High Frequency Cyclicity, Facies and Deposition of Condensed Zones in the Fayetteville Shale (Miss) – An Outcrop to Subsurface Perspective*

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Abstract

Exploration for unconventional gas in the Fayetteville Shale of north Arkansas takes place just a few 10's of miles structurally downdip and down the paleo-depositional slope from the outcrop belt of the Fayetteville Shale and overlying Pitkin Limestone (Mississippian-Chesterian age). The succession was deposited in an E-W trending ramp bordering the southern margin of Laurussia. Surface to subsurface transects utilizing outcrops, cores and well-logs are key to documenting the stratigraphic architecture and facies belts from the inner to outer ramp system, where organic-rich, condensed zones are the exploration targets in the subsurface. Stacking patterns indicate that the lower Fayetteville Shale deepens upward above the Moorefield-Batesville lowstand wedge to a condensed zone at 328.3 Ma in starved outer-ramp setting. The condensed zone consists of several high-frequency cycles of organic-rich shale and calcareous shale. These cycles are the distal downlapping toesets of progradational, highstand deposits, which are present ~10 miles updip as inner-middle ramp wackestones-grainstones and outer ramp calcareous shales. The condensed zone cycles range from 15-30 ft thick. Each begins with transgressive, fining-upward, thin storm beds and starved ripples followed by organic-rich high GR shale, which represent maximum sediment starvation and organic preservation. The regressive hemicycle coarsens upward with starved ripples followed by thin storm beds to an erosional surface. These cycles are variously composed of transported fossil debris, mud clasts, phosphatic grains, siliciclastic silt, biogenic silica, clay and organic matter. The thickness and composition of laminasets and bedsets in each hemicycle are controlled by sediment input (siliciclastic, carbonate, biogenic silica) and depositional site (proximal-distal and axial or marginal). All of these factors are critically important for identifying target zones and locations for drilling and reservoir stimulation.

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Introduction

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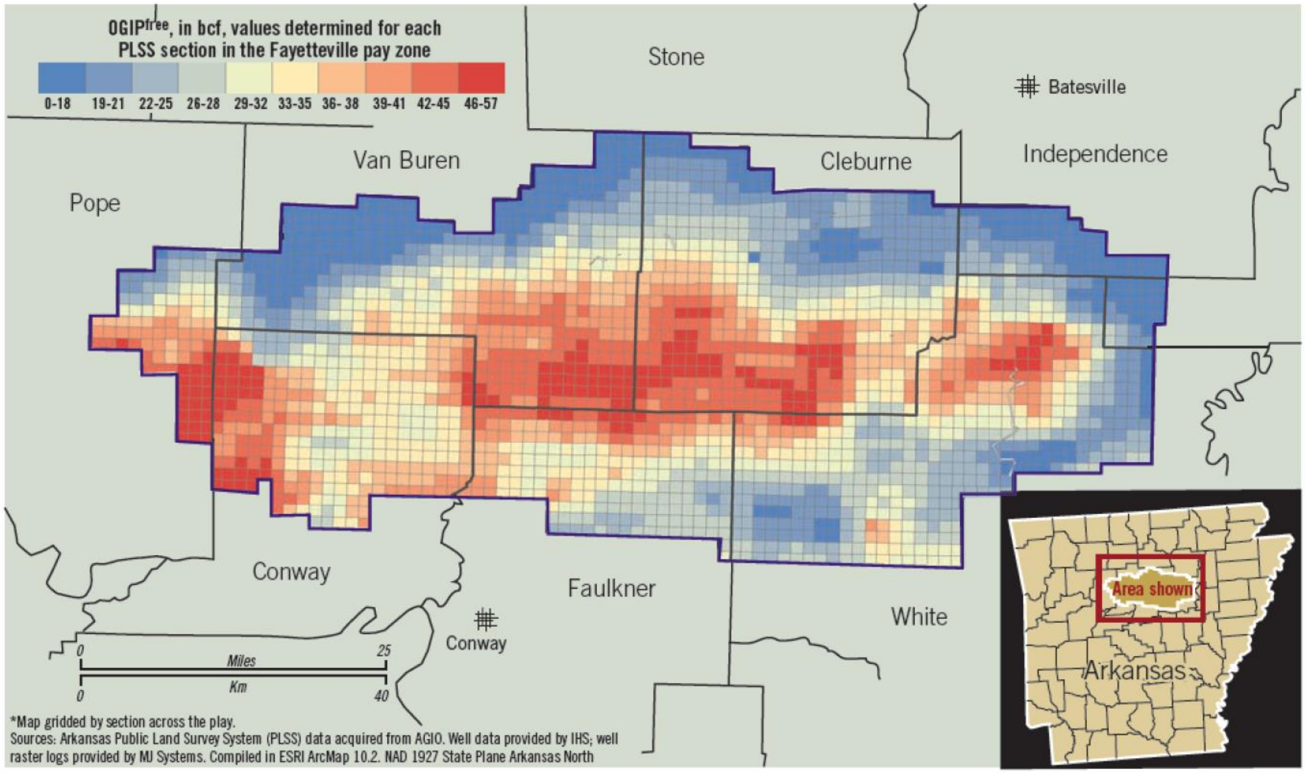
- Mississippian Fayetteville Shale contains 18 tcf of economically recoverable reserves (BEG, 2014).

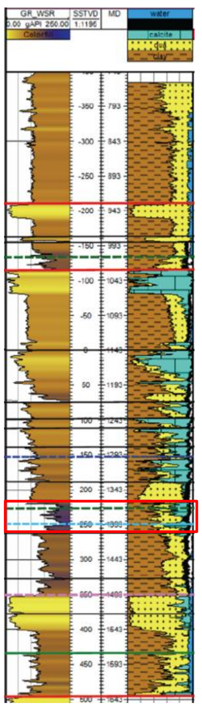


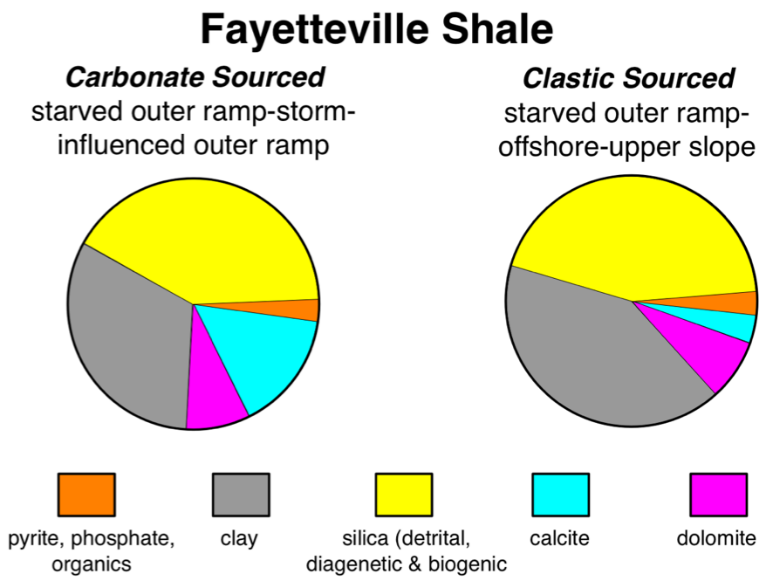
OGIP free

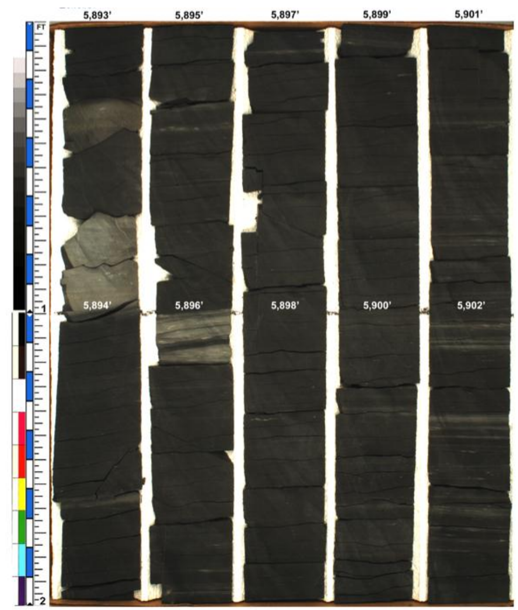
Introduction

- The producing interval comprises several condensed zones chiefly made up of varying amounts of carbonate mud, detrital silt and clay, biogenic silica, organic matter, phosphate, & pyrite.

