Transgressive Reworking of Deltaic Headlands and the Formation of Isolated Shelf Sandstone Reservoirs*

Lee F. Krystinik[1]

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Abstract

Pronounced deltaic headlands and other geomorphic features along a coastline can dramatically impact the provenance, genesis, placement and preservation of isolated sandstone bodies in the nearshore to shelf setting, especially during transgressions that follow a significant lowstand.

Much of the sand in the Upper Mississippian Springer Formation in the northern Anadarko basin of Oklahoma was delivered via incised valleys and lowstand deltas that pumped clastic sediment into a low accommodation setting with strong longshore currents. Subsequent transgressive erosion and longshore transport produced progressive migration of elongate and isolated “bar” sands (stranded shoreline deposits and shelf shoals) on the Springer shelf. This process placed these reservoirs far from their sediment source and encased them within sealing, shelfal mudstones. The preserved Springer gas reservoirs bear no apparent genetic relationship to the initial incised valley or deltaic source of the sediment.

A similar relationship exists for numerous isolated sandstones in the Mid- to Upper Cretaceous of Wyoming. Significant structural uplift and erosion in western Wyoming fed at least two major deltaic progradations across much of the state (Turonian Frontier Formation and Campanian Ericson Formation). Subsequent preservation of transgressively reworked sand derived from these lowstand-deltaic headlands wthin tectonically mediated lows and further transgressive reworking created a series of highly productive, stratigraphically trapped oil reservoirs.

The greatest erosion, reworking and longshore transport of sand is likely to occur during the transgression following a significant eustatic lowstand, when the deltaic headland is most pronounced into a basin. Substantive along-strike transport of sediment during transgression greatly complicates sequence stratigraphic and source-to-sink sediment-budget analysis within both the eroded source area and in the final preservation area. However, very real exploration opportunities likely exist down longshore drift from many deltaic headlands deposited in low accommodation settings.

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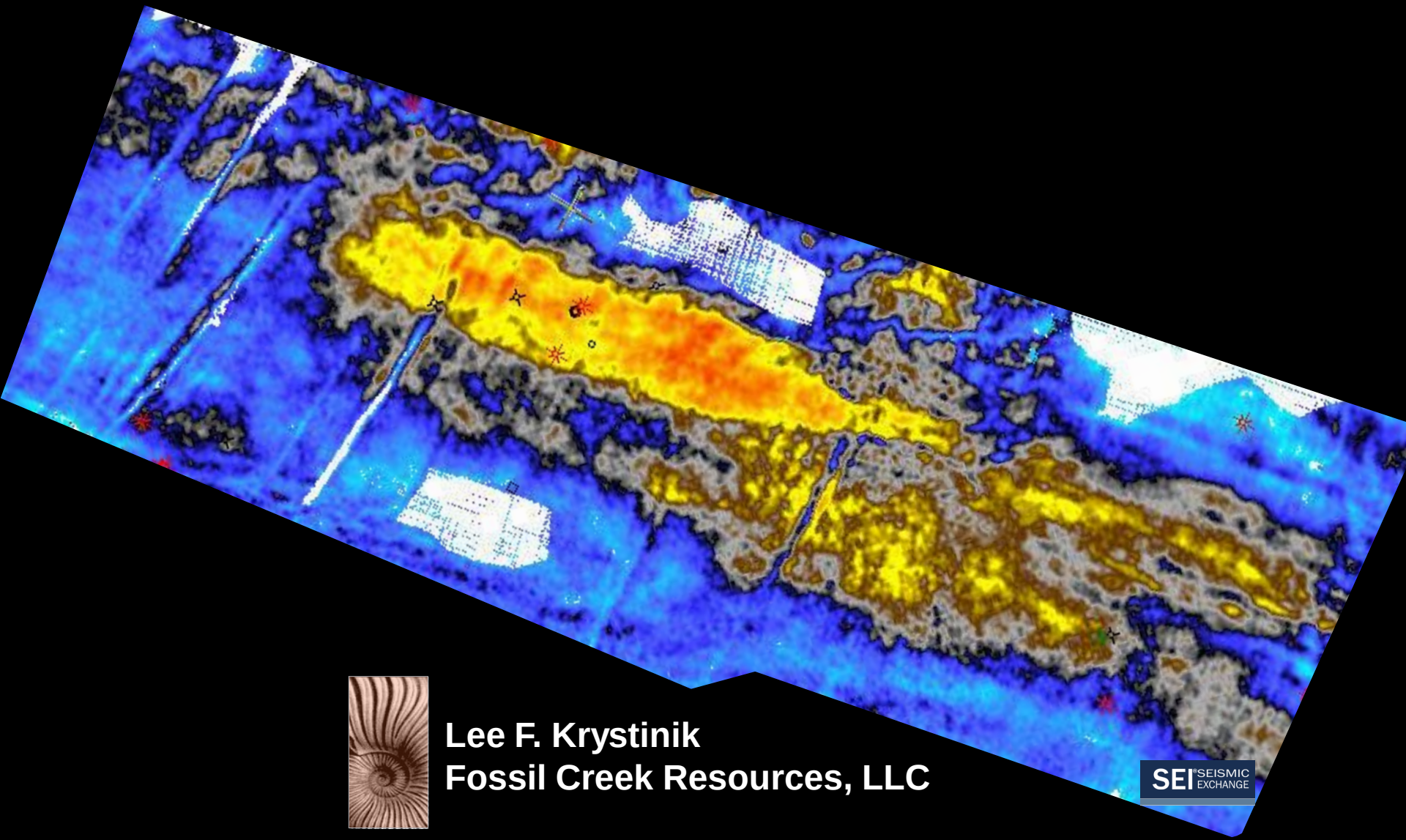
Transgressive Reworking of Deltaic Headlands & the Formation of Isolated Shelf Sandstone Reservoirs



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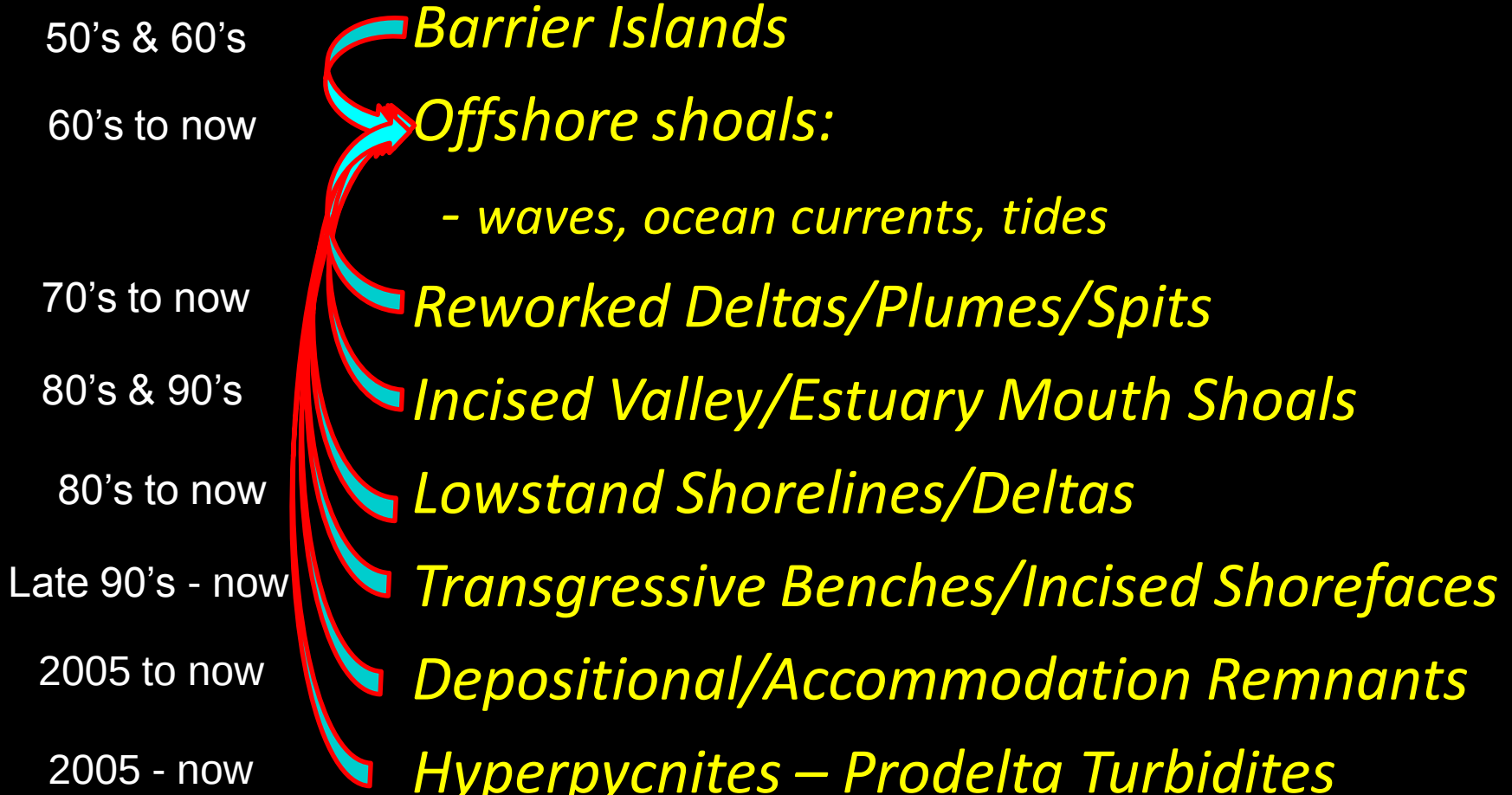
SEI SEISMIC EXCHANGE

"Bars": Abridged History of Proposed Origins for Isolated Marine Sand Bodies

50's & 60's	• *Barrier Islands*
60's to now	• *Offshore shoals – "Bars":* – *waves, ocean currents, tides*
70's to now	• *Reworked Deltas/Plumes/Spits*
80's & 90's	• *Incised Valley/Estuary-Mouth Shoals*
80's to now	• *Lowstand Shorelines/Deltas*
Late 90's - now	• *Transgressive Benches/Incised Shorefaces*
2005 to now	• *Depositional/Accommodation Remnants*
2005 - now	• *Hyperpycnites – Prodelta Turbidites*

