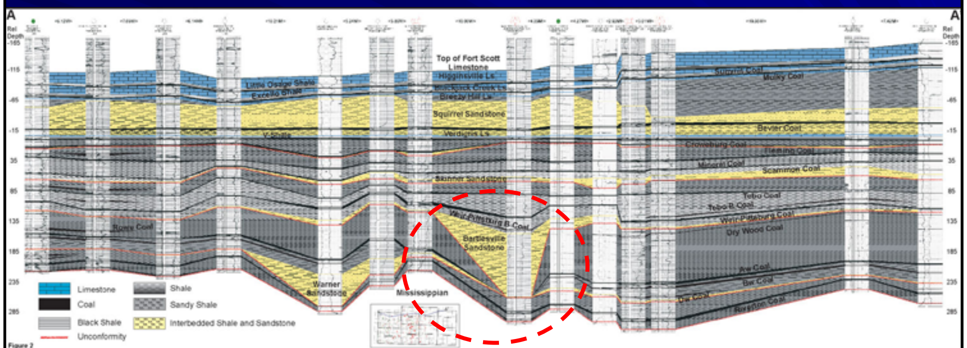


Length = 48 mi.

Johnson et al. (2003)

Example of a West-to-east stratigraphic cross section from SE Kansas shelf in same area as previous slide, illustrating stratigraphy in equivalent Bartlesville Sandstone interval

West — East

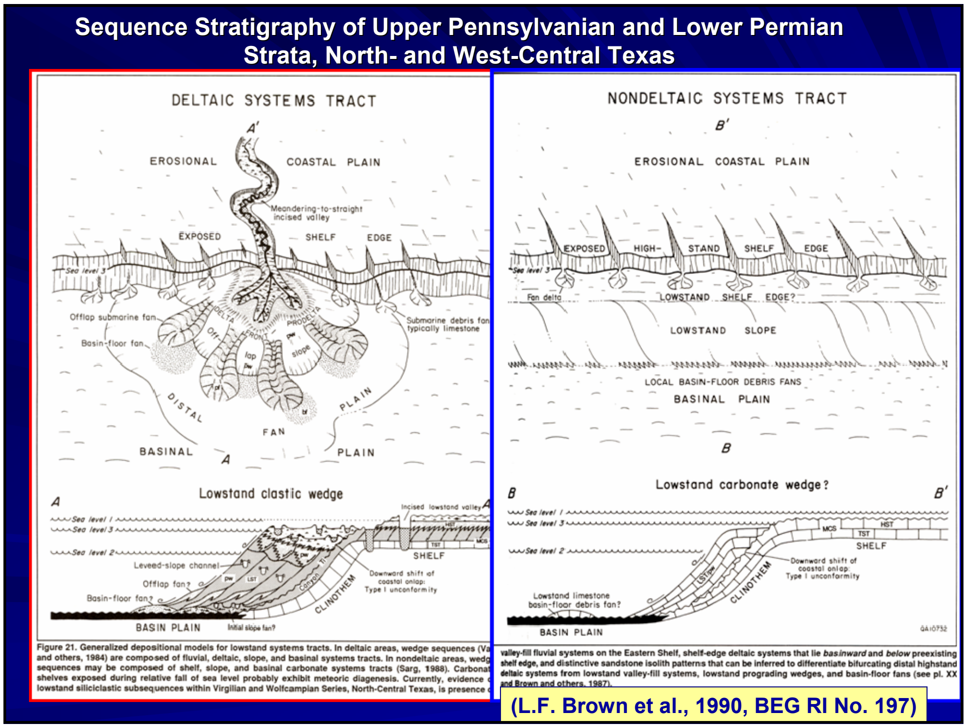


Length = 90 mi.

Johnson et al. (2003)

Additional points on incised valley fill (IVF) deposits --

- 1. Excellent analogs for Permo-Pennsylvanian coastal-plain IVF deposits in found in Quaternary strata, e.g. Gulf Coast, Indonesia.
- 2. Incised valleys are common throughout the Midcontinent and the Pennsylvanian.
- 3. Characteristics of IVF vary due to local and regional controls.
- 4. IVF sandstones are important reservoirs.
  - est. 25% of off-structure conventional clastic reservoirs worldwide are IVF (Brown, 1993)



General take home points of sequence stratigraphy section

- Systematic patterns in structure and eustacy and accommodation that they create revealed by stratigraphic response at level of within sequences and sequence sets.
- Similarly, lithofacies and early diagenetic overprinting are influenced strongly by these processes.
- Variations in shelf elevation and slope affected by local structure and sediment supply (responding in part to eustacy) dramatically change reservoir characteristics.