reservoir

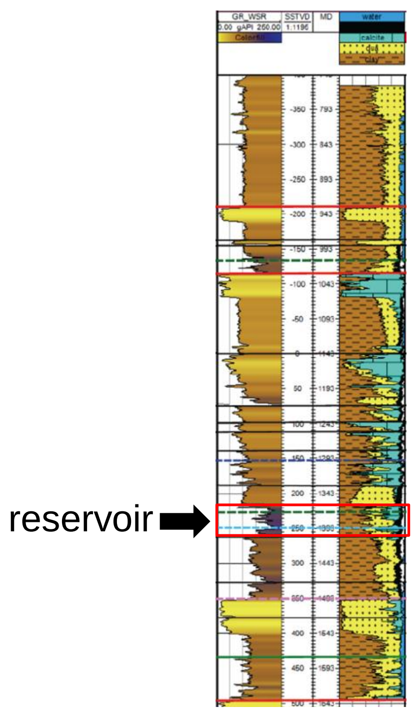


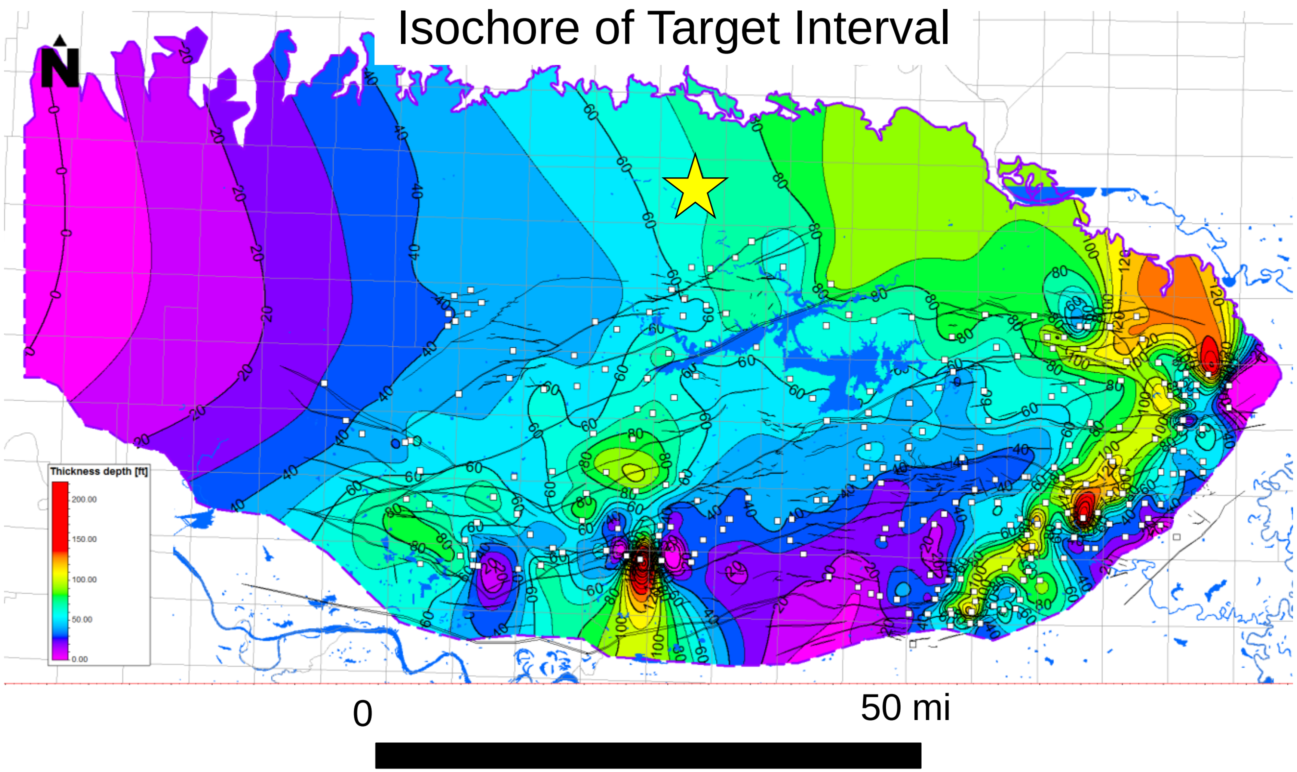




Introduction

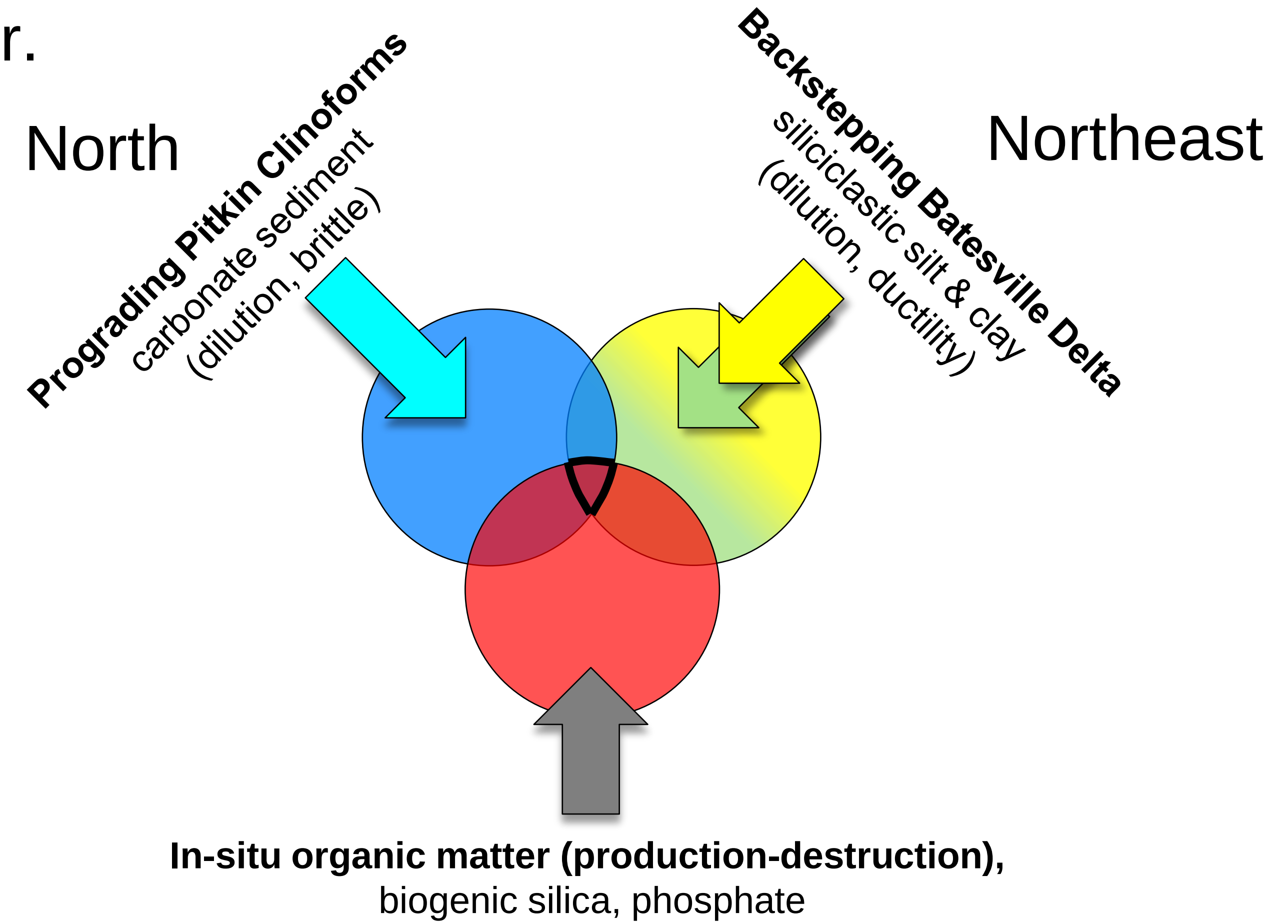
- The distribution, thickness and composition of these sediments are surprisingly variable, depending on their stratigraphic position and depositional setting.





Introduction

- The challenge is to identify and predict the best proportions of facies mixtures of a good Fayetteville reservoir.



Objectives

- Identify and characterize the fine-grained sediments of the reservoir interval of the condensed zone (core and logs).
- Document the major lithofacies and their depositional origin.
- Develop a high-frequency sequence stratigraphic framework within the condensed zone.
- Demonstrate the depositional controls over the variation in facies and their lateral distribution in the condensed zone.

Regional Setting - Mississippian Outcrop and Subsurface - Ozarks-Arkoma Basin

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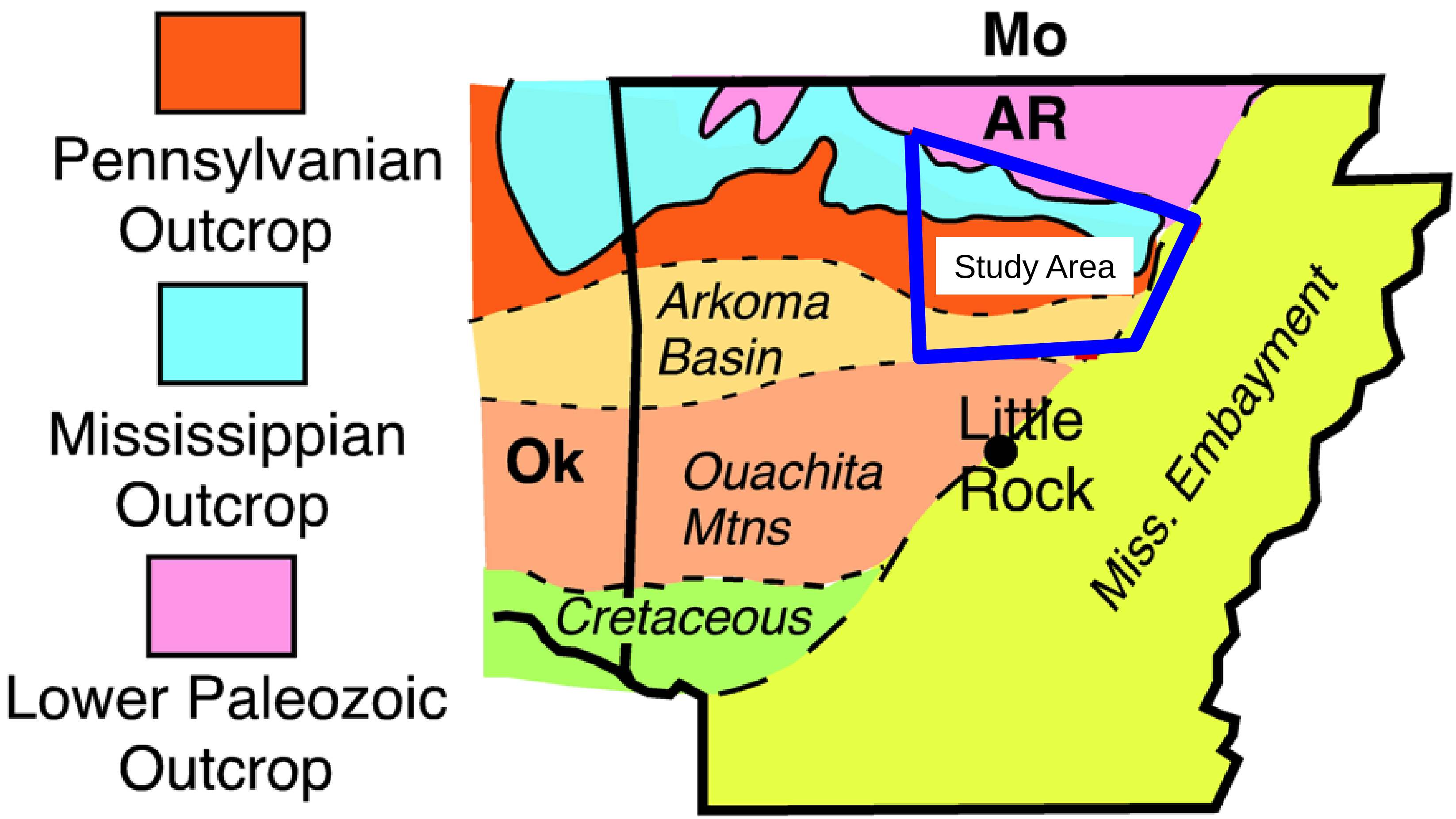