Sand Sources for Isolated Marine Sand Bodies

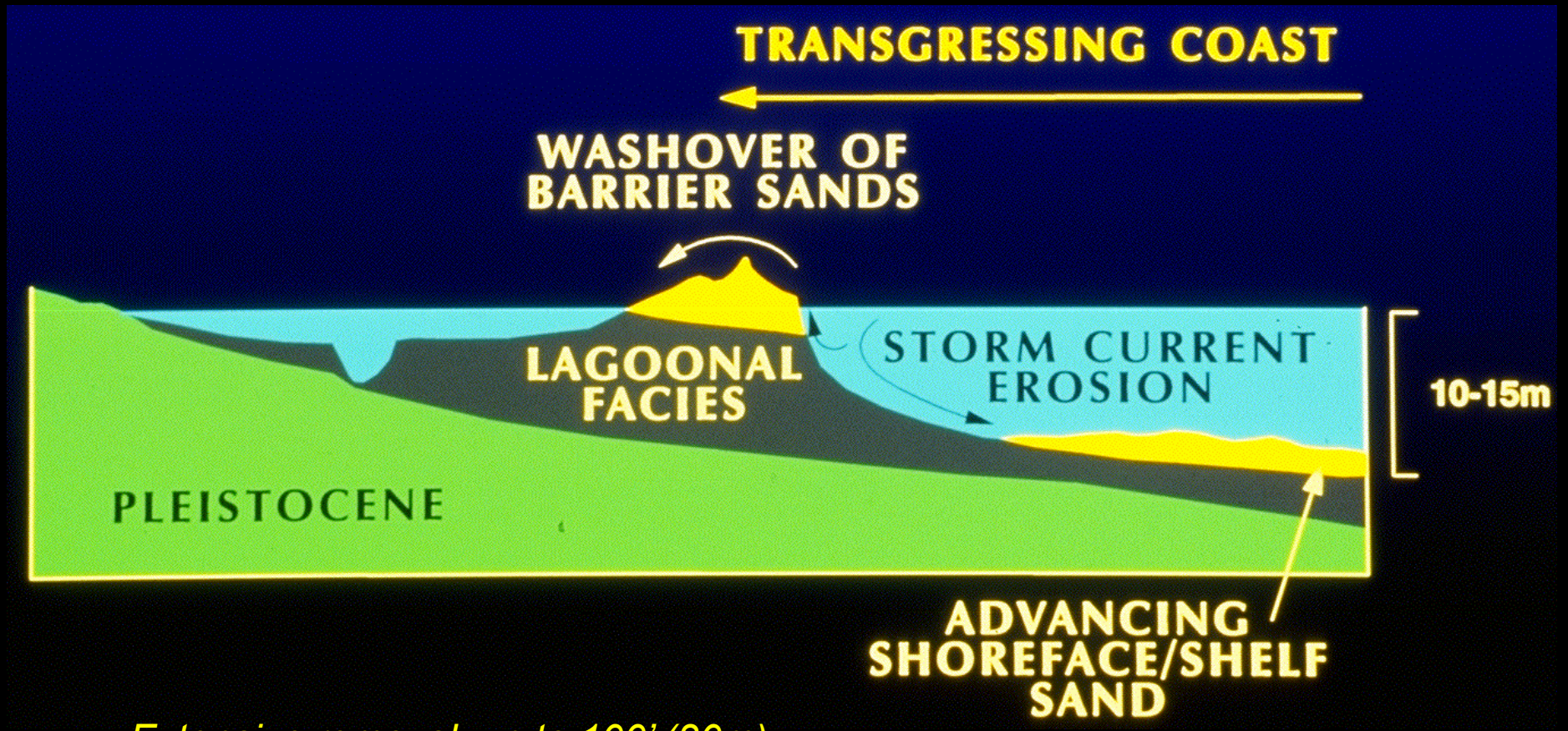


All of the Above!!!... Subject to Major Syn/Post Transgressive Reworking

Deltas: Dominant Source of Sand to Shelf

Simple deltaic progradation does **NOT** create isolated “bars”

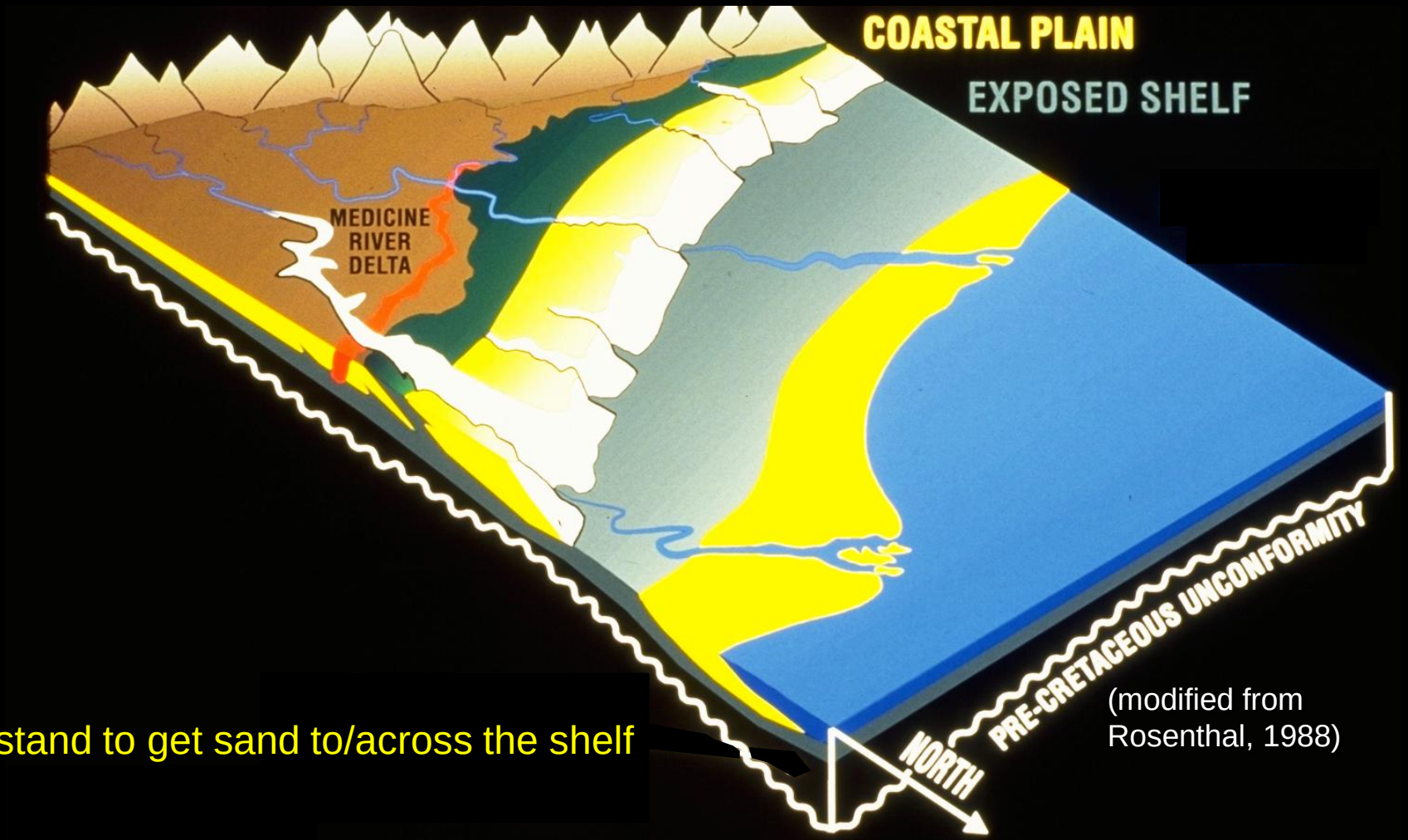
Transgressive Erosion



- *Extensive removal, up to 100’ (30m)*
- *Rapid & can be repeated*
- *Cuts benches & terraces*
- *Strongly redistributes sand along shore*

Relative Sea Level: Implications for Isolated Sand Bodies

Getting the Sand Out There

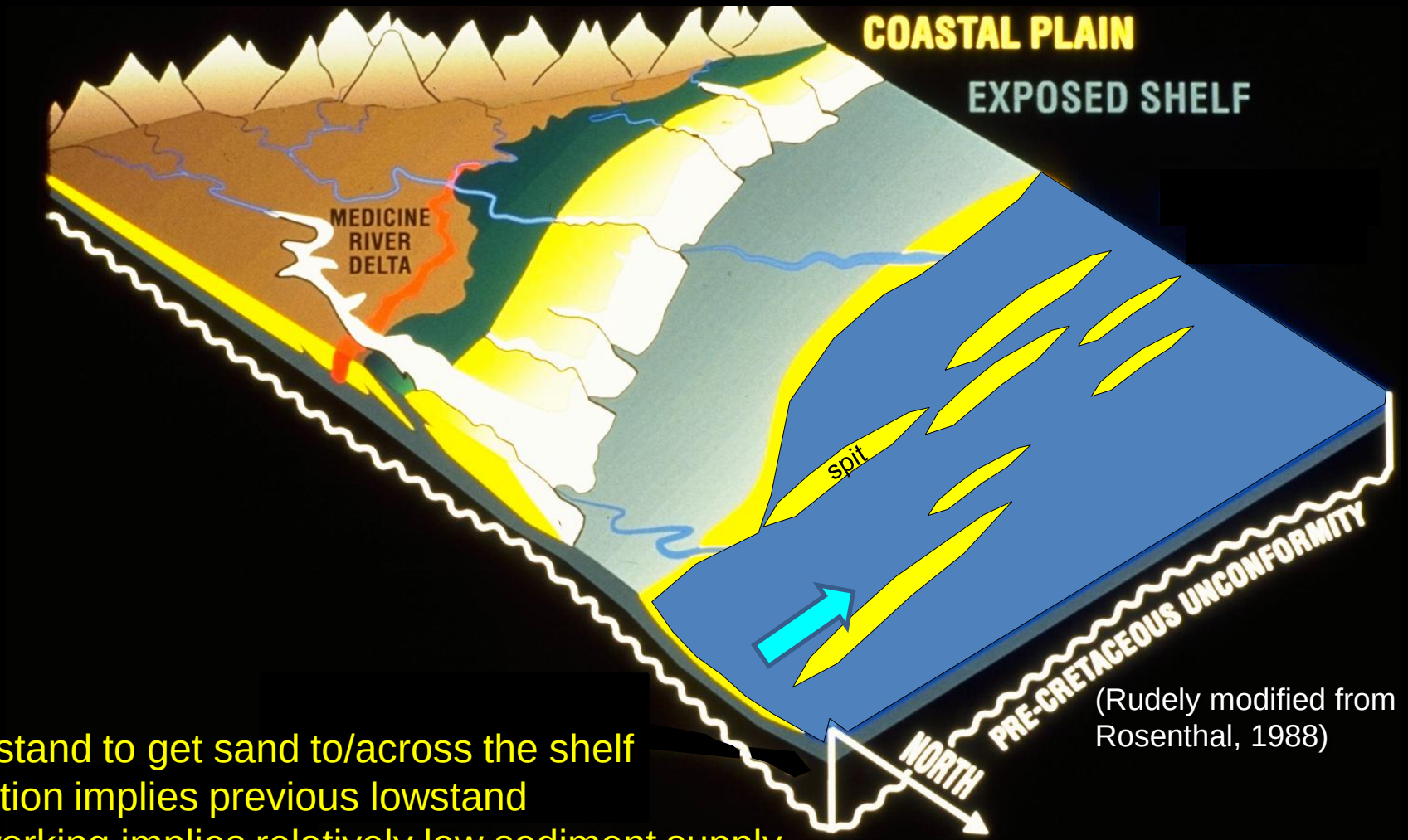


(modified from Rosenthal, 1988)