PREDICTING SPATIAL DISTRIBUTION OF CRITICAL PORE TYPES AND THEIR INFLUENCE ON RESERVOIR QUALITY, CANYON (PENNSYLVANIAN) REEF RESERVOIR, DIAMOND M FIELD, TEXAS

by

AARON JAY FISHER

Texas A&M University

MASTER OF SCIENCE
December 2005

Canyon Phylloid Algal Reservoir – Diamond M Field, Horseshoe Atoll

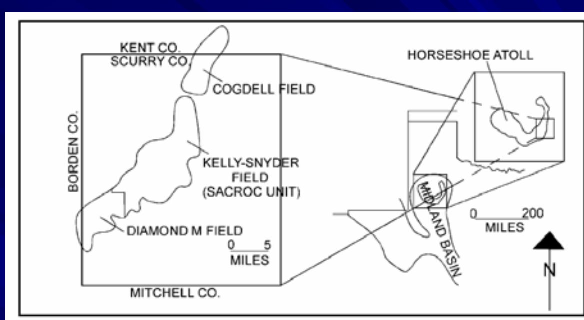


Figure 1. Map of West Texas showing the Horseshoe Atoll

- Three borehole cores, well information including production history, completion reports, geological studies, existing base maps and cross sections
- Gamma ray/neutron logs along with modern gamma-ray, spontaneous potential, caliper, neutron, and litho-density logs
- 500 ft of core taken from three recently drilled wells, core analysis
- Calculated porosity, permeability, water saturation, oil saturation, bulk density, and fluorescence on the three cored wells.

Fisher (2005)

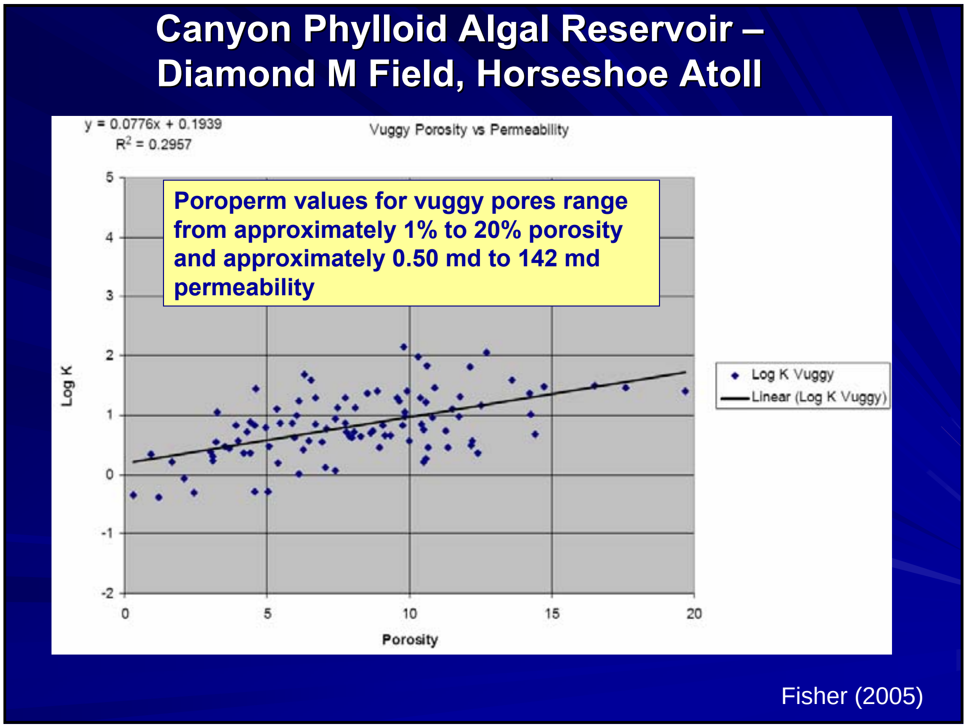
Canyon Phylloid Algal Reservoir – Diamond M Field, Horseshoe Atoll