Late Mississippian (325 Ma) Paleogeography
South-Facing Carbonate Ramp

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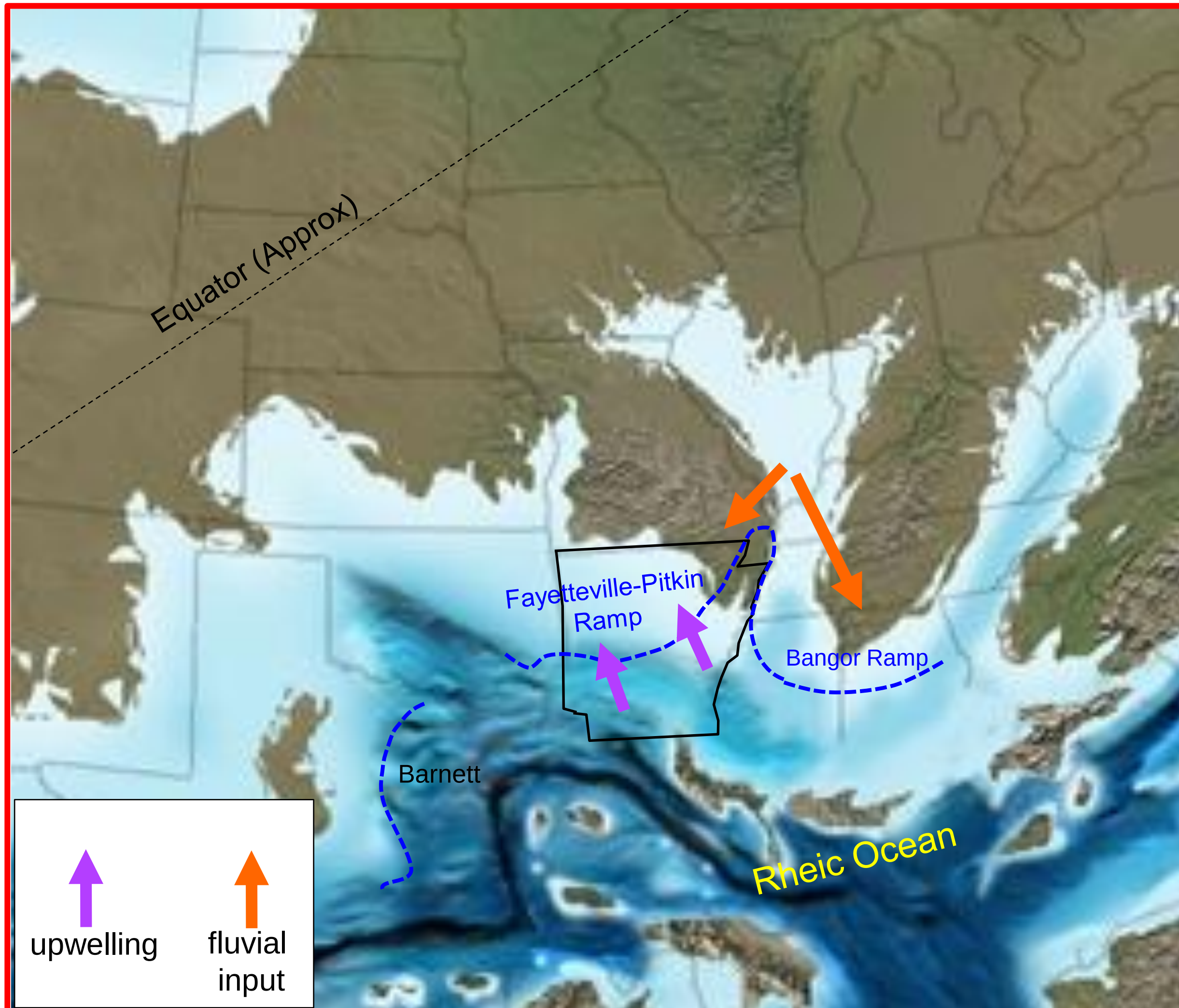
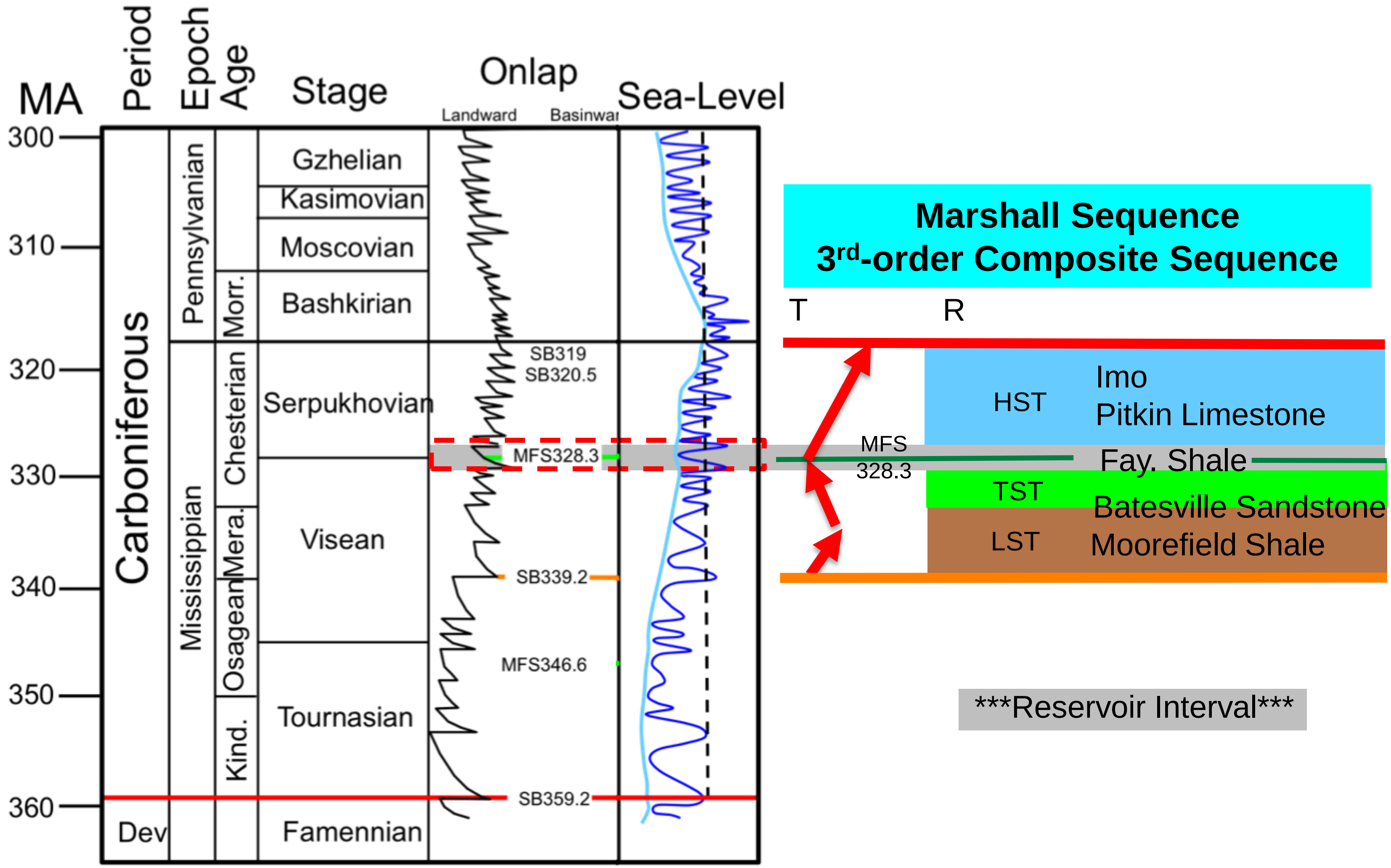
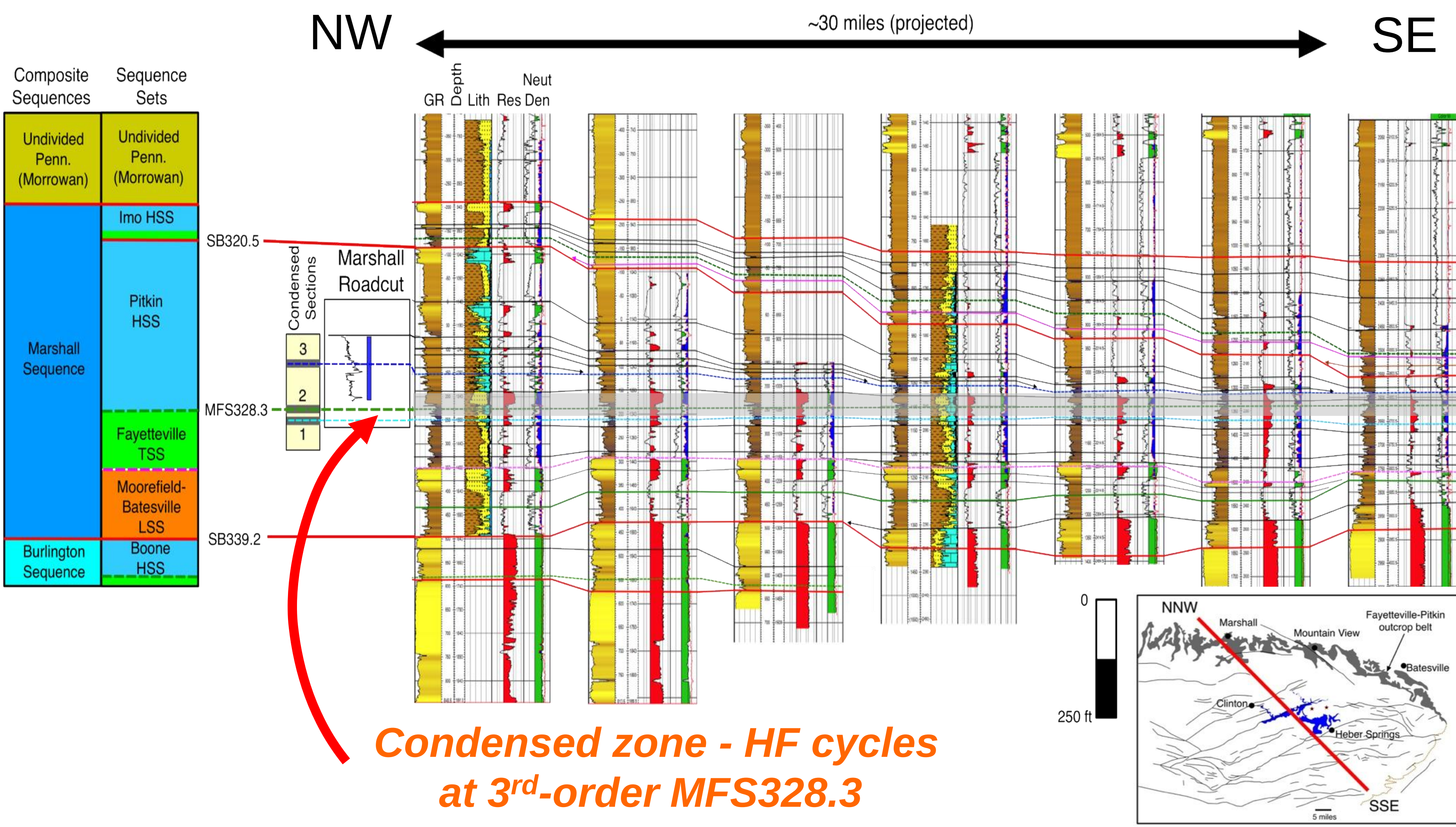
Late Mississippian (325 Ma)
Blakey, 2005



Fayetteville Reservoir - 3rd-order MFS at Visean-Serpukhovian Boundary

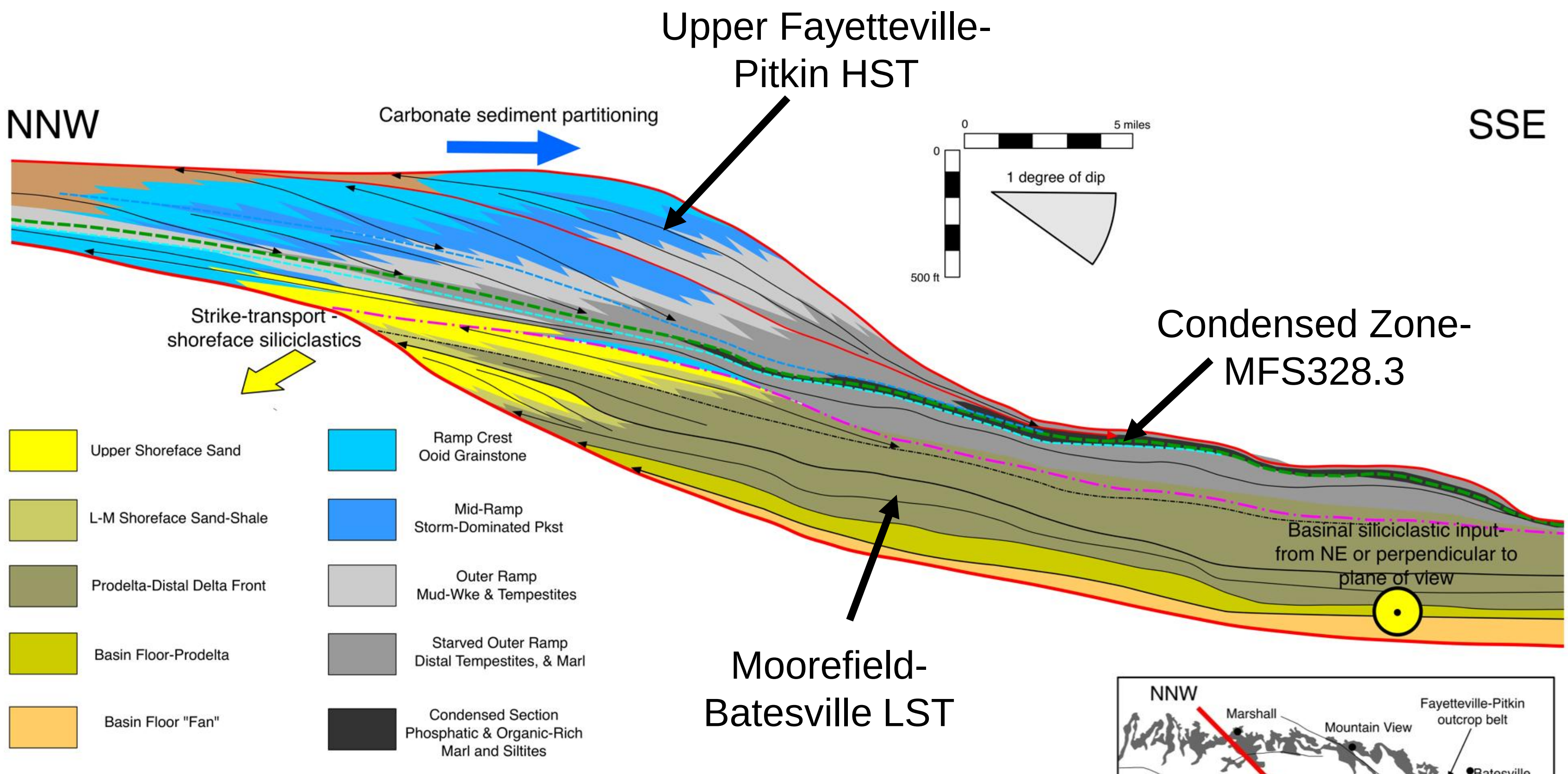


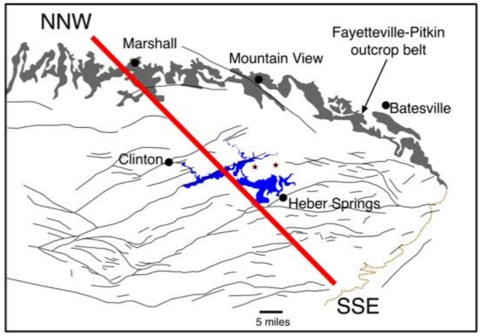
MFS328.3 - Downlap Surface of Southward Progradational Clinoforms (U.Fay-Pitkin)