- Lowstand to get sand to/across the shelf

Relative Sea Level Rise: Transgressive Reworking

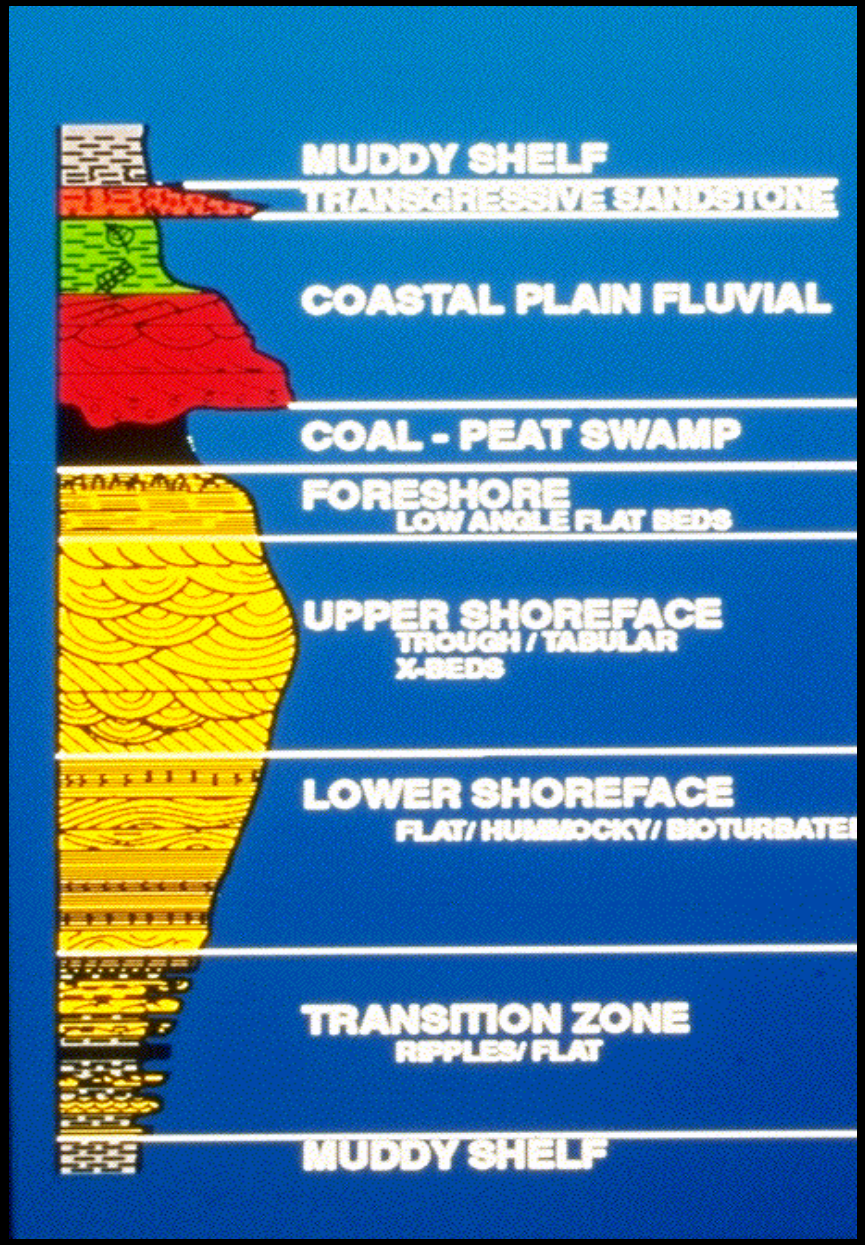
…Then Ongoing Reworking by Waves, Currents, Tides

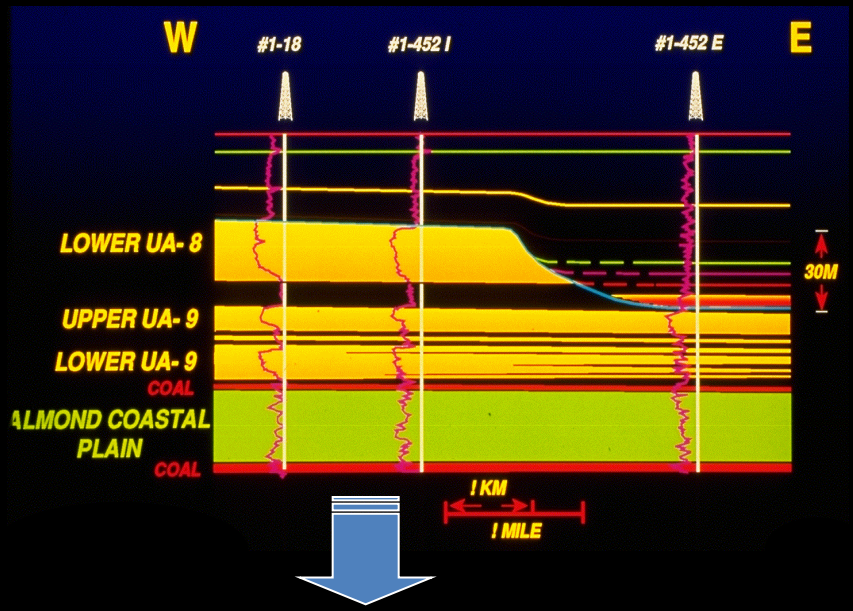


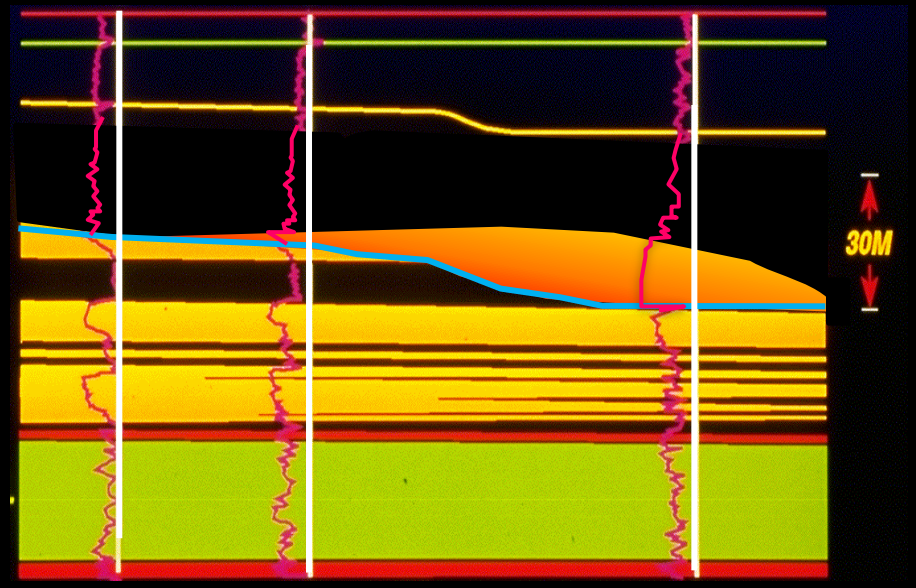
(Rudely modified from Rosenthal, 1988)

- Lowstand to get sand to/across the shelf
- Position implies previous lowstand
- Reworking implies relatively low sediment supply
- Process continues long after initial ravinement event
- Preservation contingent upon accommodation & subsequent sediment supply