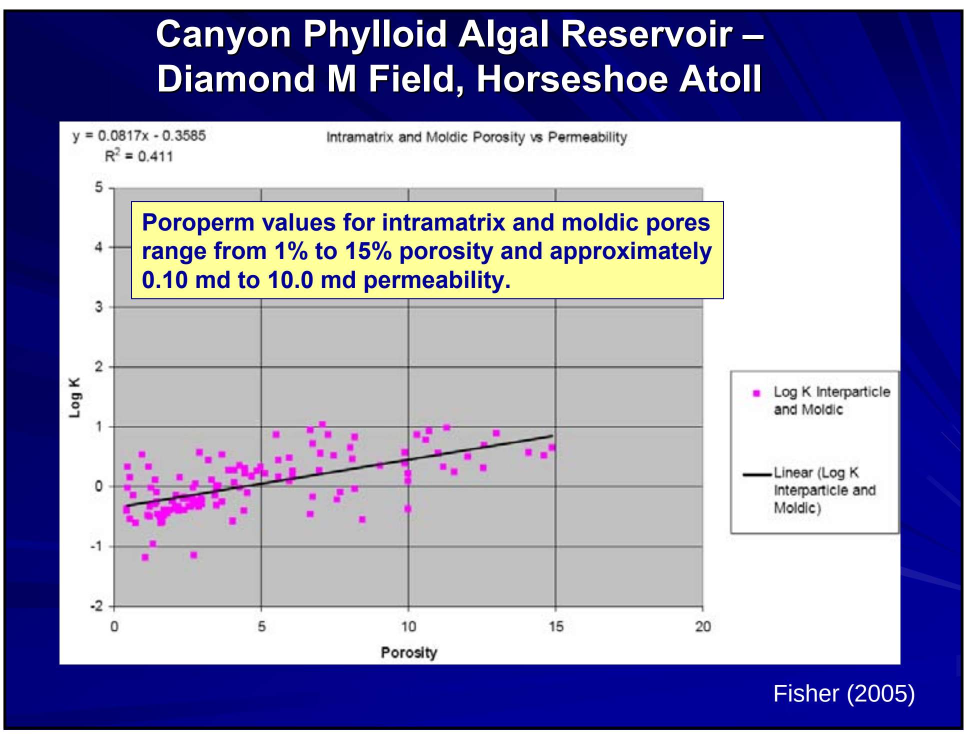
- Stratigraphic architecture, depositional and diagenetic histories, and resulting reservoir characteristics that have influenced the occurrence, distribution, and quality of flow units in the Diamond M field, Scurry County, Texas.
- The study area is located in the Midland Basin. The field has production from the Canyon (Pennsylvanian) Horseshoe Atoll carbonate buildup.
- Recent drilling in the Diamond M field was done to evaluate ways to improve recovery by water flooding.
- Classification of depositional texture based on detailed petrologic and petrographic studies on three cores was done. Subsequent genetic classification of pore types by thin section petrography revealed three dominant pore types: intramatrix, moldic, and vuggy.

Fisher (2005)

Canyon Phylloid Algal Reservoir – Diamond M Field, Horseshoe Atoll

- The reservoir was zoned according to dominant pore type and log signatures to evaluate correlations at field scale by using neutron logs. Equations determined from core analyses used to estimate porosity and permeability, which were used to develop a ranking scheme for reservoir quality based on good, intermediate, and poor flow units at field scale.
- Ultimately slice maps of reservoir quality


Canyon Phylloid Algal Reservoir –
Diamond M Field, Horseshoe Atoll
y = 0.0776x + 0.1939
R² = 0.2957
Vuggy Porosity vs Permeability
Poroperm values for vuggy pores range from approximately 1% to 20% porosity and approximately 0.50 md to 142 md permeability
Log K
Porosity
Log K Vuggy
Linear (Log K Vuggy)
Fisher (2005)

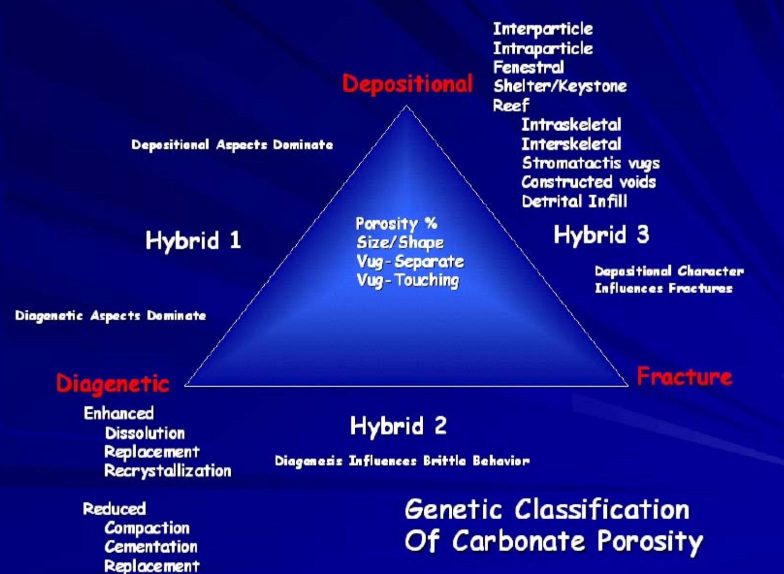

Canyon Phylloid Algal Reservoir –
Diamond M Field, Horseshoe Atoll
y = 0.0817x - 0.3585
R² = 0.411
Intramatrix and Moldic Porosity vs Permeability
Poroperm values for intramatrix and moldic pores range from 1% to 15% porosity and approximately 0.10 md to 10.0 md permeability.
Log K
Porosity
Log K Interparticle and Moldic
Linear (Log K Interparticle and Moldic)
Fisher (2005)

Canyon Phylloid Algal Reservoir – Diamond M Field, Horseshoe Atoll

- These high quality zones correspond to high percentages of vuggy porosity.
- Flow units dominated by intramatrix and moldic porosity.
- Rarely have porosity values greater than 13.3 and permeability values over 10 md.

Fisher (2005)

Pore classification after Ahr (2005)



Fisher (2005)

Canyon Phylloid Algal Reservoir – Diamond M Field, Horseshoe Atoll

Figure A-1. A) Core photo taken from Jade # 1 @ 6,848' representing Reef Facies 1. B) Core photo taken from Topaz # 1 @ 6,752' representing Reef Facies 2 as well as abundant vuggy porosity.