Condensed zone - HF cycles at 3rd-order MFS328.3

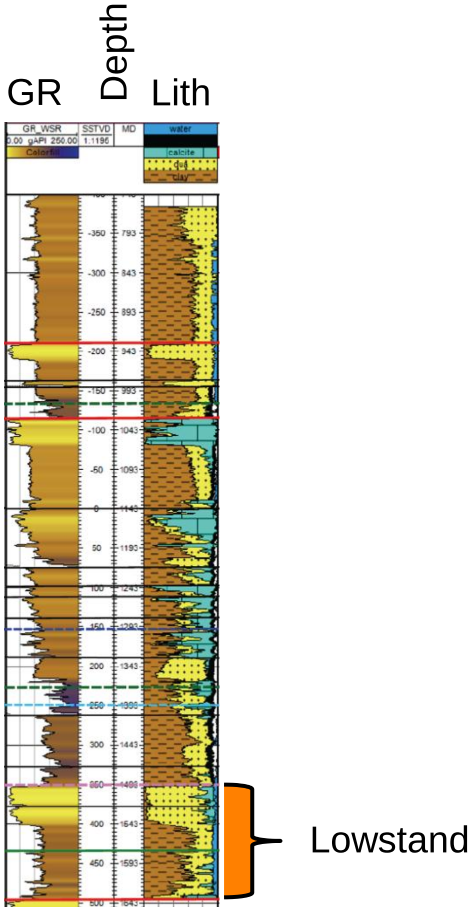
Facies and Sequence Stratigraphy of 3rd-Order Composite Marshall Sequence

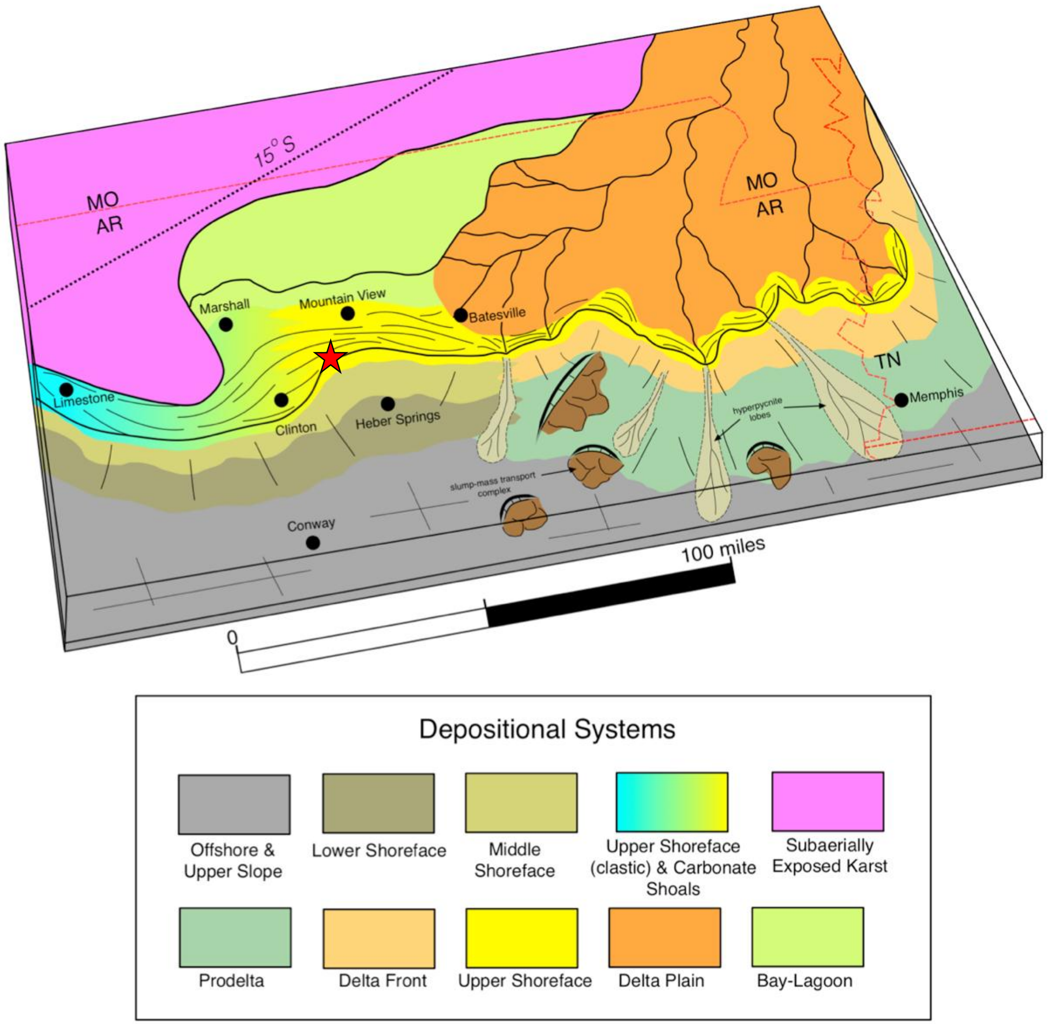




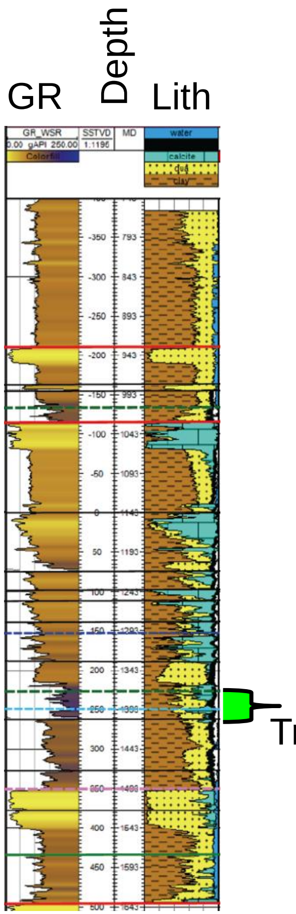
Facies change from ramp crest grainstones
to starved outer ramp mudstones ~10 miles

Meramecian Lowstand ~ 338 Ma

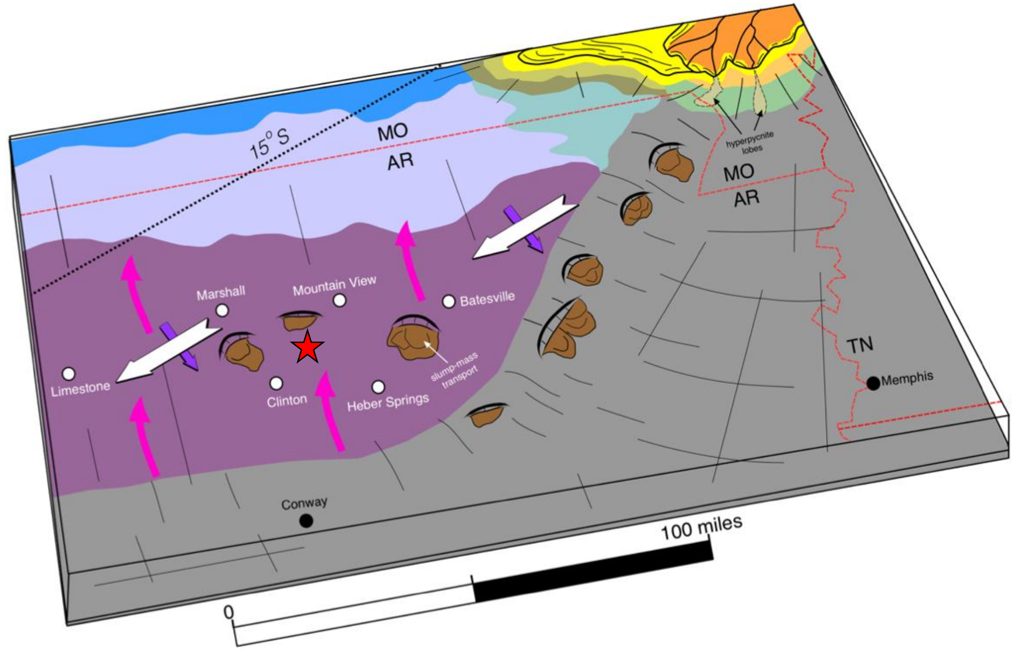


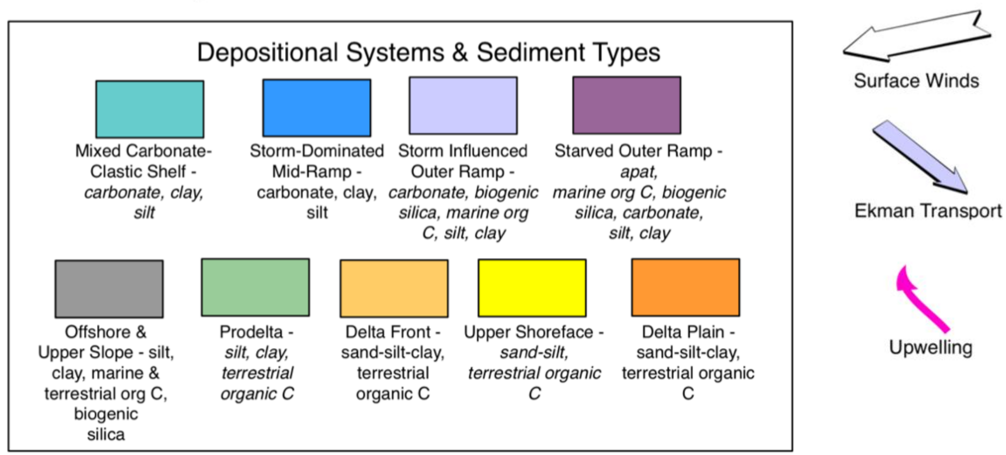


Early Chesterian Transgression 328.3 Ma



Maximum Transgression





Late Chesterian Highstand ~323 Ma)

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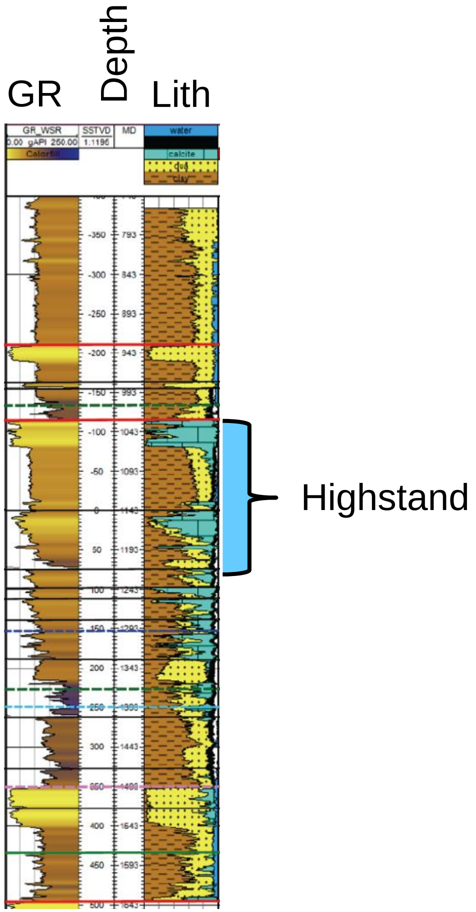
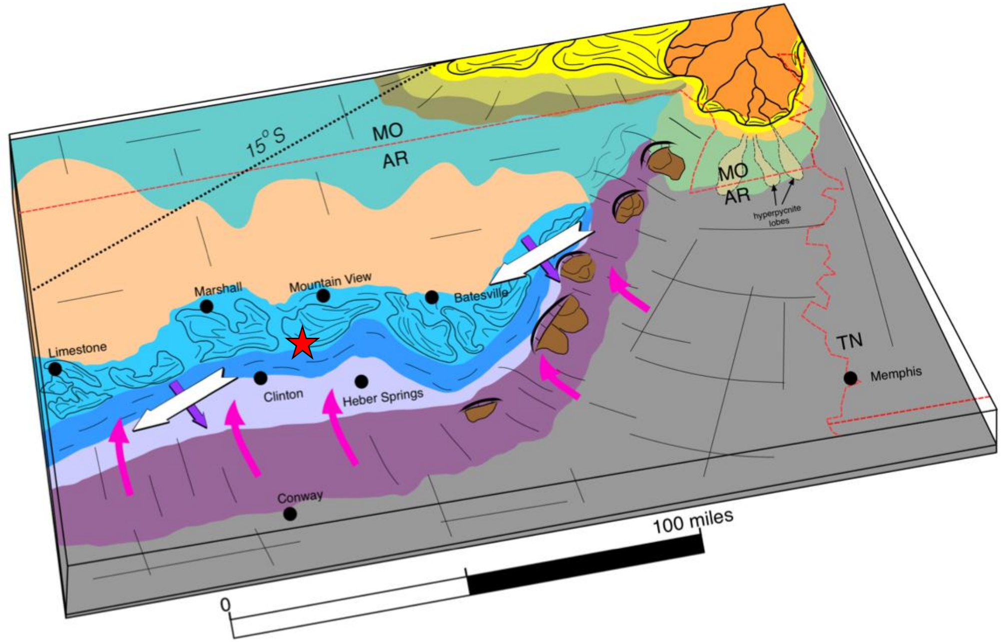
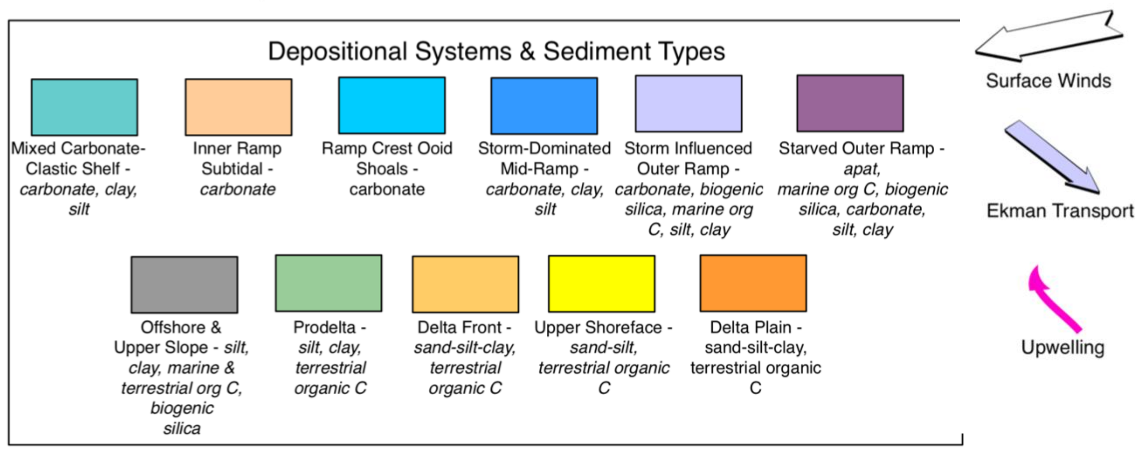