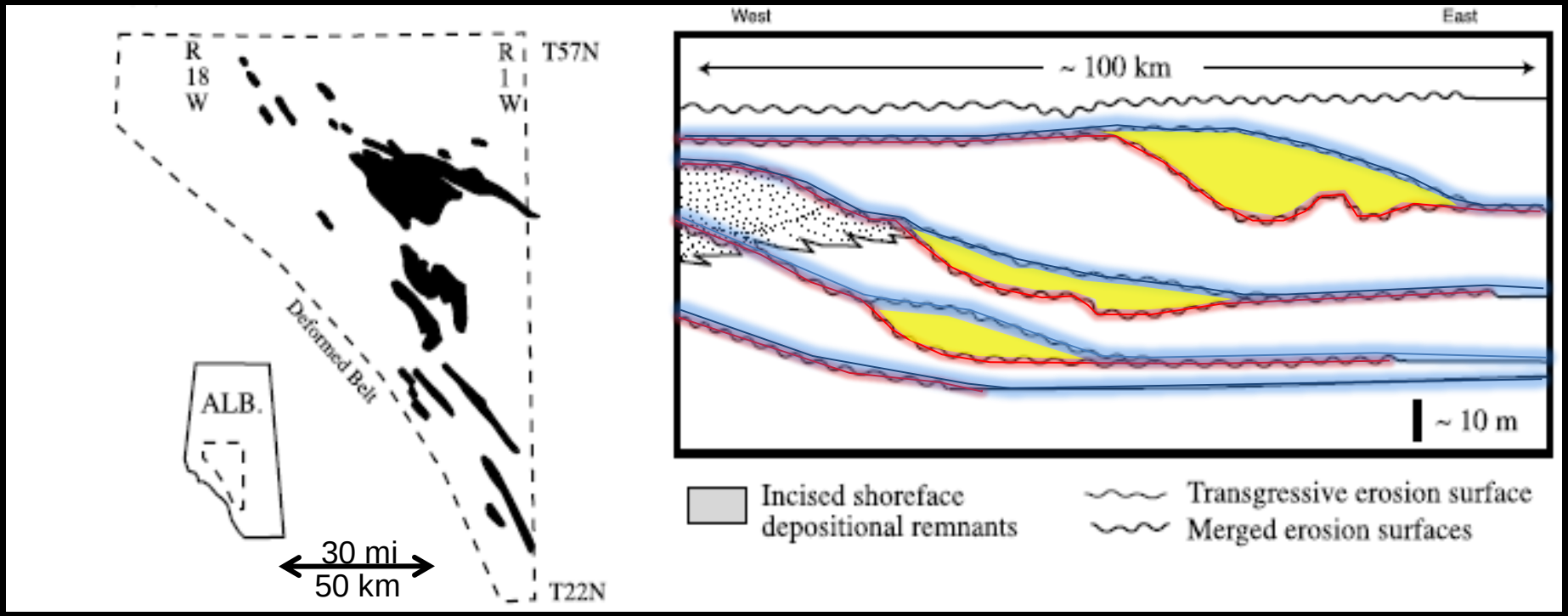
Transgressive Erosional Bench/Terrace







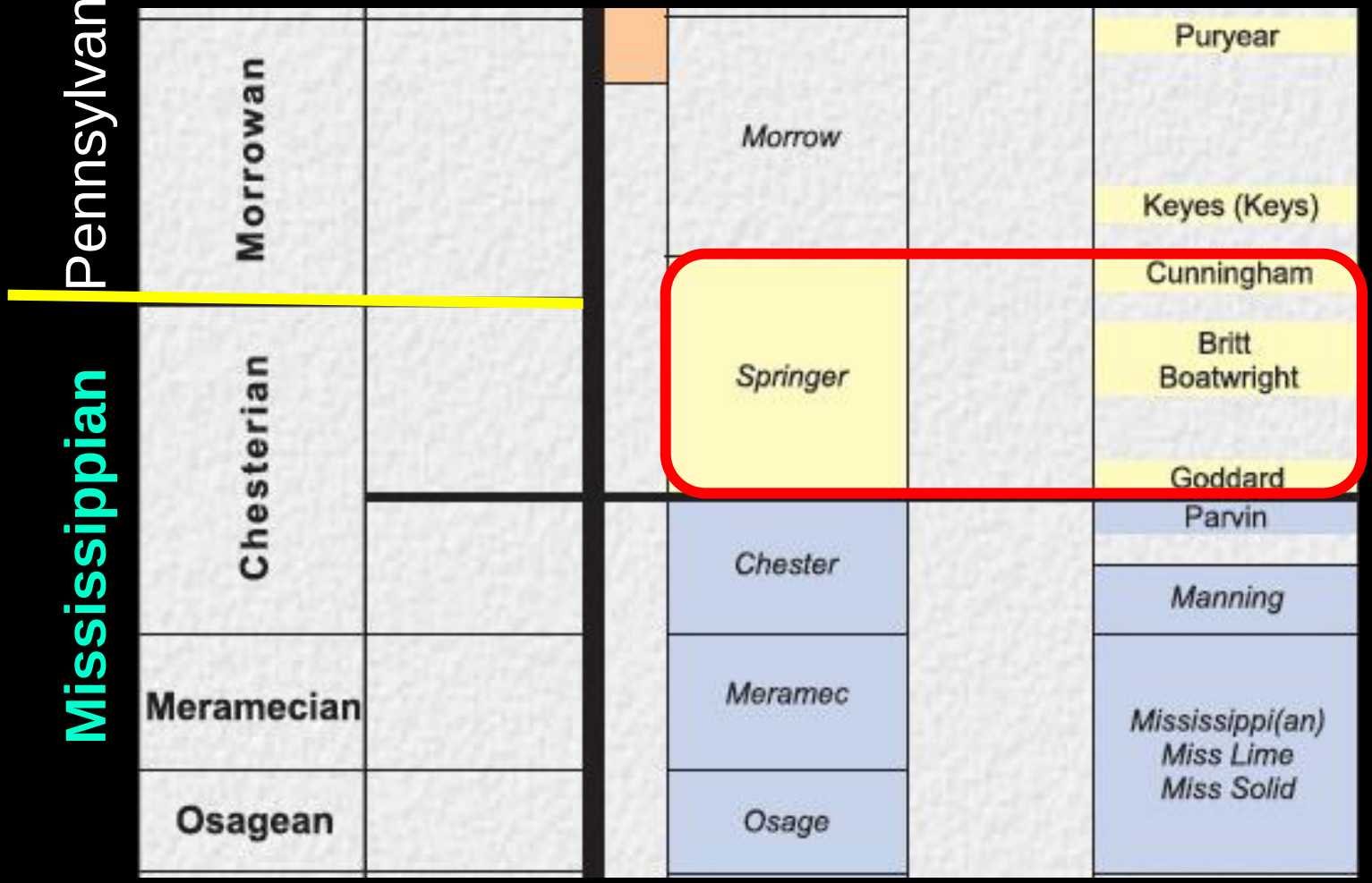
Transgressive Benches: Cardium Fm.



Plint, 1986

- *Long, linear sand bodies, isolated in marine shale*
- *Abrupt, sharp landward base*
- *Gentle basinward taper*
- *Blocky log response*
- *Tied to ravinement surface… A Separate Case*

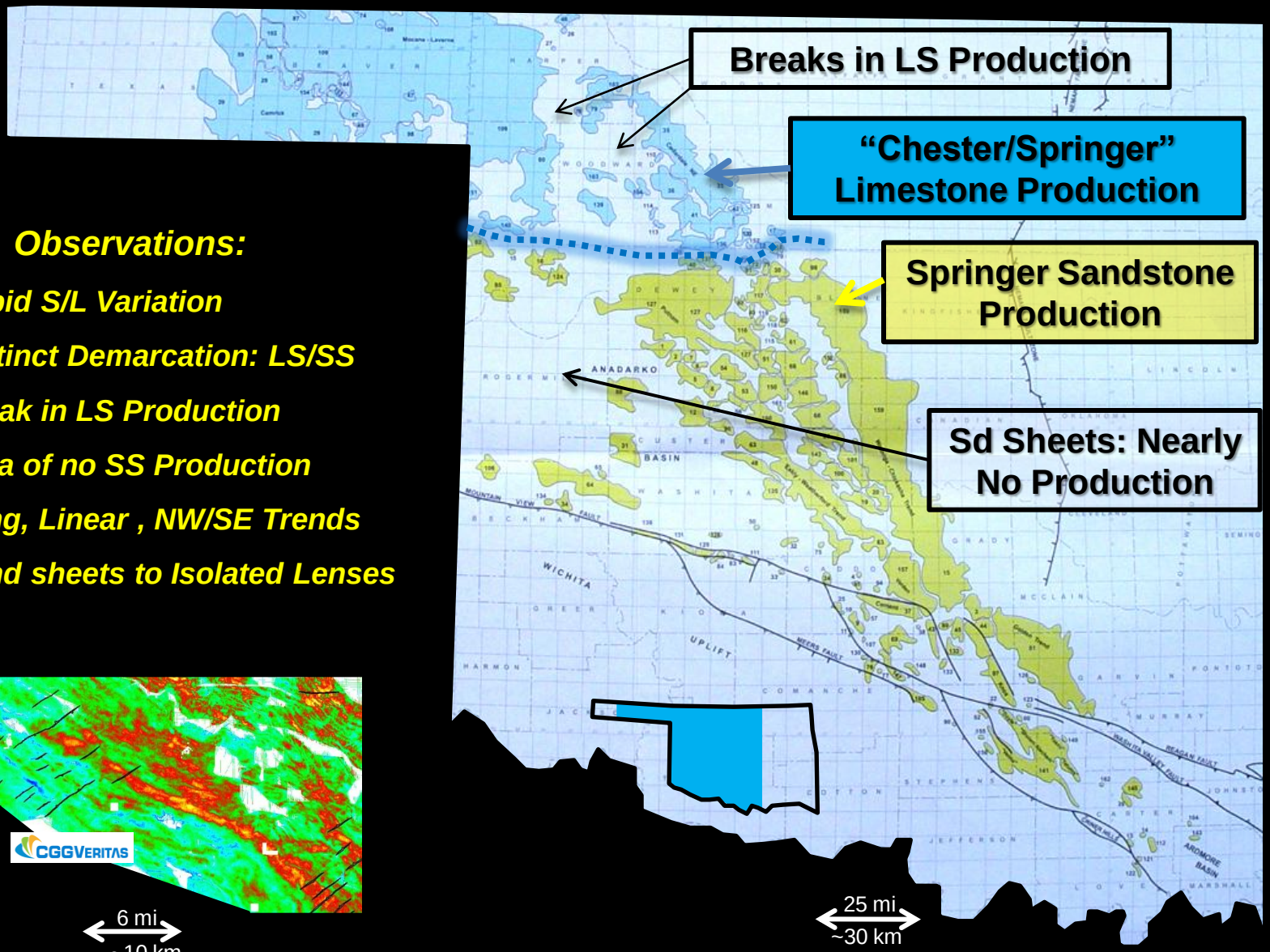
Stratigraphic Chart: Springer



OGS Stratigraphic Guide, SP 2008-1

Springer deposited in a time of rapid, repeated & high-amplitude sea-level fluctuation

Springer Sd. Producing Fields: Mostly Strat Traps

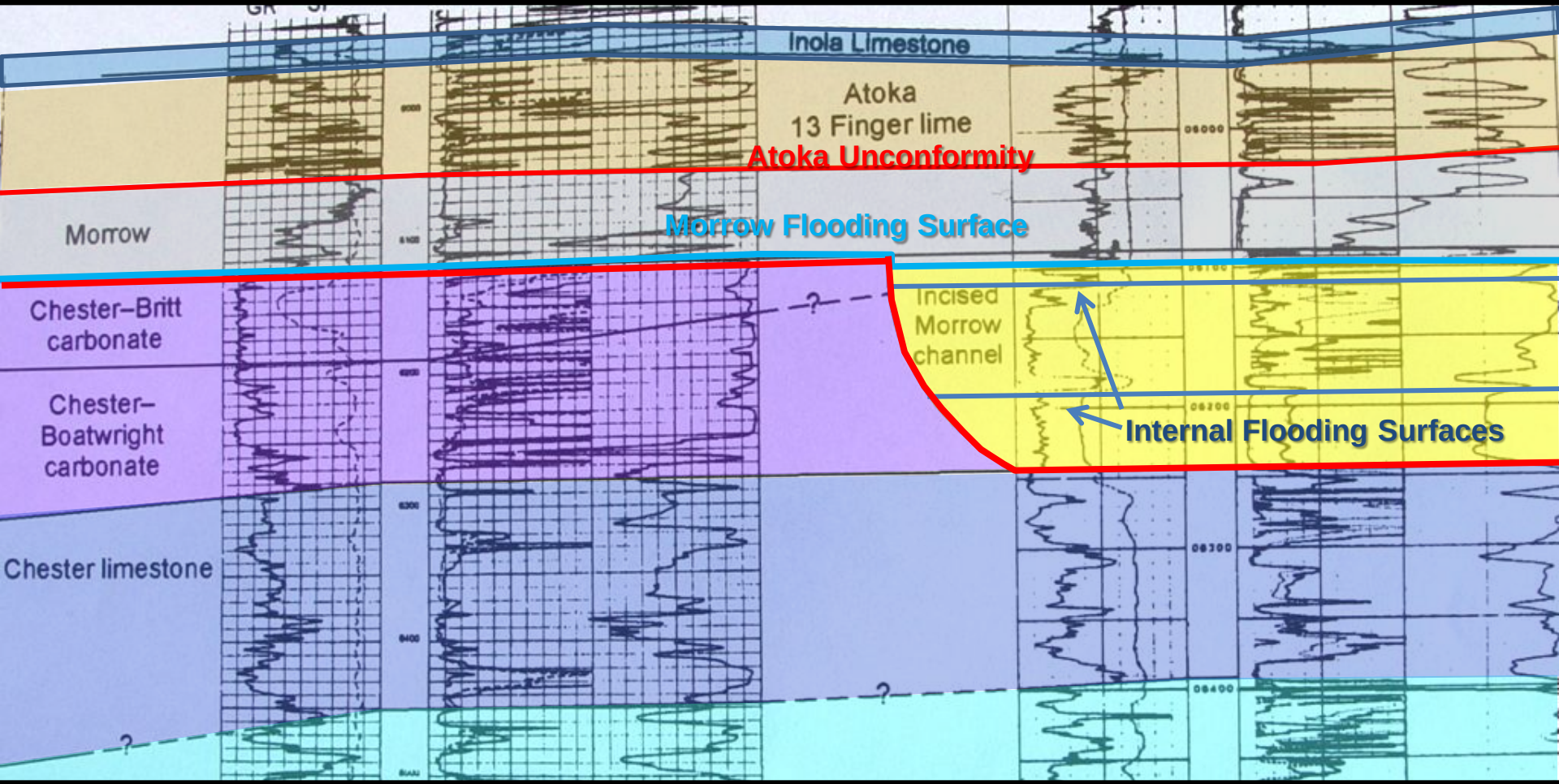


Observations:

- ***Rapid S/L Variation***
- ***Distinct Demarcation: LS/SS***
- ***Break in LS Production***
- ***Area of no SS Production***
- ***Long, Linear , NW/SE Trends***
- ***Sand sheets to Isolated Lenses***