Fisher (2005)

Diamond M Porosity Slice Map

0 to 10 ft below Top of Reef

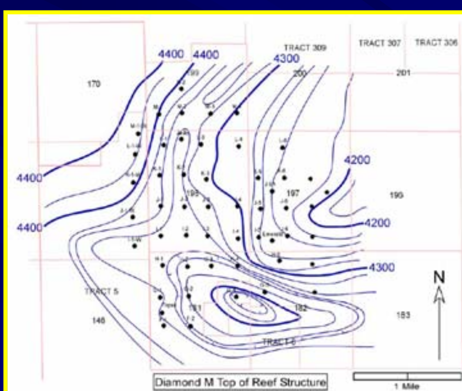
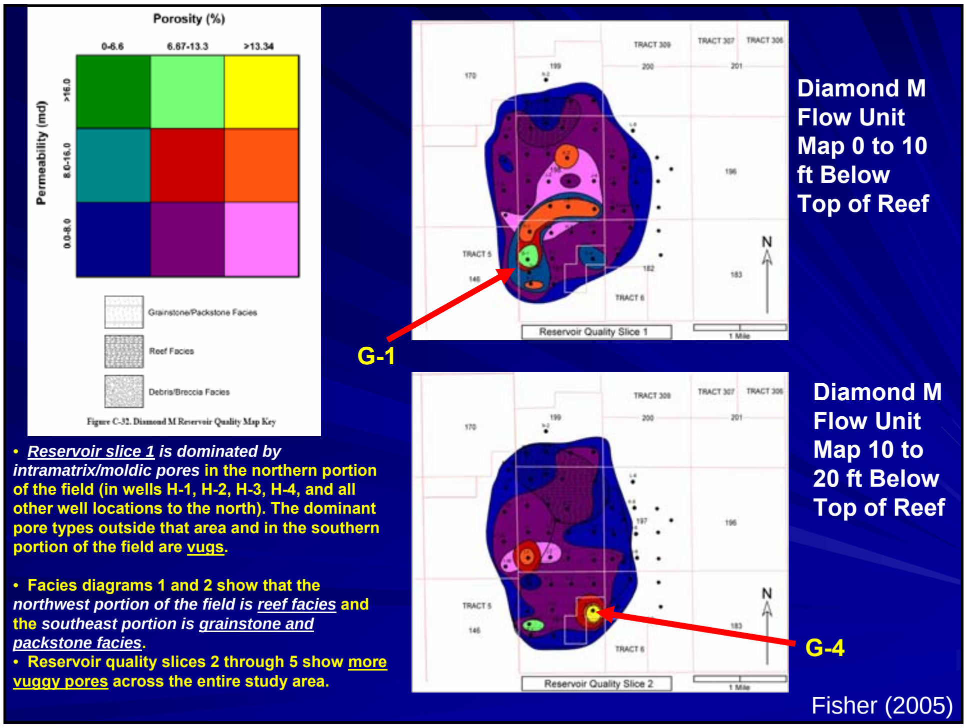


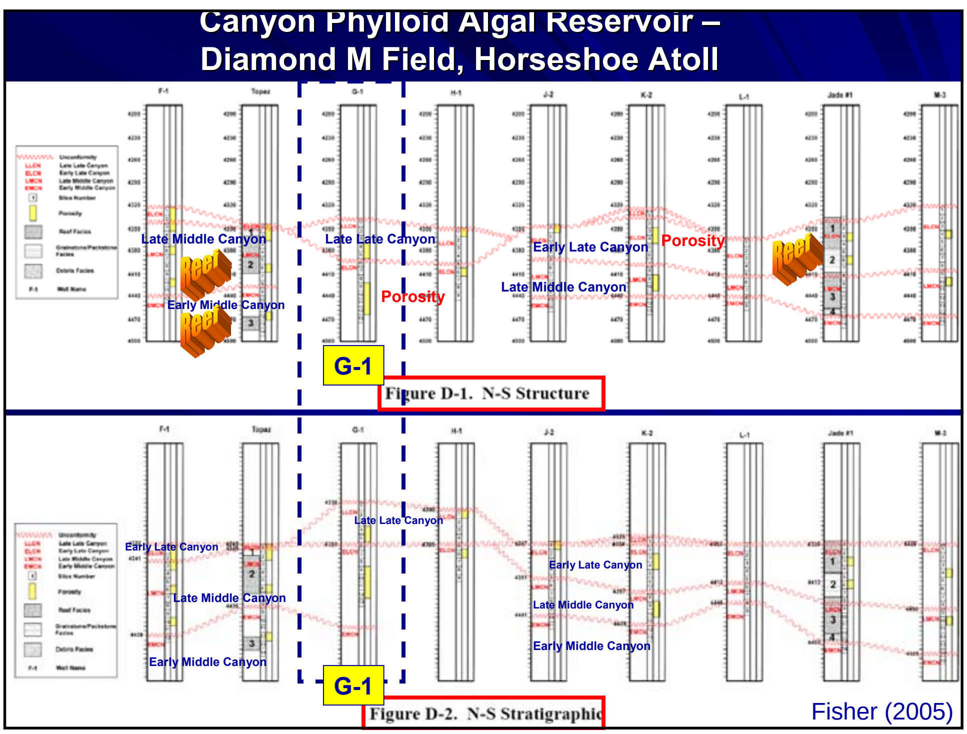
Figure C-1. Diamond M Top of Reef Stucture Map