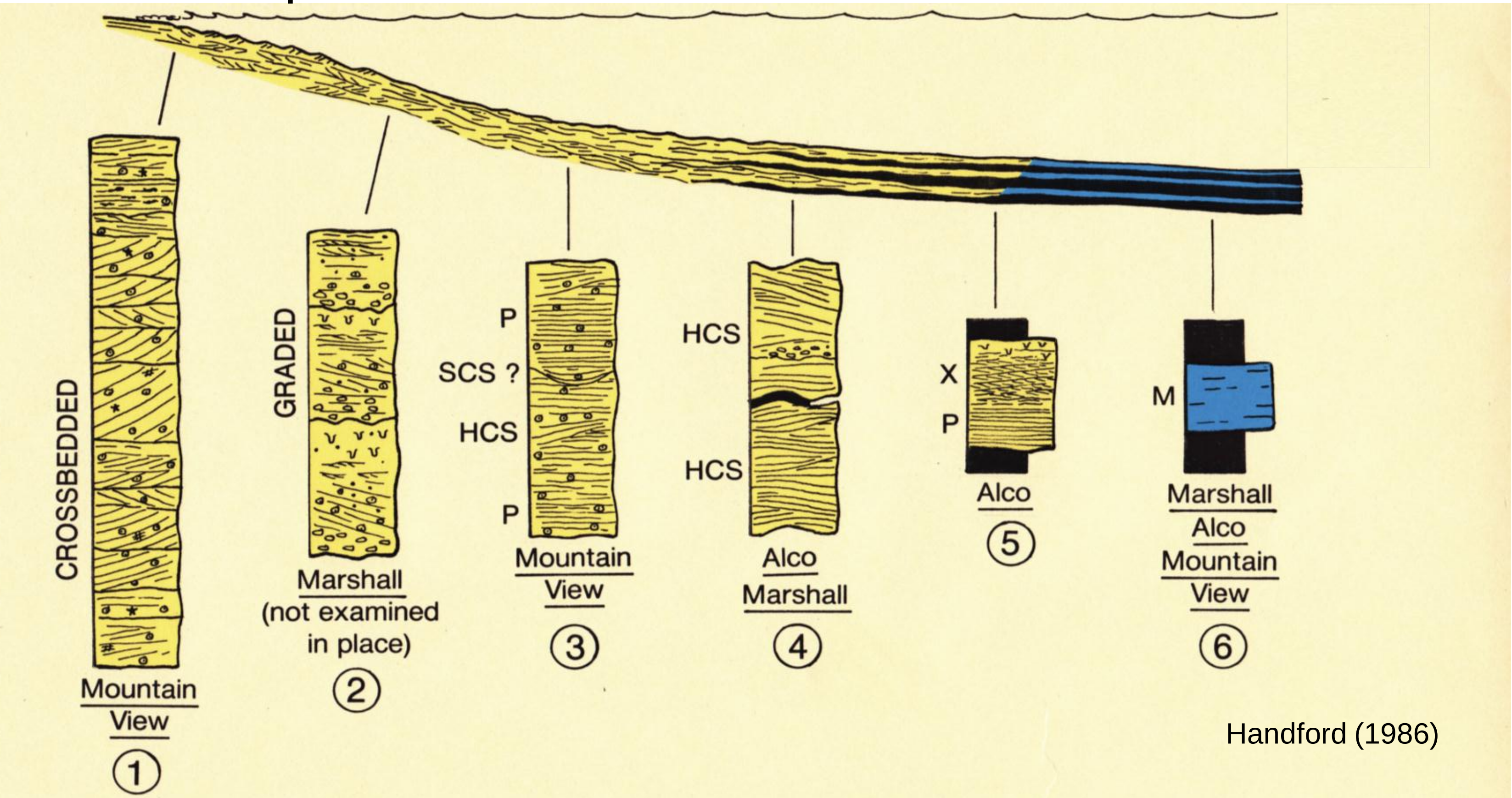
Fayetteville-Pitkin Outcrops Reveal Inner Ramp to Starved Outer Ramp Facies

Upper Fayetteville-Pitkin:
tempestites to
oolitic grainstones

Lower-Middle Fayetteville:
organic-rich “shale”
and carbonate tempestites

Storm-Dominated Facies with Distinctive Proximal-Distal Changes

Ramp Crest Ooid-Shoal Grnst	Storm-Dominated Middle Ramp Pkst	Outer Ramp Tempestites, Wke & Shale	Starved Outer Ramp Distal Tempestites & Shale



Handford (1986)

What is the Character of the Starved Outer Ramp & Condensed Section in Subsurface?

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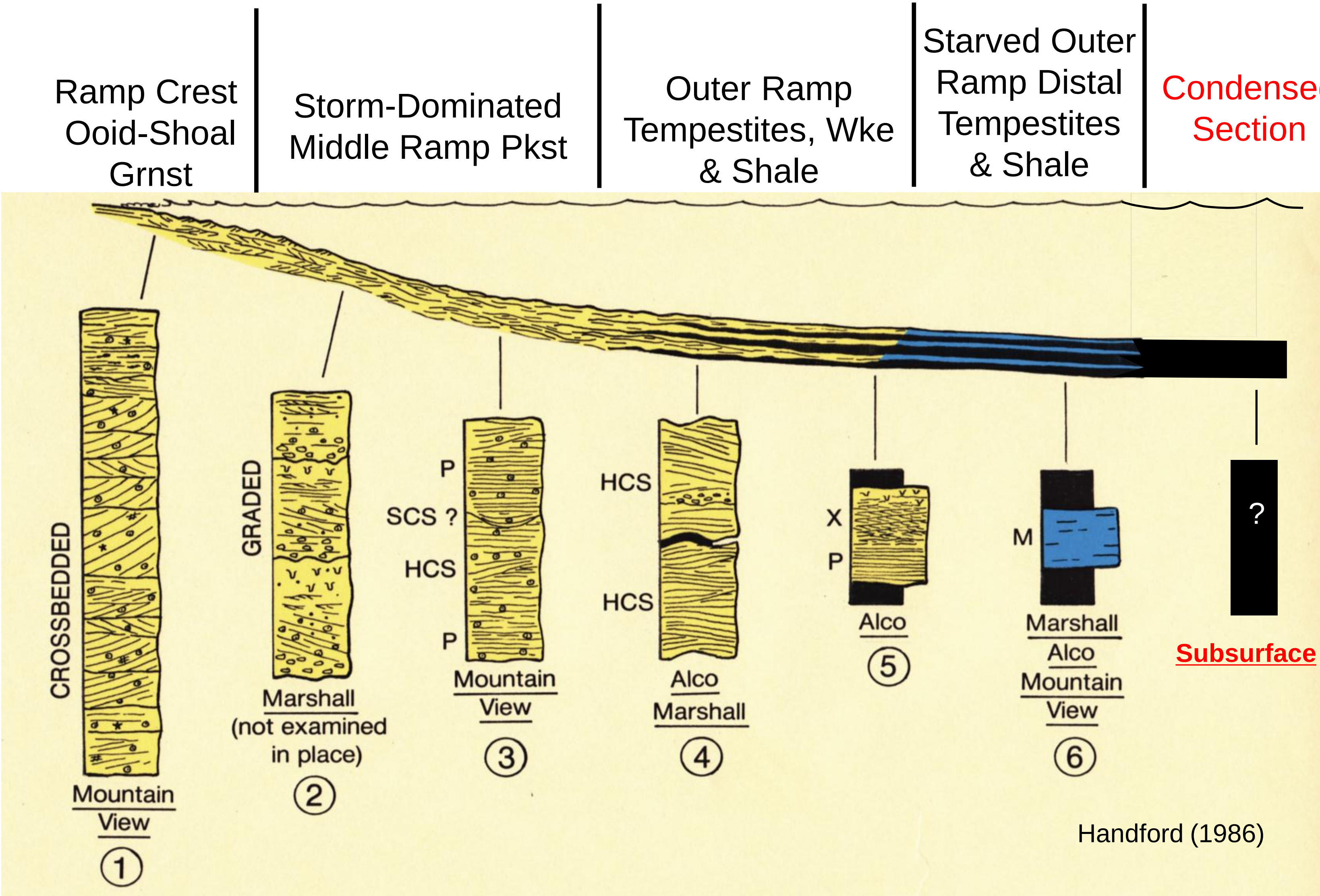

Organic-Rich Mudstone

- Black, organic-rich (4.5 wt% TOC), calcareous-dolomitic, siliceous (detrital & biogenic), phosphatic & pyritic, vaguely laminated mudstone.
- *Possible processes include (1) suspension settling, (2) dilute storm flows, (3) fluid muds associated with wave resuspension of previously deposited muds,(4) cohesive flows, (5) upwelling to foster biogenic silica and phosphate deposition.*

Mudstone with Brachiopods

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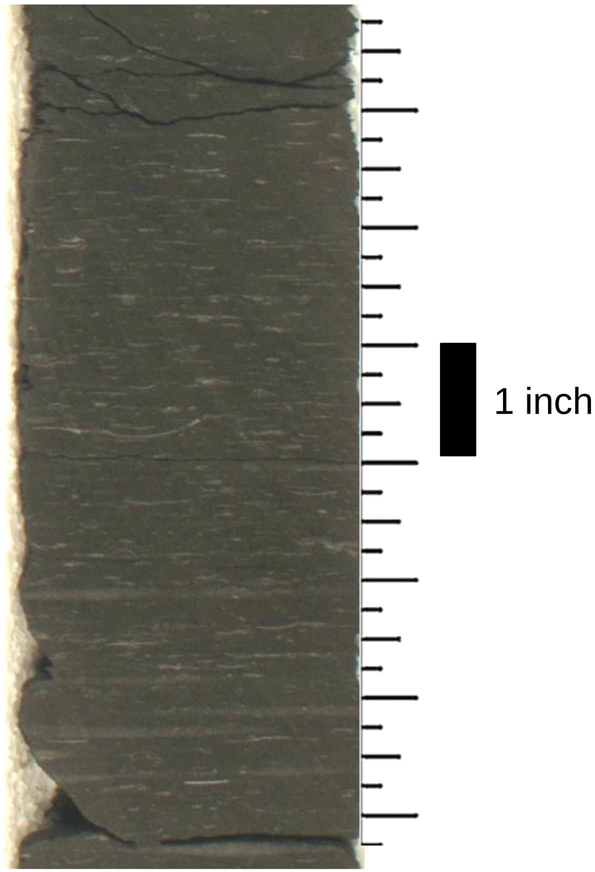
- Organic-rich mudstone with thin-shelled brachiopods. Dispersed to nested clustering, concordant to perpendicular orientation, articulated-disarticulated (concave and convex-up). Vaguely laminated.
- *Concave-up shells indicate suspension settling. Convex-up articulated are in situ but convex-up disarticulated are transported and flipped. Nested shells indicate wave/current concentration*