Modified from Andrews, 2001

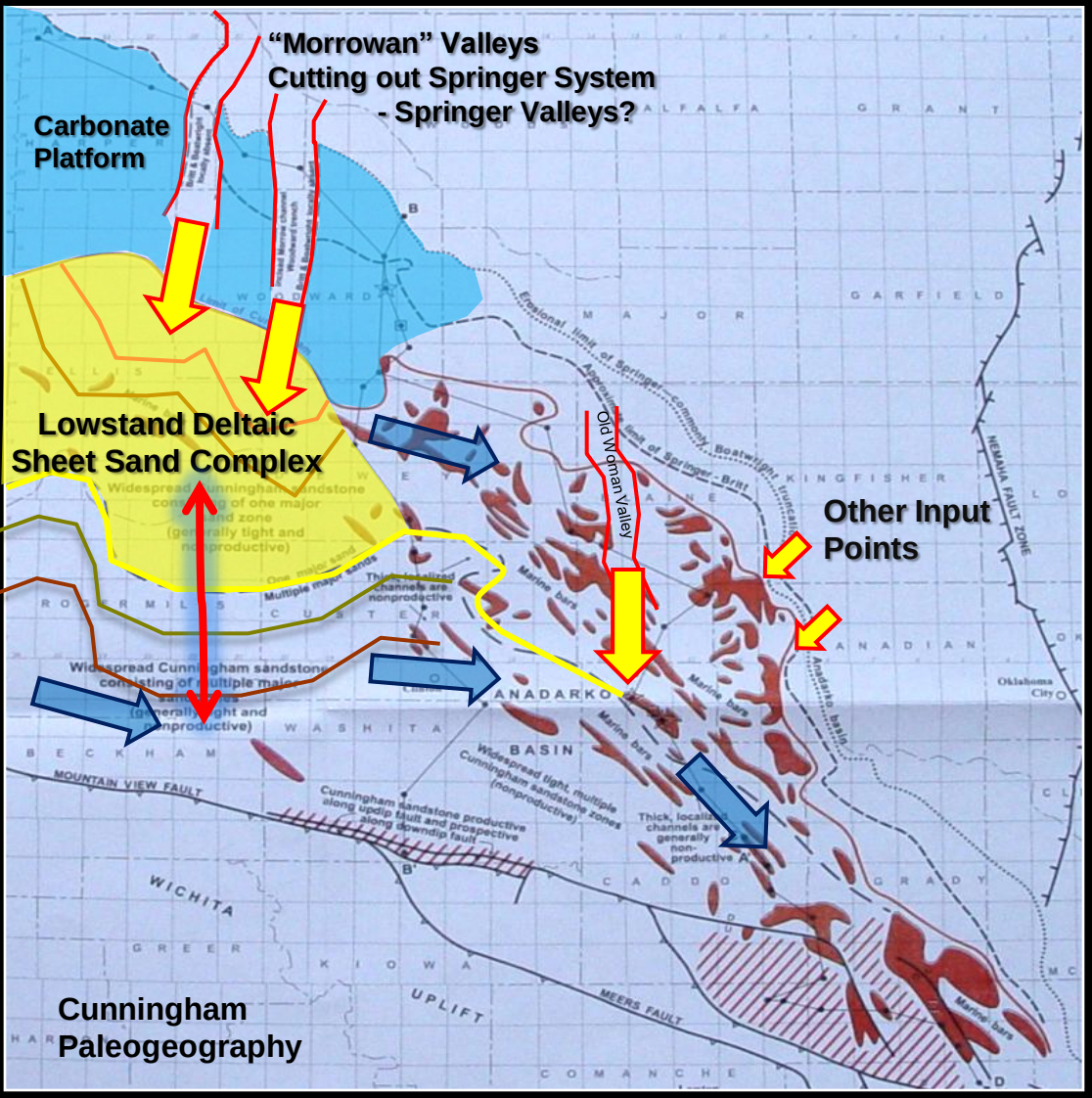
“Morrow” vs. Springer Valleys



Modified from Andrews, 2001

- *>150’ (50m) Valleys cut out entire Springer System*
- *Internal flooding surfaces in valley below Morrow FS*
- *Morrow FS common with surface on Springer LS*

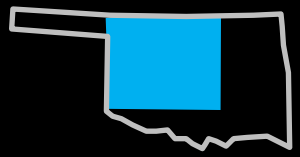
Regional Springer Distribution



- *Point-Sourced Sediment Supply*
- *Variable Rates of Sedimentation*
- *Strong Longshore Transport*
- *Sheets & Isolated Sandbodies*

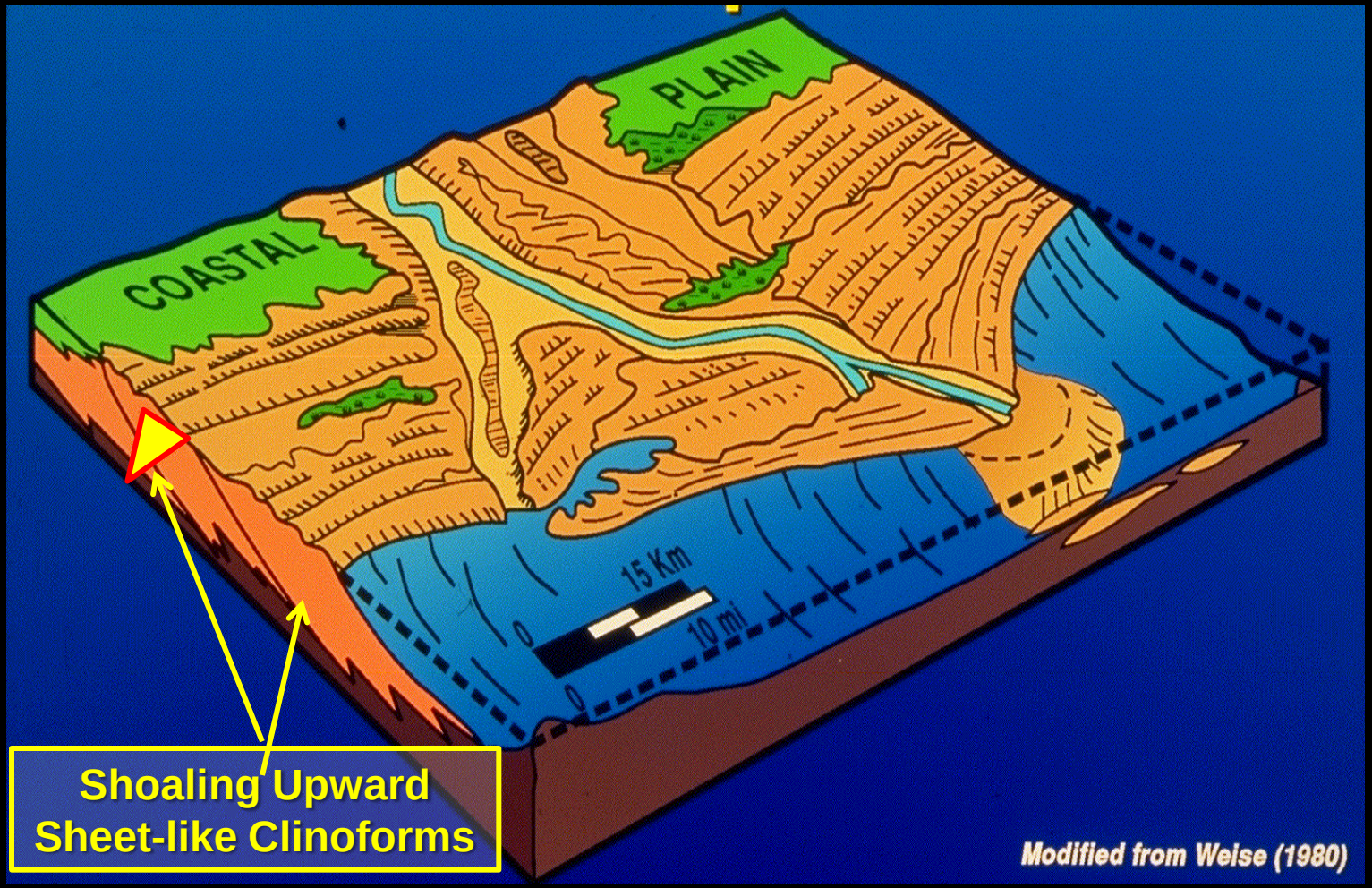
- *Sand Sheets:*
  - *High Sediment Supply*
  - *Moderate Accommodation*
  - *Minimal Strat Traps*
  - *Need Structure*

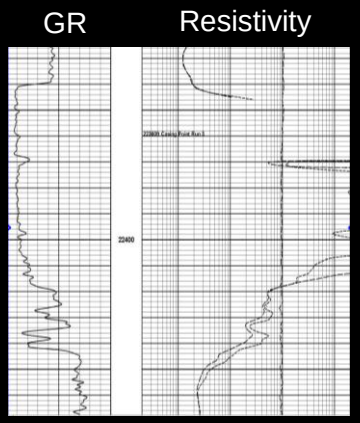
- *Isolated Sandbodies:*
  - *Lower Accommodation*
  - *Low(er) Sediment Supply*
  - *Numerous Strat Traps*
  - *Far from Source of Sand*