Diamond M Porosity Slice Map

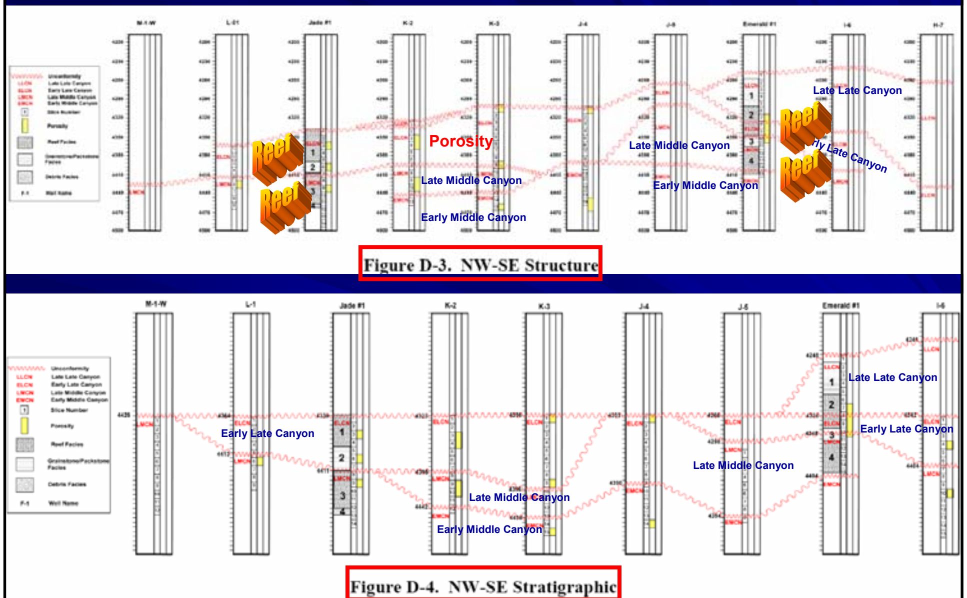
10 to 20 ft below Top of Reef

Fisher (2005)


Porosity (%)
0-6.6
6.67-13.3
>13.34
Permeability (md)
>16.0
8.0-16.0
0.0-8.0
Grainstone/Packstone Facies
Reef Facies
Debris/Breccia Facies
Figure C-32. Diamond M Reservoir Quality Map Key
• Reservoir slice 1 is dominated by intramatrix/moldic pores in the northern portion of the field (in wells H-1, H-2, H-3, H-4, and all other well locations to the north). The dominant pore types outside that area and in the southern portion of the field are vugs.
• Facies diagrams 1 and 2 show that the northwest portion of the field is reef facies and the southeast portion is grainstone and packstone facies.
• Reservoir quality slices 2 through 5 show more vuggy pores across the entire study area.
G-1
G-4
Reservoir Quality Slice 1
Reservoir Quality Slice 2
Diamond M Flow Unit Map 0 to 10 ft Below Top of Reef
Diamond M Flow Unit Map 10 to 20 ft Below Top of Reef
Fisher (2005)