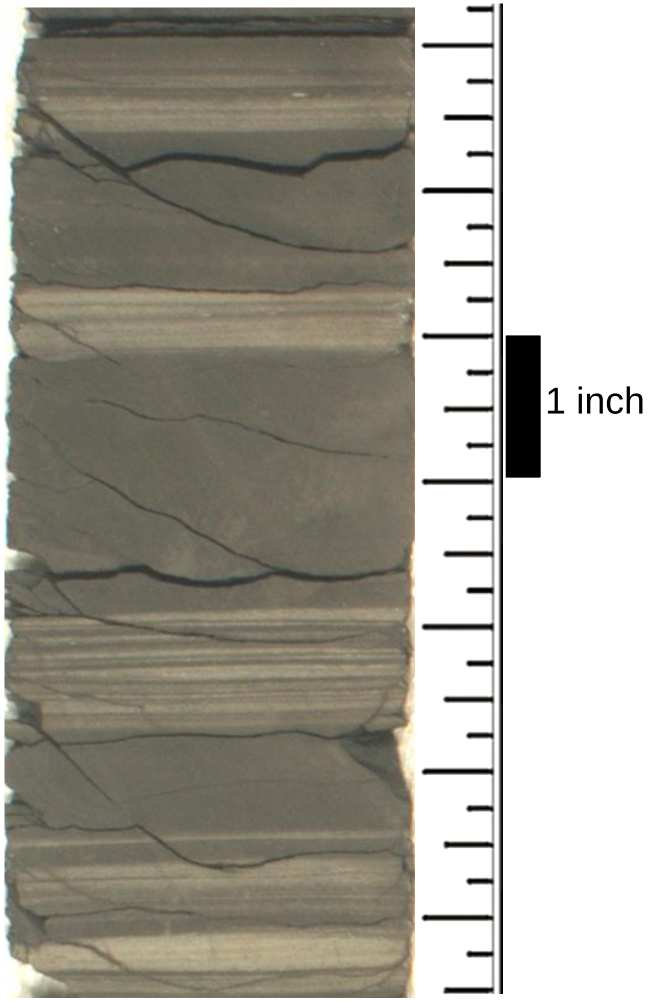


Mudstone with Starved Ripple Laminae

- Organic-rich mudstone with starved ripple laminae composed of silt- to vf sand-size fossil debris, phosphatic grains.
- *Traction deposition from dilute, unidirectional storm flows in distal outer ramp.*

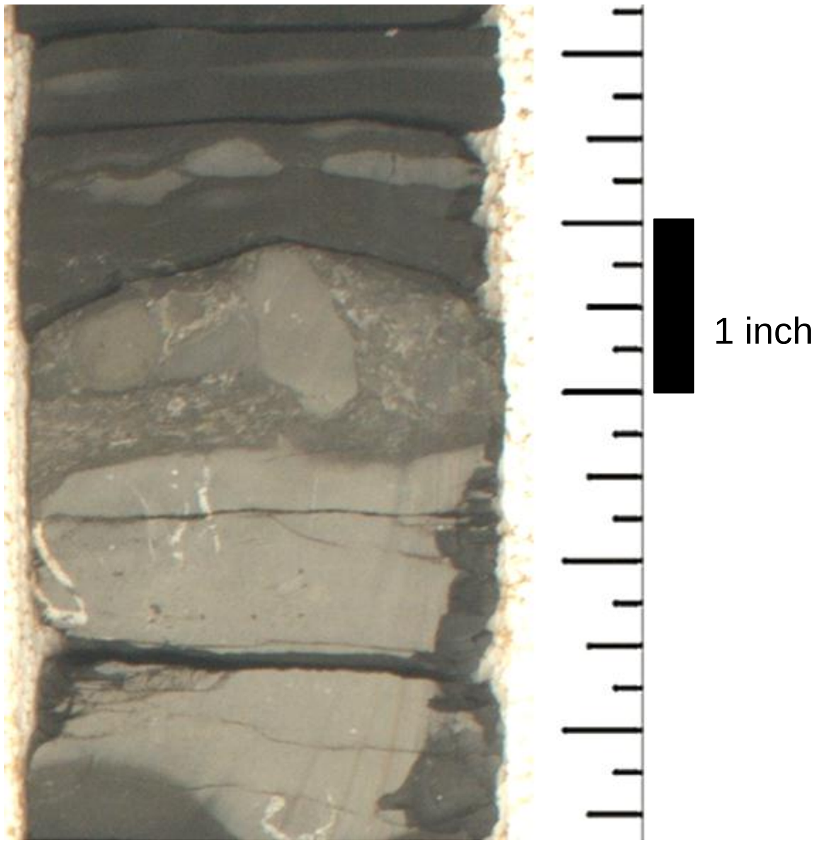
Laminated Packstone (siltite) & Mudstone

- Gray, calcareous-dolomitic, laminated packstone (silt-size fine fossil debris, phosphatic grains). Some sharp-based beds, c-u & f-u laminae.
- *Traction deposition from sustained and episodic unidirectional shelf storm flows, sufficiently vigorous to erode bottom.*

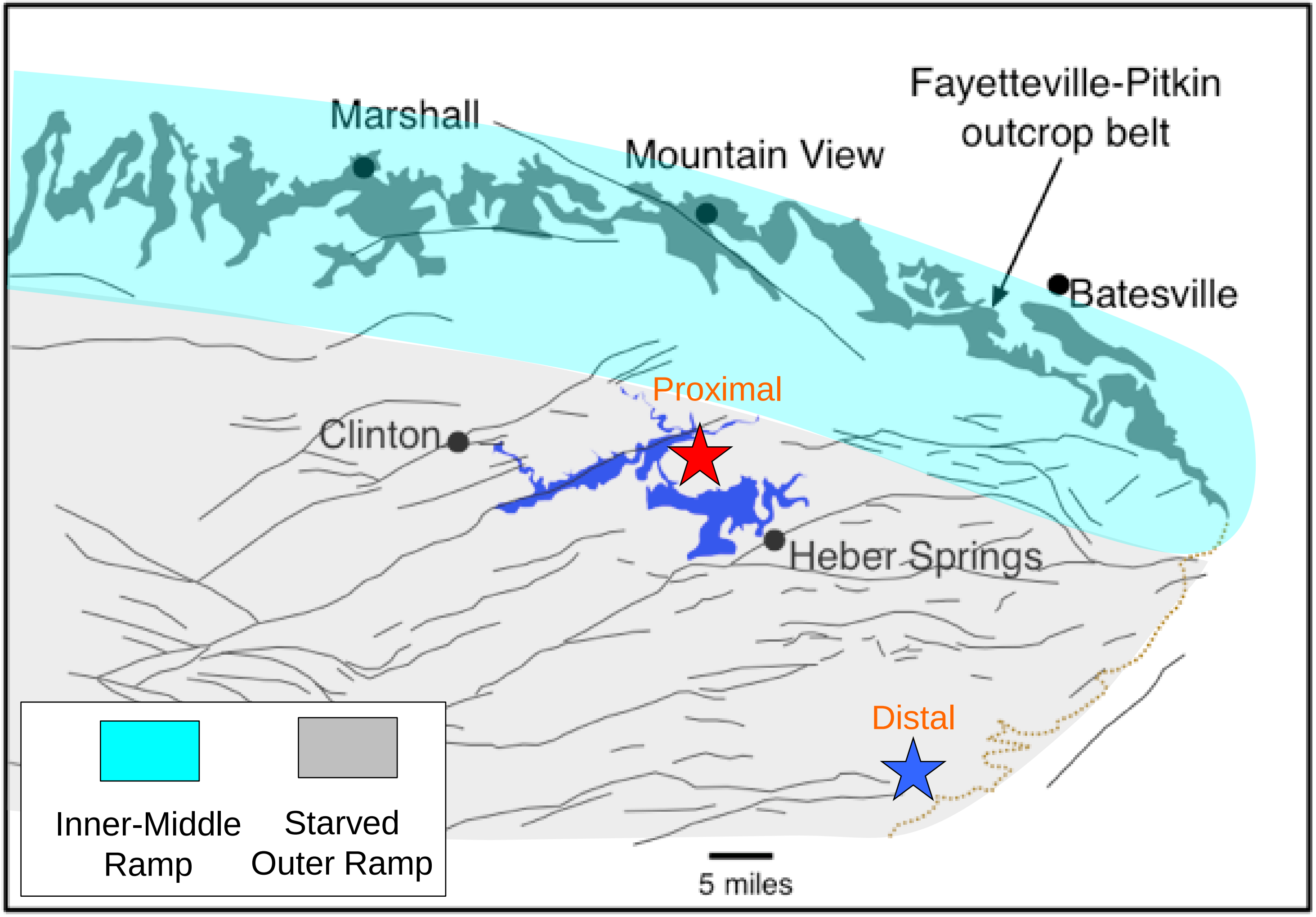


Debrites - Lithoclast Floatstone/Rudstone

- Lithoclast floatstone/rudstone made up of subrounded, fragments of early diagenetic concretions. Accessory brachiopod and crinoid grains.
- *Episodic erosion of sea-floor by unidirectional flows stripped mud down to concretion level and reworked small concretions as clasts. Some beds show evidence of cohesive debris flow deposition.*