Crudely modified from Andrews, 2001

Progradational Storm-Dominated Delta/Strandplain

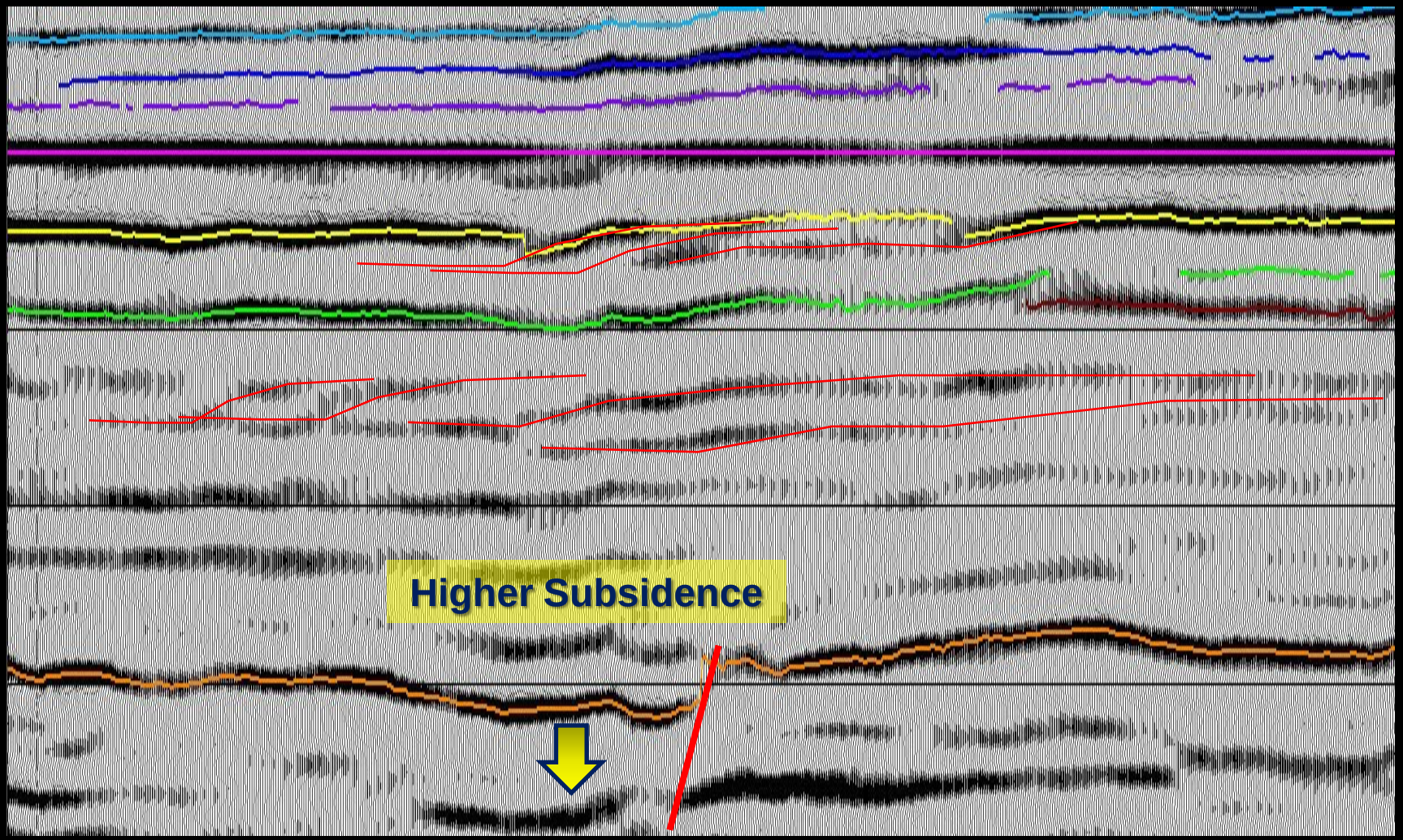




Springer Log: Deltaic

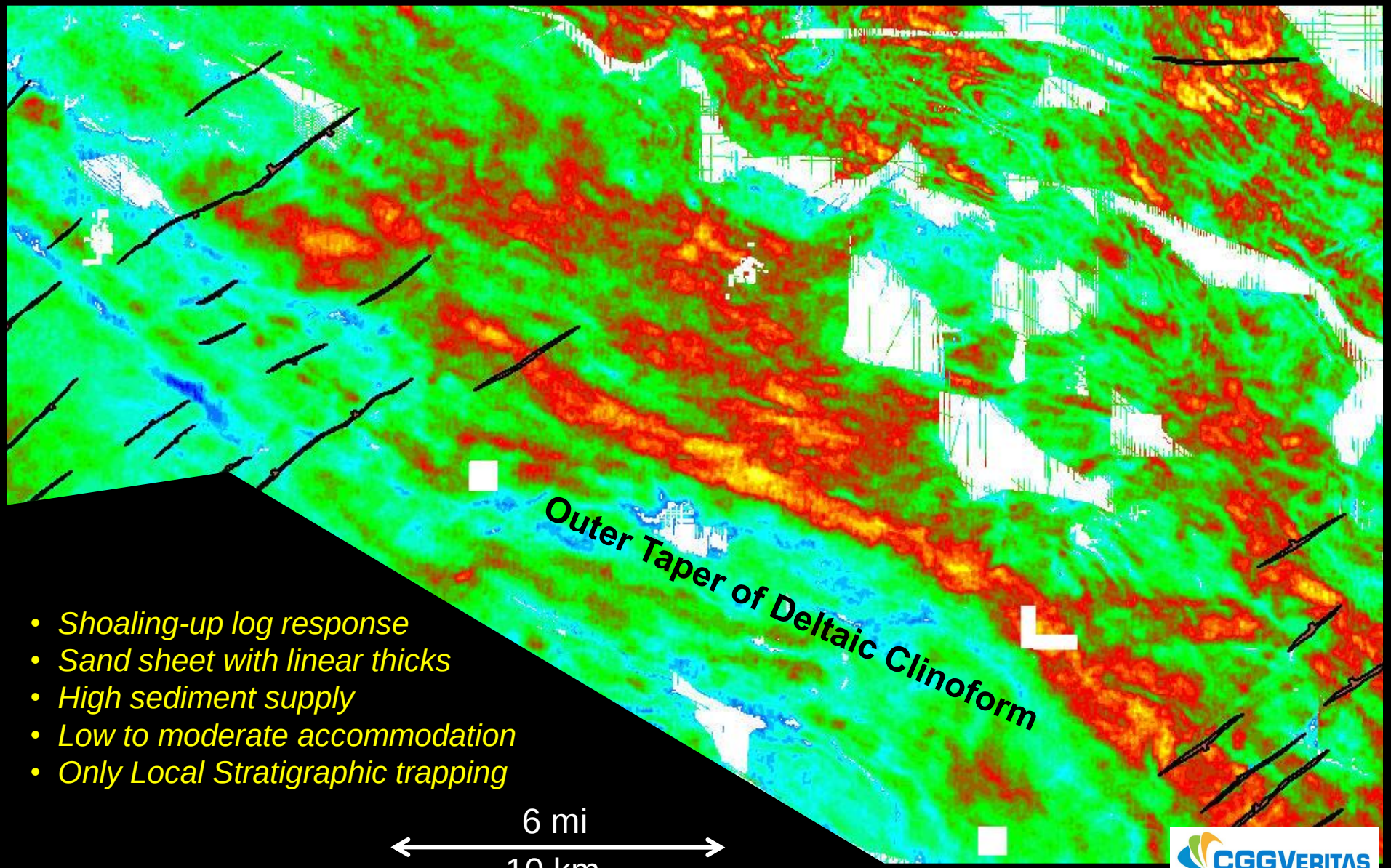
Relatively High Accommodation & Sediment Supply

Deltaic Clinoforms: Sand Sheets



Reservoir focused into & preserved in higher subsidence areas

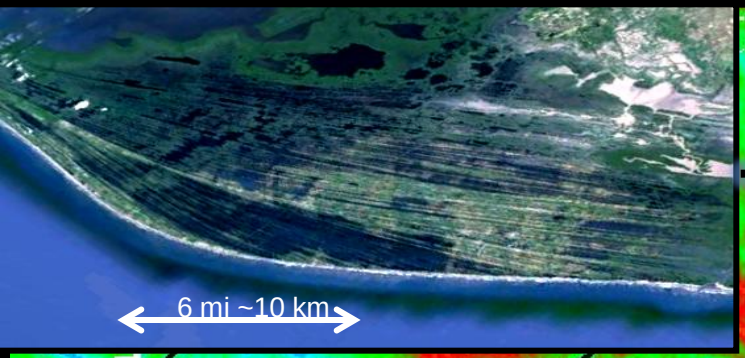
Reworked Top of a Progradational Deltaic/Strandplain



- *Shoaling-up log response*
- *Sand sheet with linear thicks*
- *High sediment supply*
- *Low to moderate accommodation*
- *Only Local Stratigraphic trapping*

CGGVERITAS

Reworked Top of a Progradational Deltaic/Strandplain



Partially Reworked Area – Shoals/"Bars"

Transgressive Bench – Incised Shoreface

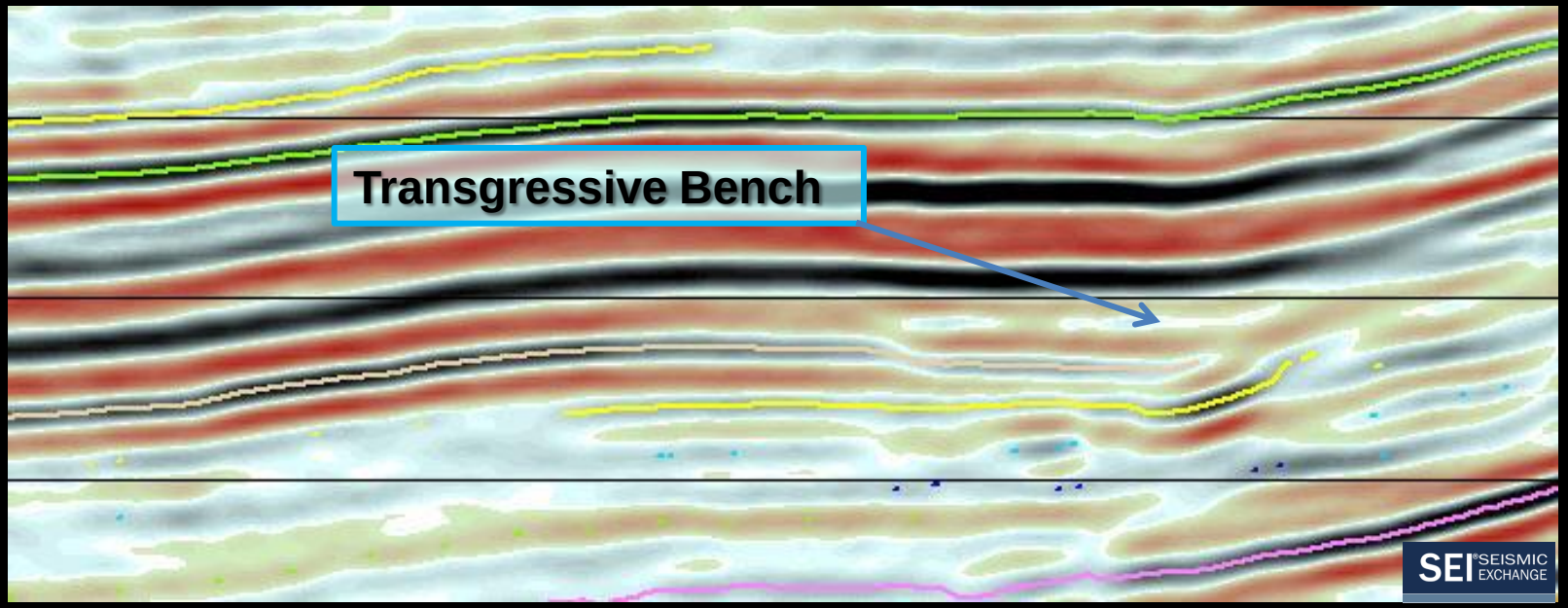
Outer Taper of Clinoform

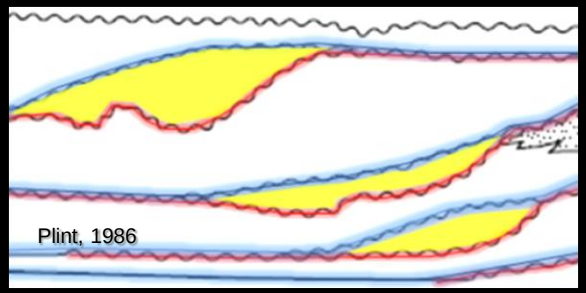
- *Shoaling-up log response*
- *Sand sheet with linear thicks*
- *High sediment supply*
- *Low to moderate accommodation*
- *Only Local Stratigraphic trapping*