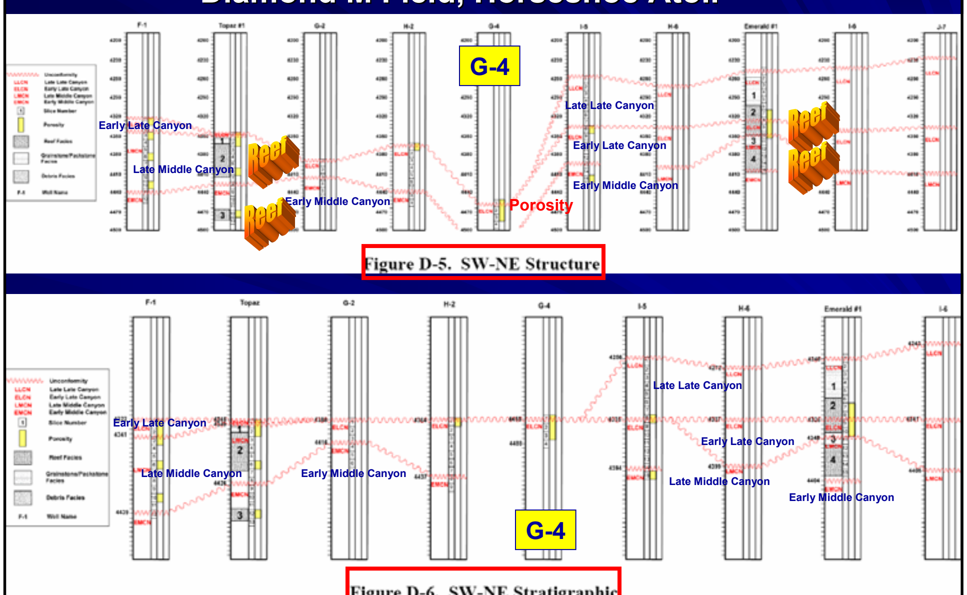

Canyon Phylloid Algal Reservoir – Diamond M Field, Horseshoe Atoll
Late Middle Canyon
Early Middle Canyon
Reef
Late Late Canyon
Porosity
Early Late Canyon
G-1
Figure D-1. N-S Structure
Figure D-2. N-S Stratigraphic
Fisher (2005)

Canyon Phylloid Algal Reservoir – Diamond M Field, Horseshoe Atoll



Fisher (2005)

Canyon Phylloid Algal Reservoir – Diamond M Field, Horseshoe Atoll



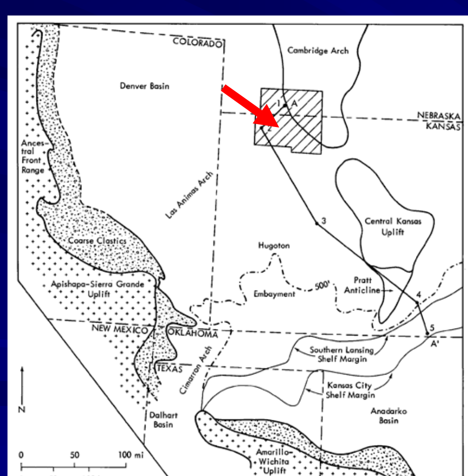
Fisher (2005)

Conclusions

- Diamond M Field produces from a diagenetically altered depositional pore system (hybrid porosity) in a *micritic, platy algal, skeletal wackestones to grainstone reservoir*.
- Pore types can be identified in thin section and correlated across the field, resulting in detailed reservoir quality maps.
- Pore types (V, SEIM, and M) are readily identifiable in thin section and can be *correlated across the field using poroperm values and neutron log traces*.
- Methods used in the study may be *applied to other West Texas Paleozoic reef fields* with similar depositional and diagenetic characteristics.
- Core material should be taken from future wells to aid in identifying reservoir quality.

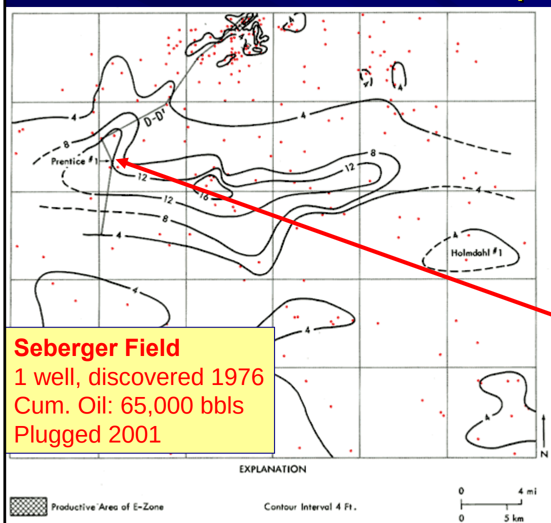
Fisher (2005)

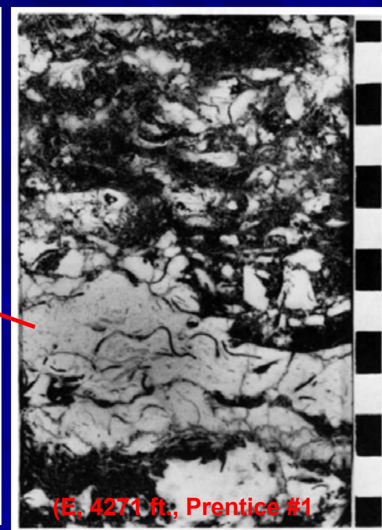
Field producing from the phylloid algal mound lithofacies from the Plattsburg Limestone in Northwest Kansas – upper shelf, thin buildups, intensely subaerially exposed



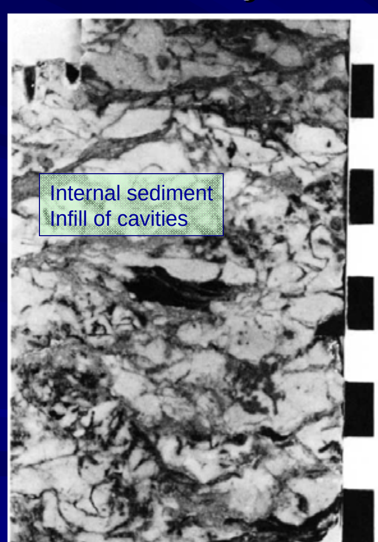
Group	Stage	Series
WABAUNSEE	VIRGILIAN	UPPER PENNSYLVANIAN
SHAWNEE		
DOUGLAS		
LANSING	MISSOURIAN	
KANSAS CITY		
PLEASANTON		
MARMATON	DESMOINESIAN	MIDDLE PENN.
CHEROKEE		