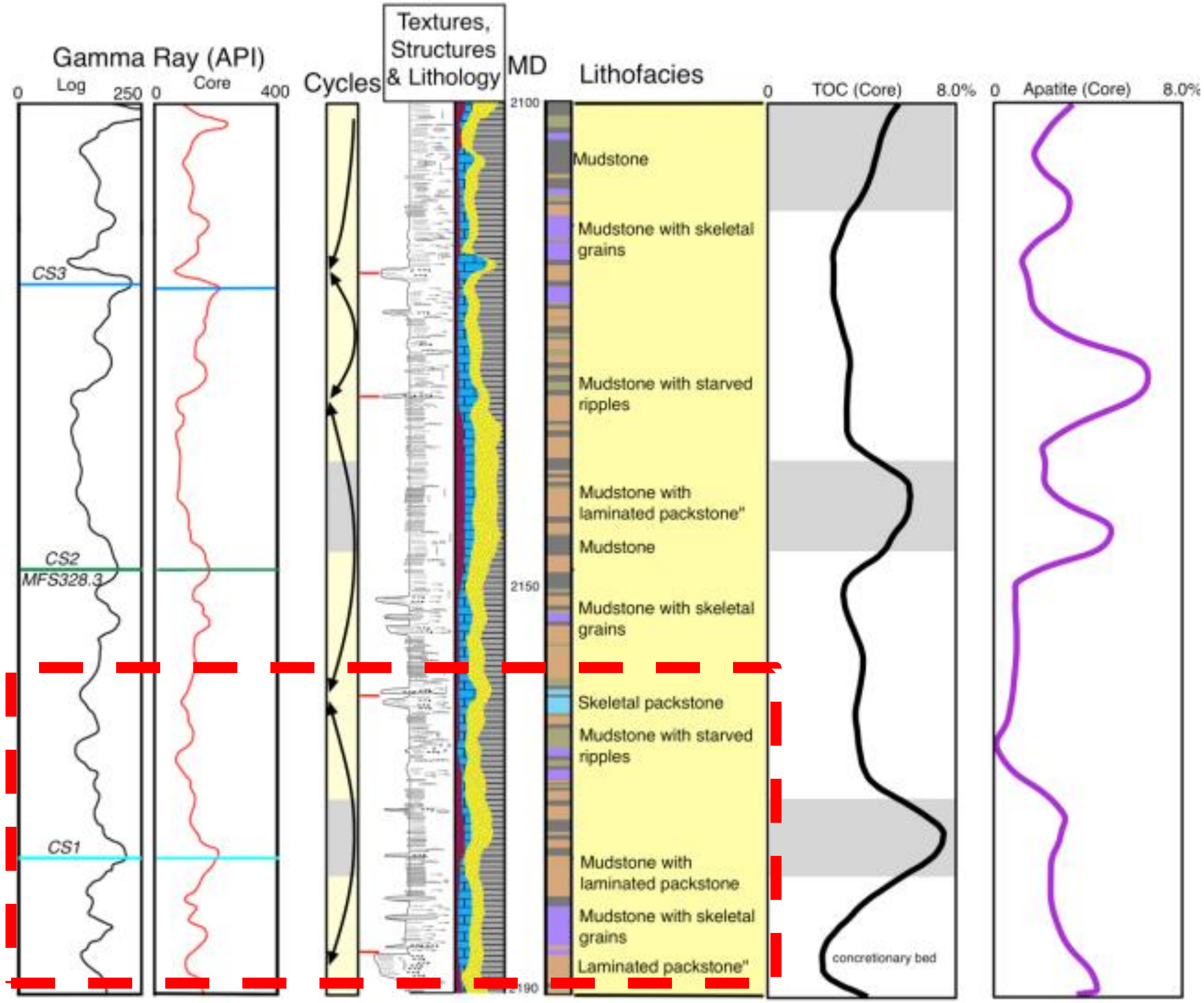


“Proximal-Distal” Condensed Section



“Proximal” Condensed Section

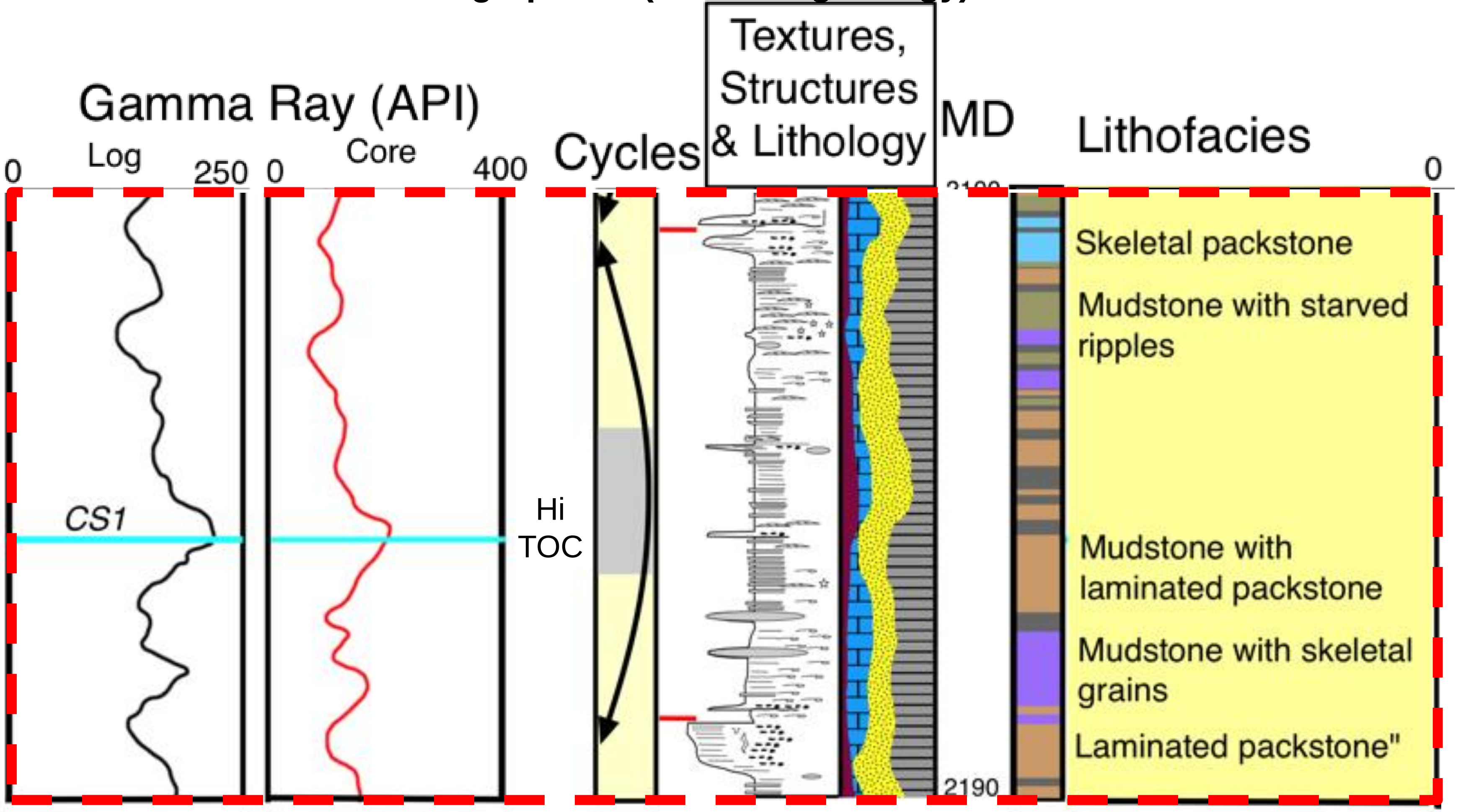
symmetrical cycles of laminated packstones and mudstone



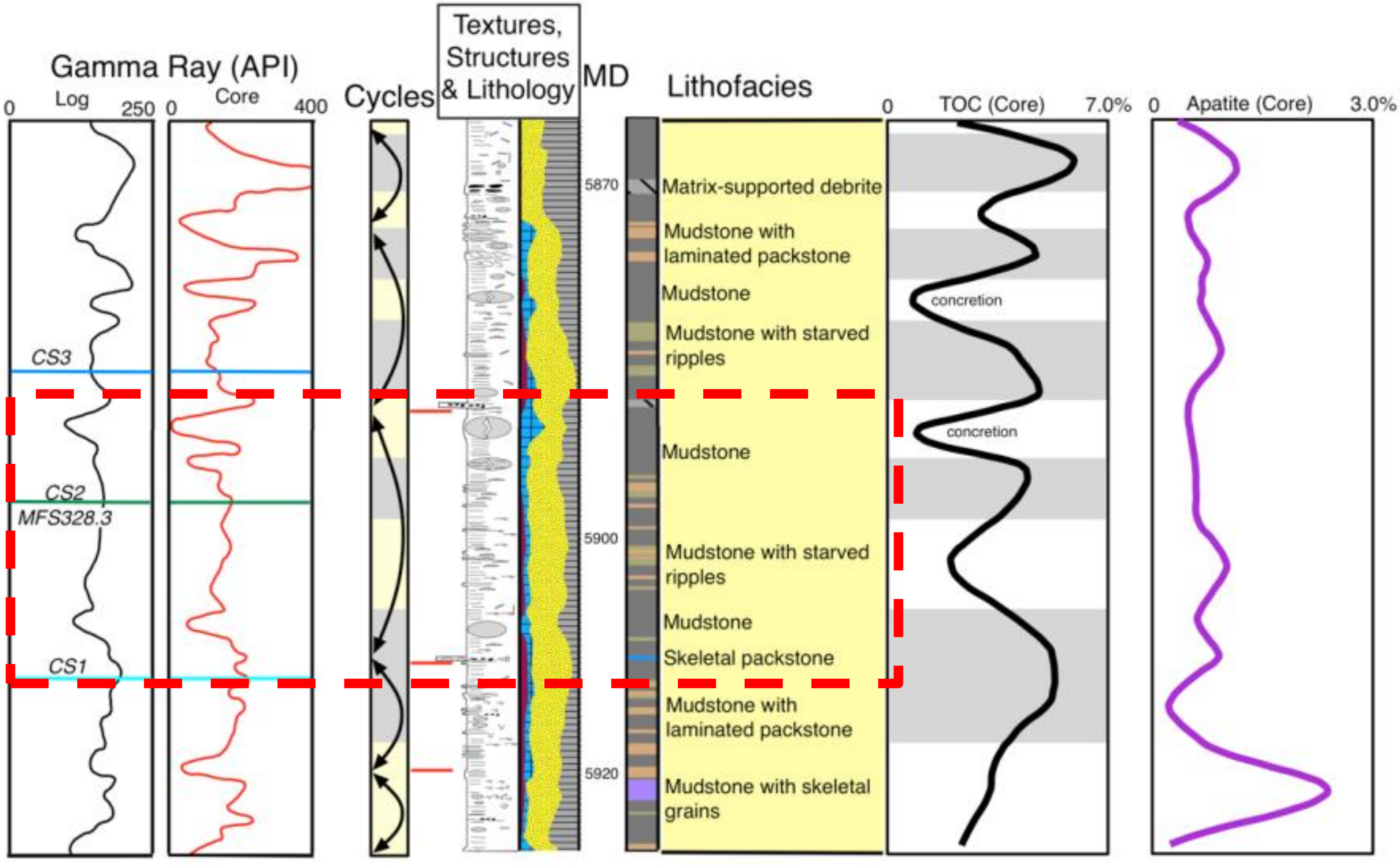
"Proximal" Condensed Section

symmetrical high-frequency cycle

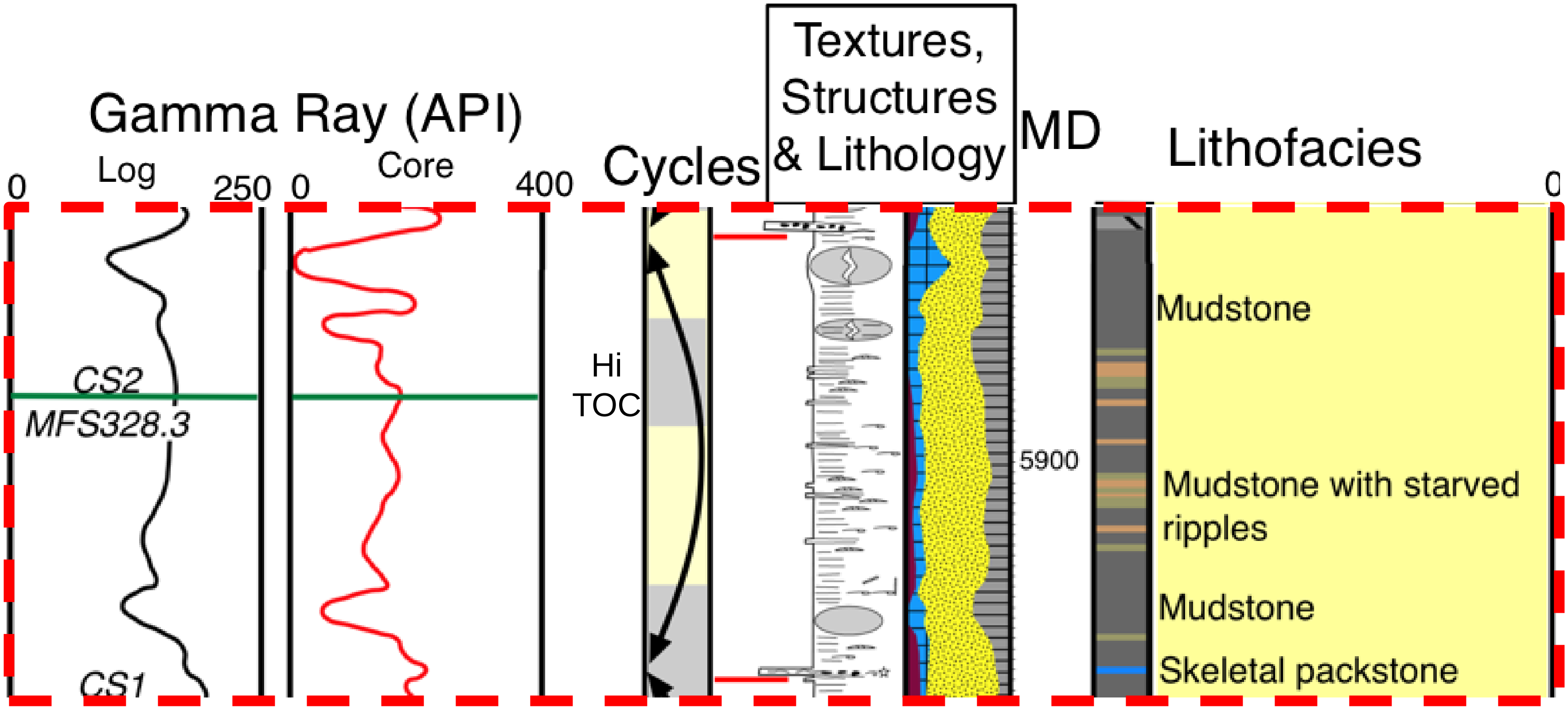
Cycle comprised of fining-upward (decreasing energy) followed by coarsening-upward (increasing energy) facies