6 mi
10 km

CGGVERITAS

Transgressive Benches/Terraces

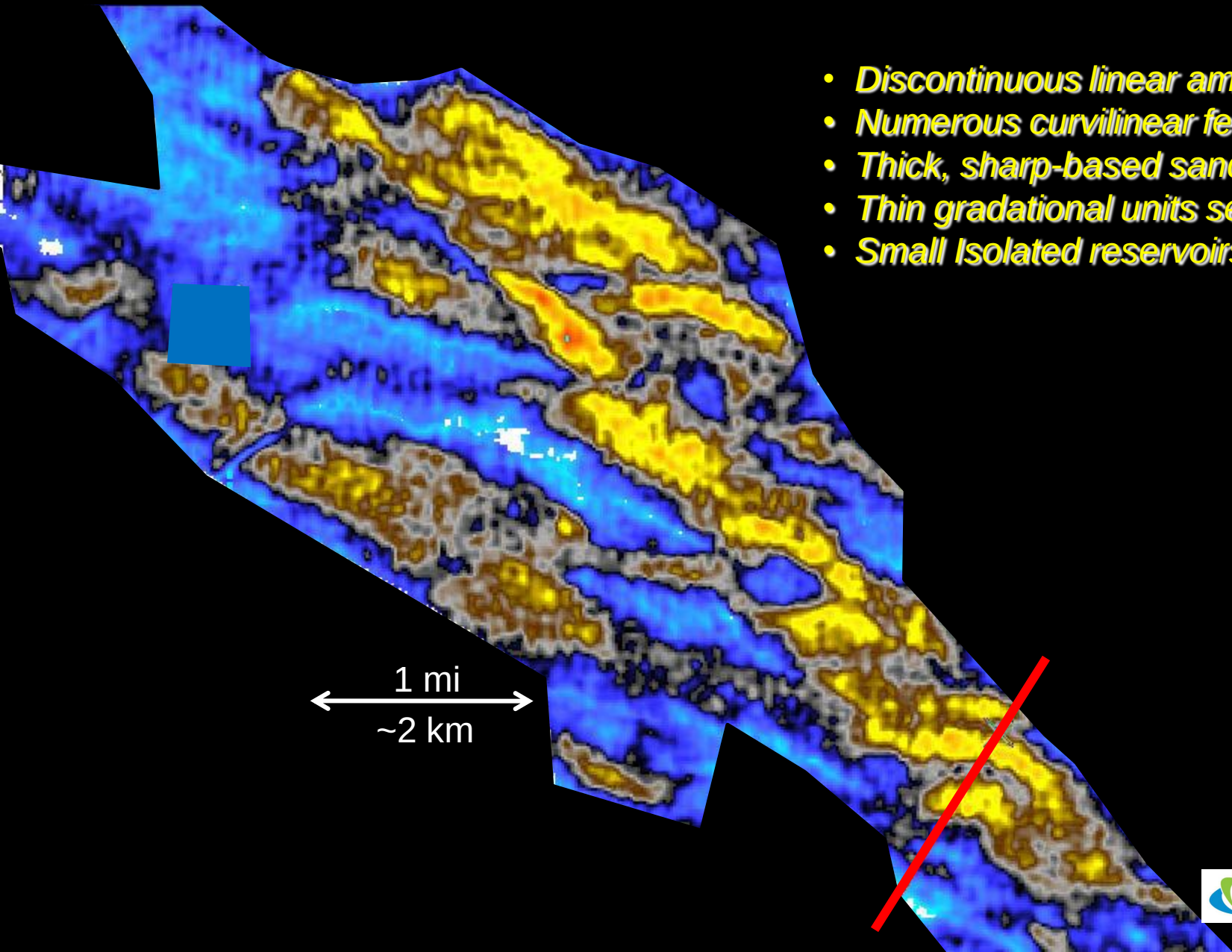




Product: Narrow, Linear Sand Bodies

- *Sharp bases, Blocky*
- *Anomalous thickness mostly landward*
- *Taper basinward*

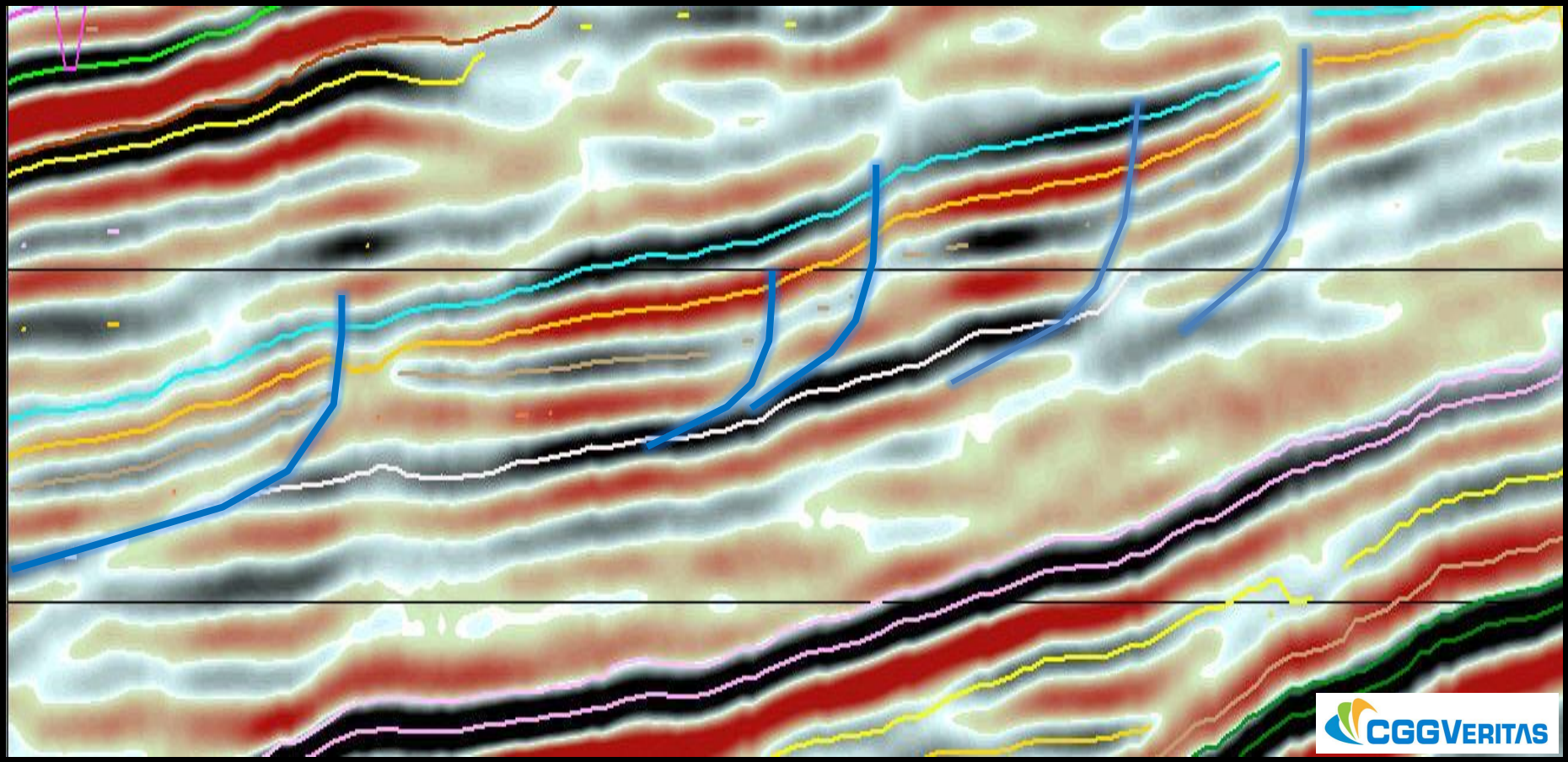
Underlying Succession



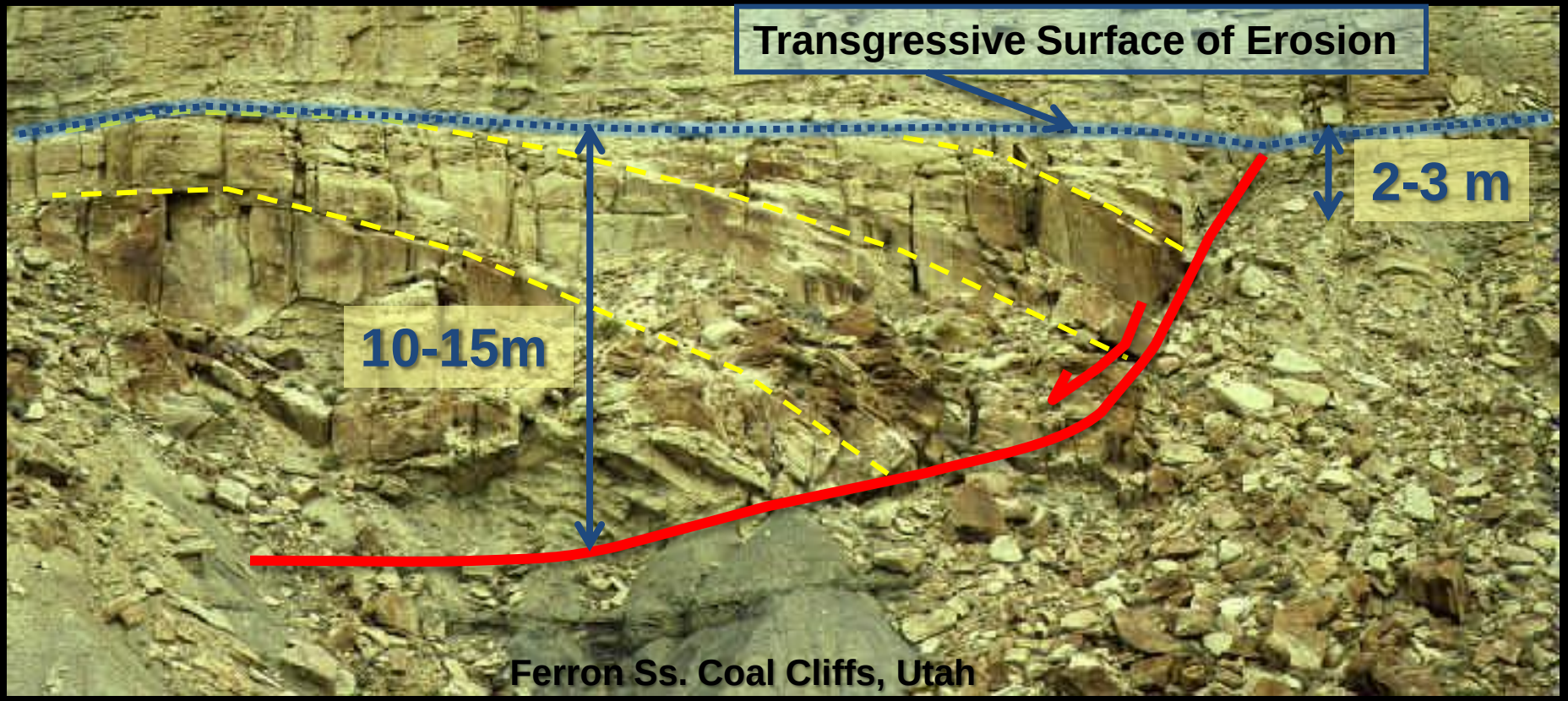
- *Discontinuous linear amplitudes*
- *Numerous curvilinear features*
- *Thick, sharp-based sands*
- *Thin gradational units seaward*
- *Small Isolated reservoirs*