Transgressive phylloid algal mounds Plattsburg sequence – thin, vugs and microspar

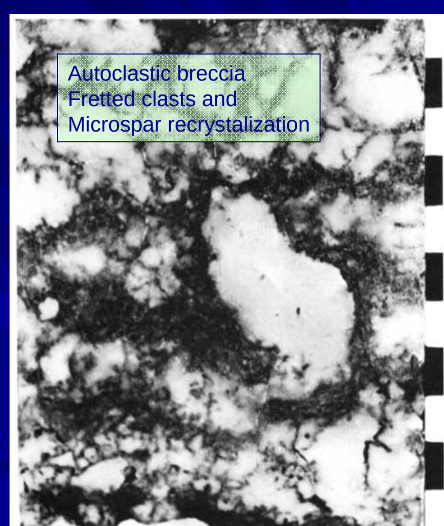




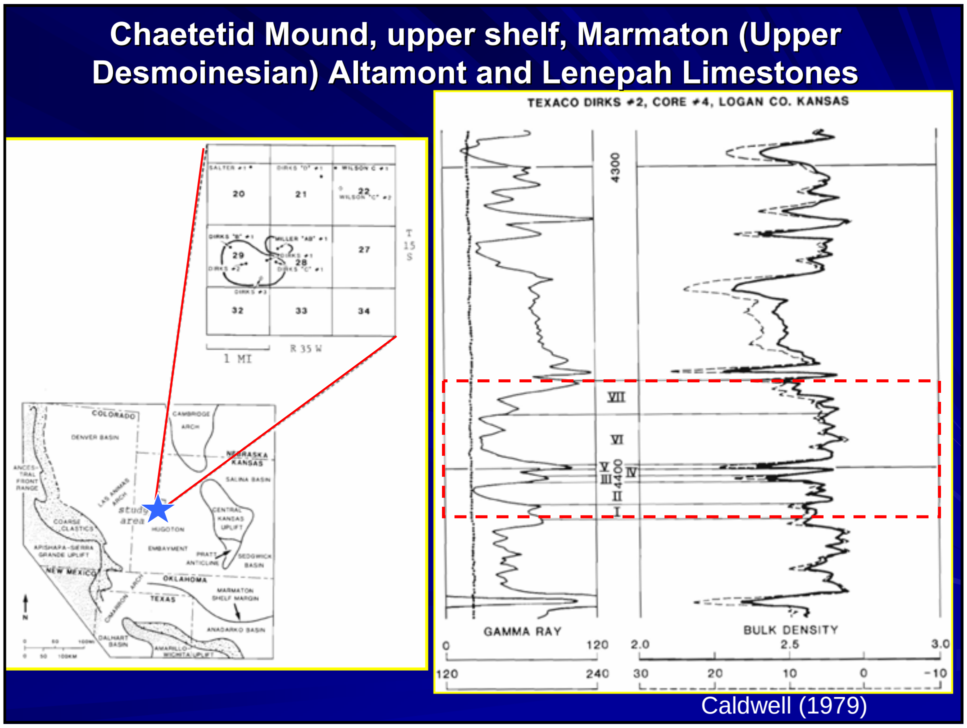
Plattsburg Limestone Phylloid Algal Mounds