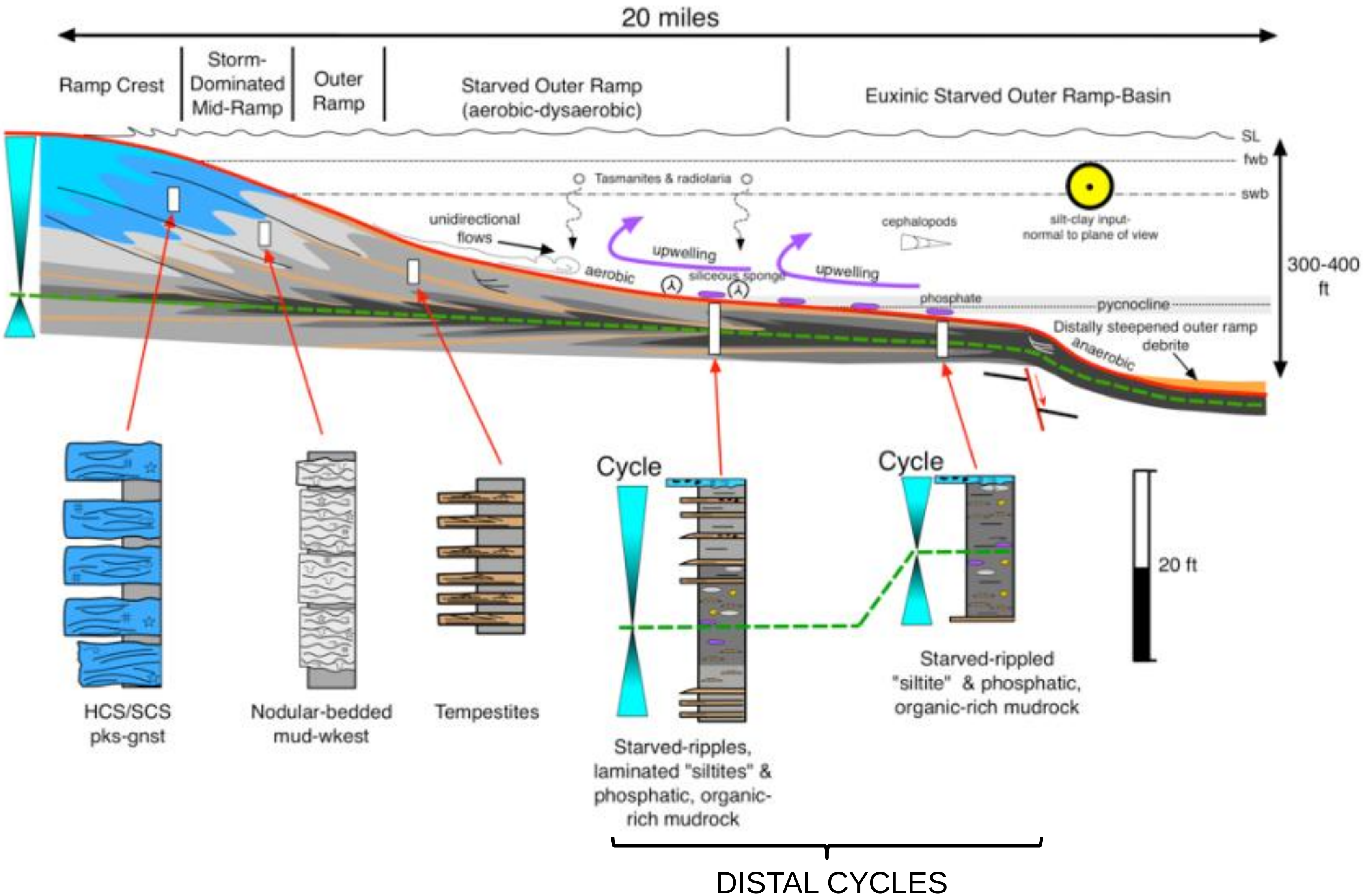
“Distal” Condensed Section:
symmetrical cycles of mudstone & starved ripple facies



"Distal" Condensed Section:
symmetrical high-frequency cycle



Depositional Profile



Condensed Zone Summary

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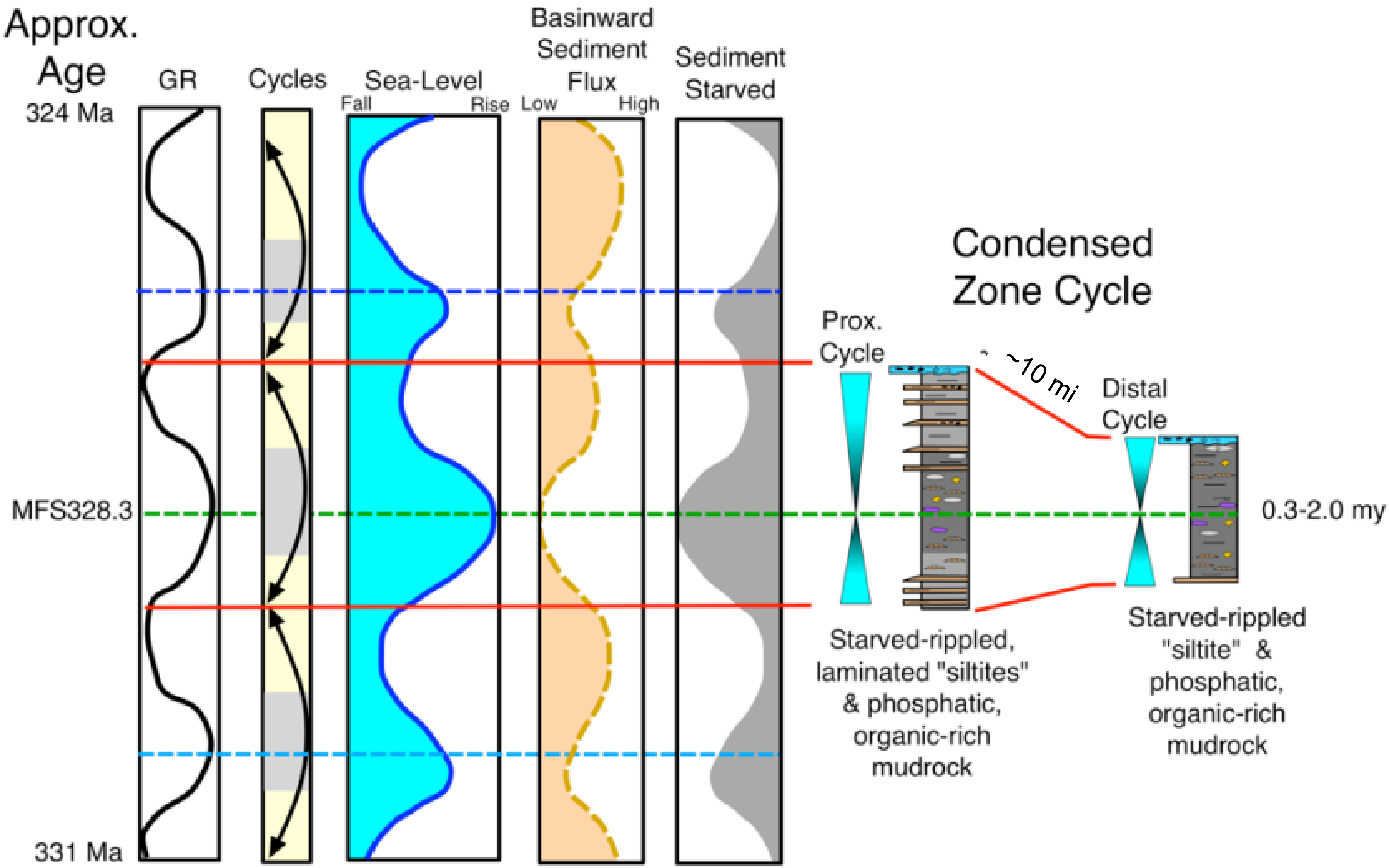
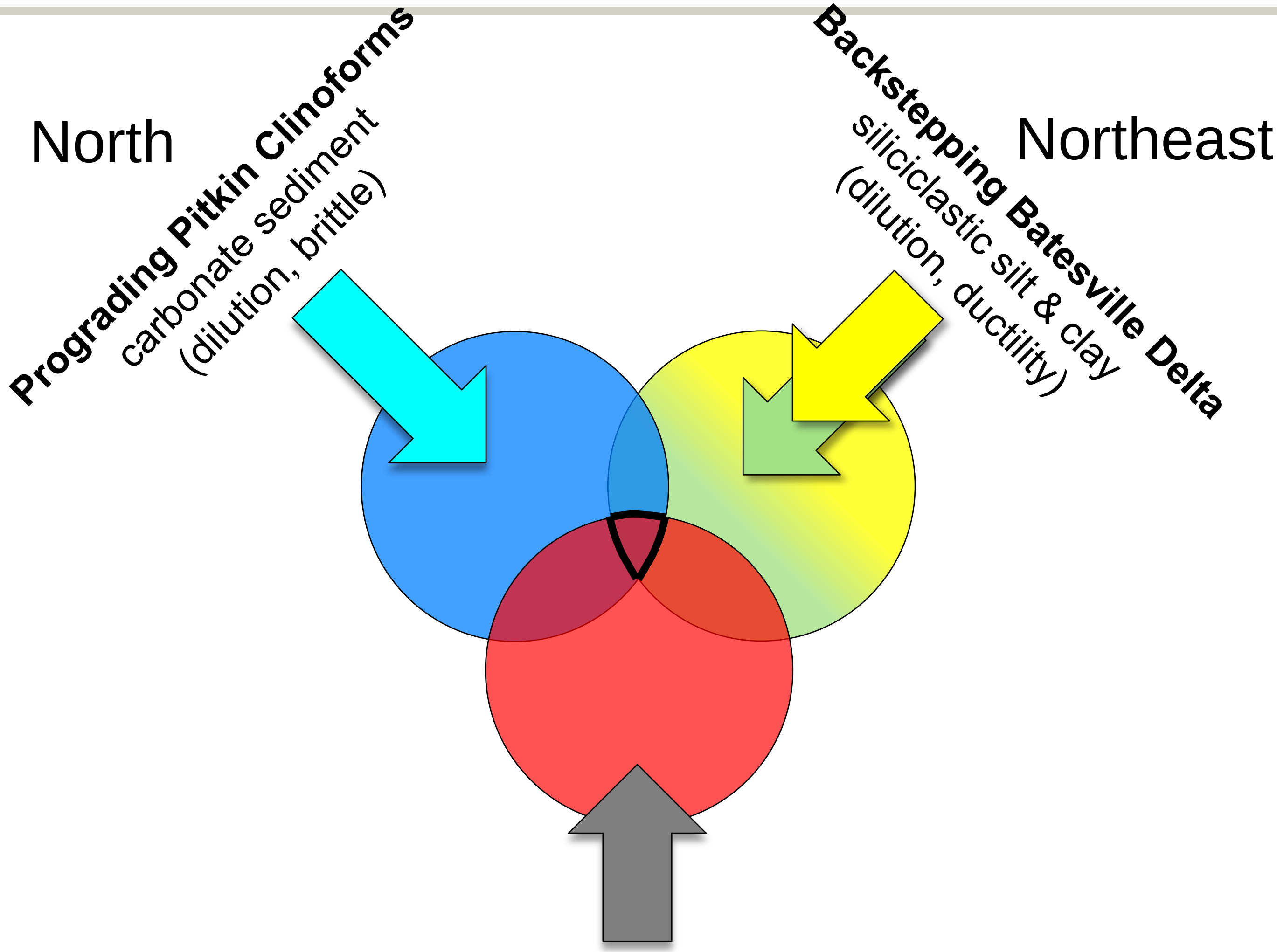


Sediment Flux - “Goldilocks” Zone



In-situ organic matter (production-destruction),
biogenic silica, phosphate

Conclusions

I. *The Fayetteville gas reservoir is centered around MFS 328.3 Ma of a 3rd-order Upper Mississippian composite sequence in North Arkansas.*

II. *Fayetteville Reservoir Facies:*

- The reservoir comprises organic-rich, calcareous-siliceous mudstones, which make up several condensed zones 20 miles downdip of the ramp crest.
- Condensed zone facies include organic-rich mud, starved-ripple-laminated “siltites”, laminated siltites, and minor debrites.
- Each shows evidence of deposition from dilute, unidirectional storm flows in the most distal parts of the outer, starved ramp.

III. *Cyclicty observed in Condensed Zone:*

- Stacking patterns reveal repetitive “coarsening” and “fining” upward hemicycles indicative of systematic changes in the occurrences of weak to moderately vigorous storm flows in the outer ramp.
- Cycles and facies stacks are best explained by high-frequency (~1 my) changes in sea level.
- Sea level fall led to increased carbonate and siliciclastic sediment flux to the starved outer ramp. Sea level rise led to sediment starvation, increased organic production/ preservation and phosphate sedimentation.