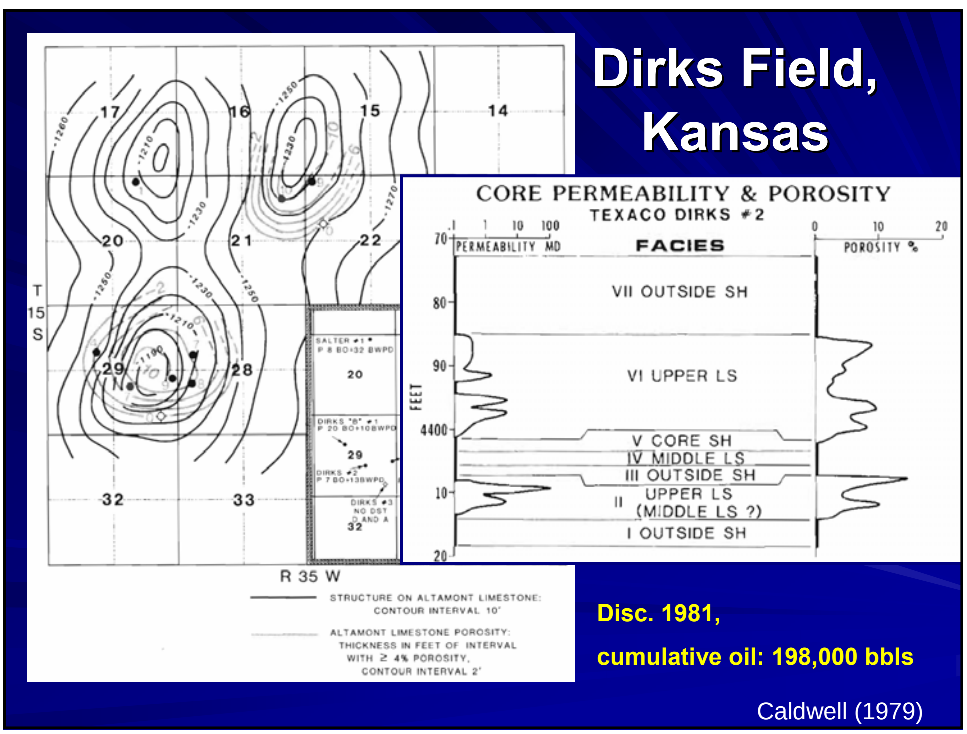


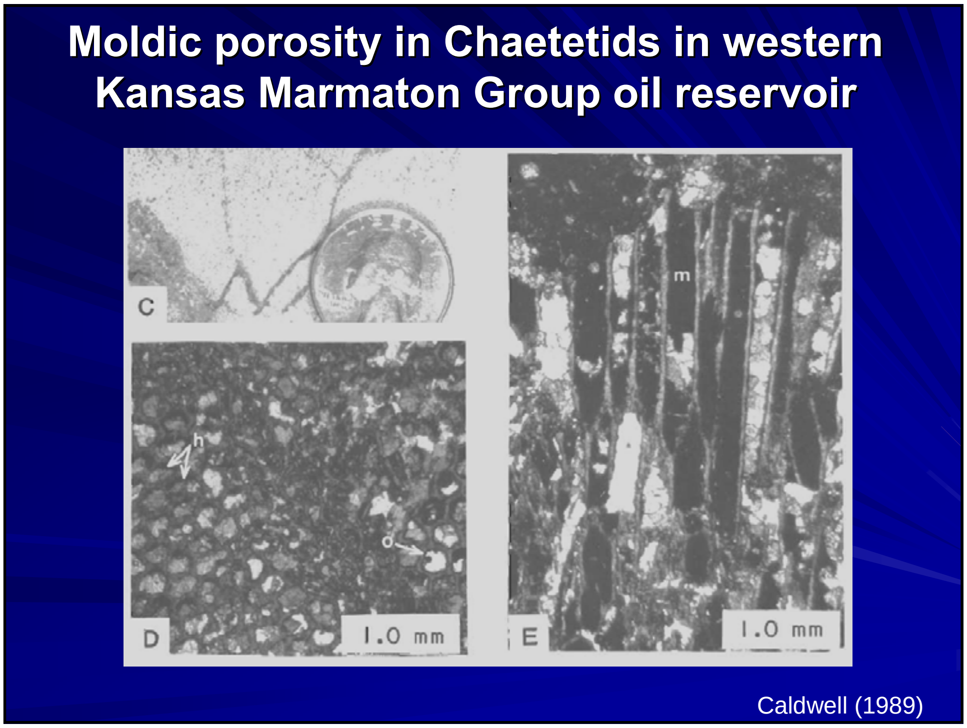
D, 4249 to 4250 ft., Prentice #1



Slab: D, 3174 ft., Nicholson #


Chaetetid Mound, upper shelf, Marmaton (Upper Desmoinesian) Altamont and Lenepah Limestones
TEXACO DIRKS #2, CORE #4, LOGAN CO. KANSAS
4300
4400
VII
VI
V
IV
III
II
I
GAMMA RAY
BULK DENSITY
R 35 W
1 MI
T 15 S
COLORADO
DENVER BASIN
NEBRASKA
KANSAS
SALINA BASIN
CENTRAL KANSAS UPLIFT
HUGOTON EMBAYMENT
OKLAHOMA
TEXAS
NEW MEXICO
ANADARKO BASIN
Caldwell (1979)


Dirks Field, Kansas
CORE PERMEABILITY & POROSITY
TEXACO DIRKS #2
PERMEABILITY MD
FACIES
POROSITY %
FEET
VII OUTSIDE SH
VI UPPER LS
V CORE SH
IV MIDDLE LS
III OUTSIDE SH
II UPPER LS (MIDDLE LS ?)
I OUTSIDE SH
R 35 W
STRUCTURE ON ALTAMONT LIMESTONE: CONTOUR INTERVAL 10'
ALTAMONT LIMESTONE POROSITY: THICKNESS IN FEET OF INTERVAL WITH ≥ 4% POROSITY, CONTOUR INTERVAL 2'
Disc. 1981,
cumulative oil: 198,000 bbls
Caldwell (1979)


Moldic porosity in Chaetetids in western Kansas Marmaton Group oil reservoir
C
D
h
o
1.0 mm
E
m
1.0 mm
Caldwell (1989)