CGGVERITAS

Underlying Succession: Delta Front Slumps/Growth Faults



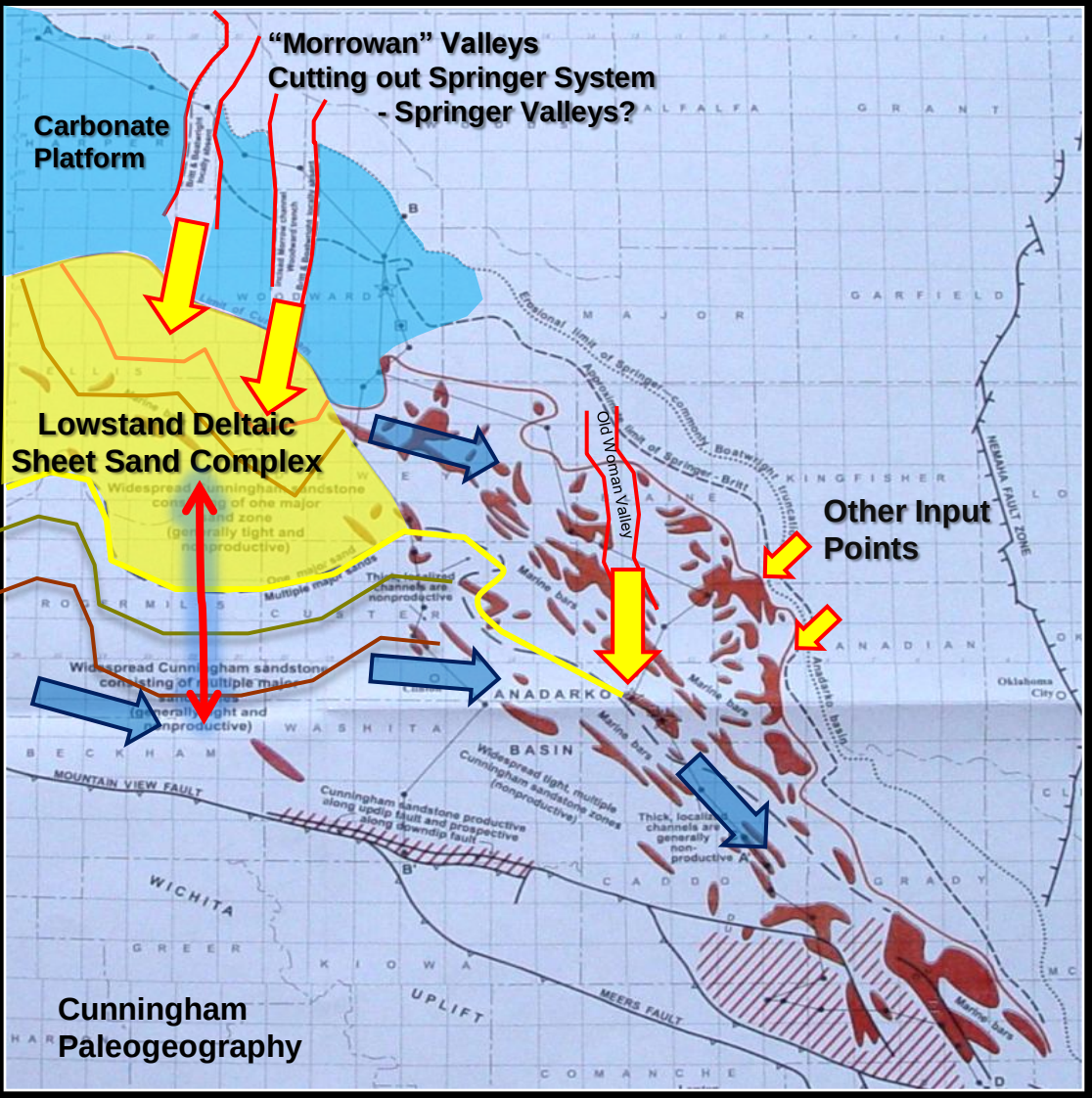
Delta-Front Slump/Growth Fault



Product: Cuspate to Spoon-shaped Sand Bodies

- *Anomalous thickness & dips*
- *Sharp base (fault plane)*
- *Blocky on landward side*
- *Taper basinward*

Regional Springer Distribution



- *Point Sourced Sediment Supply?*
- *Variable Rates of Sedimentation*
- *Strong Longshore Transport*
- *Sheets & Isolated Sandbodies*

- *Sand Sheets:*
  - *High Sediment Supply*
  - *Moderate Accommodation*
  - *Minimal Strat Traps*
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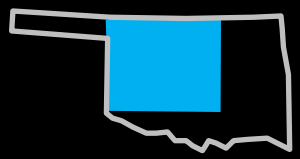
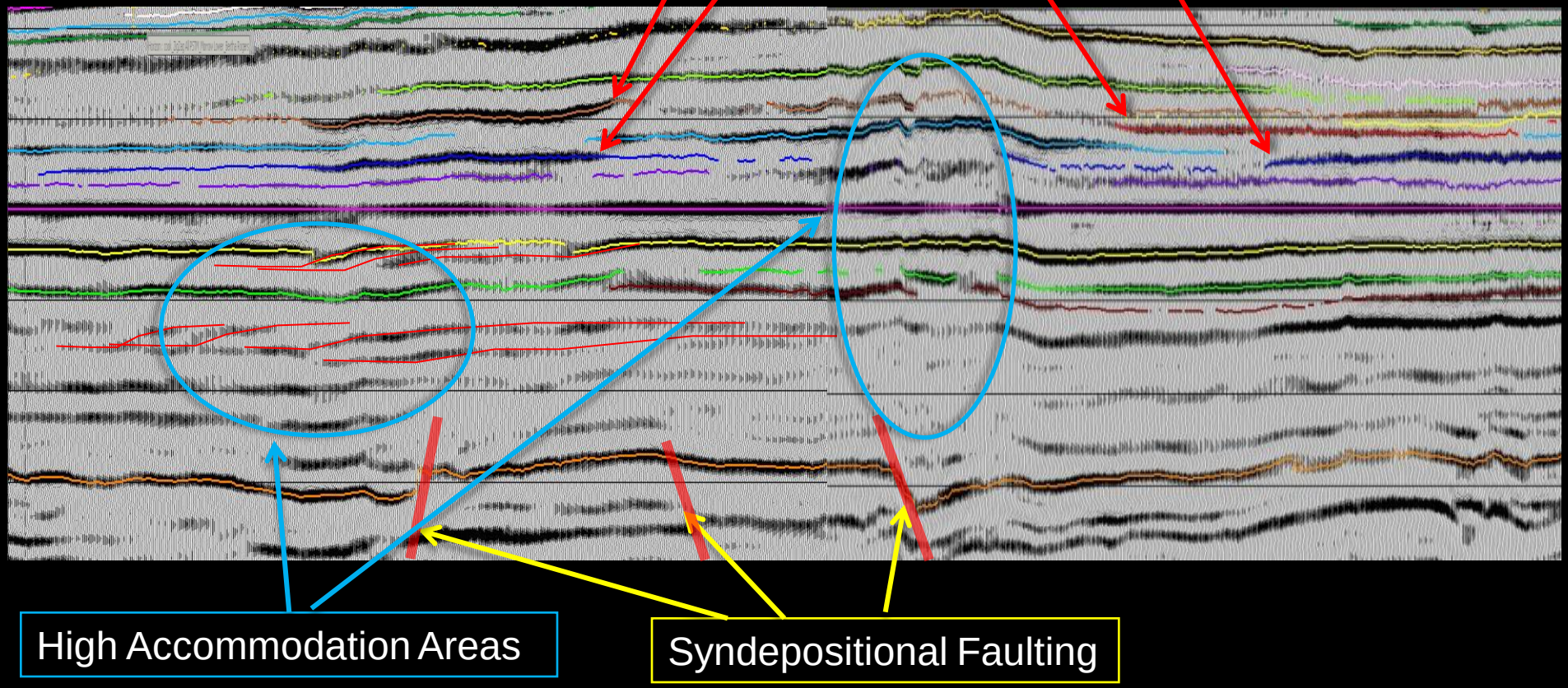


Crudely modified from Andrews, 2001

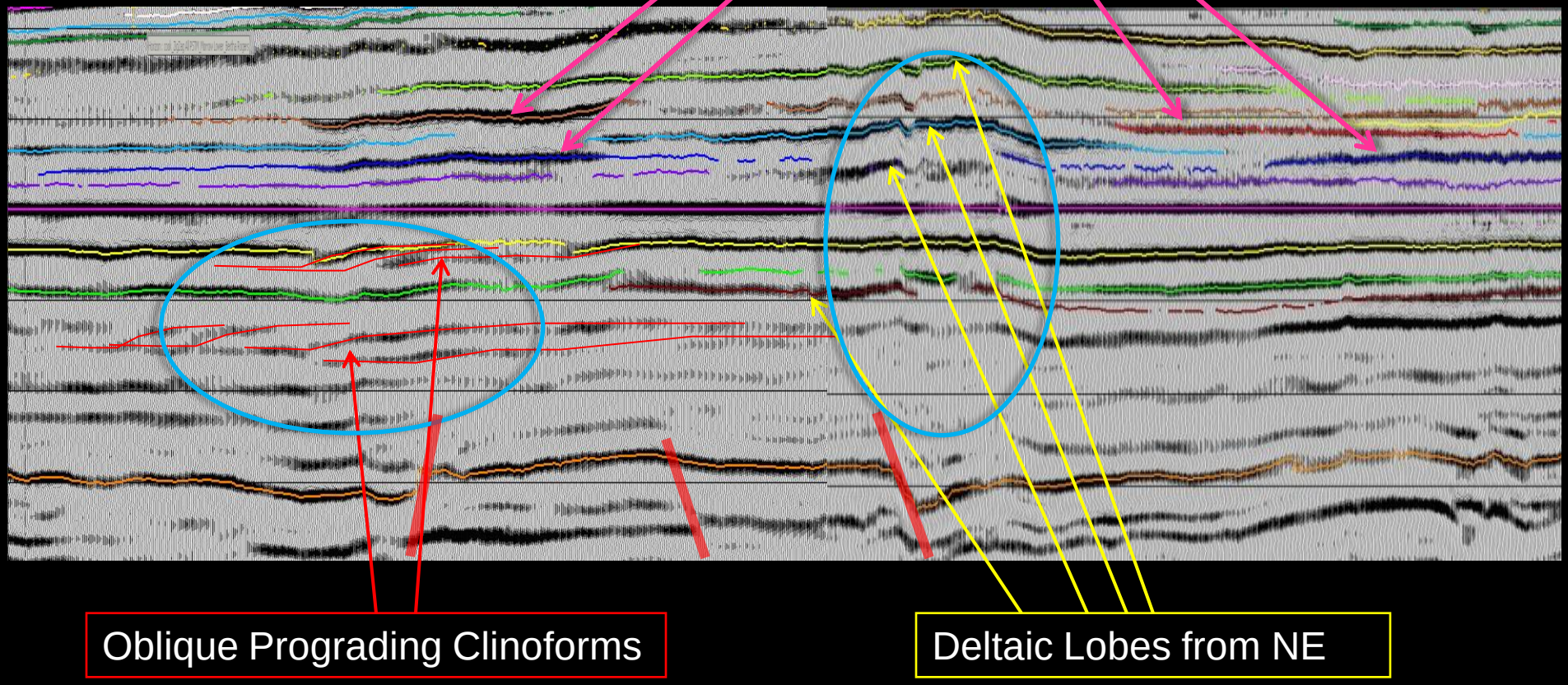
Springer Strike Section Tectonic Controls:



Synsedimentary Tectonic Controls….

- *Locus of Deltaics – high accommodation areas*
- *Transgressive truncation/reworking – low accommodation*

Strike Section:Depositional Complexity (systematic)

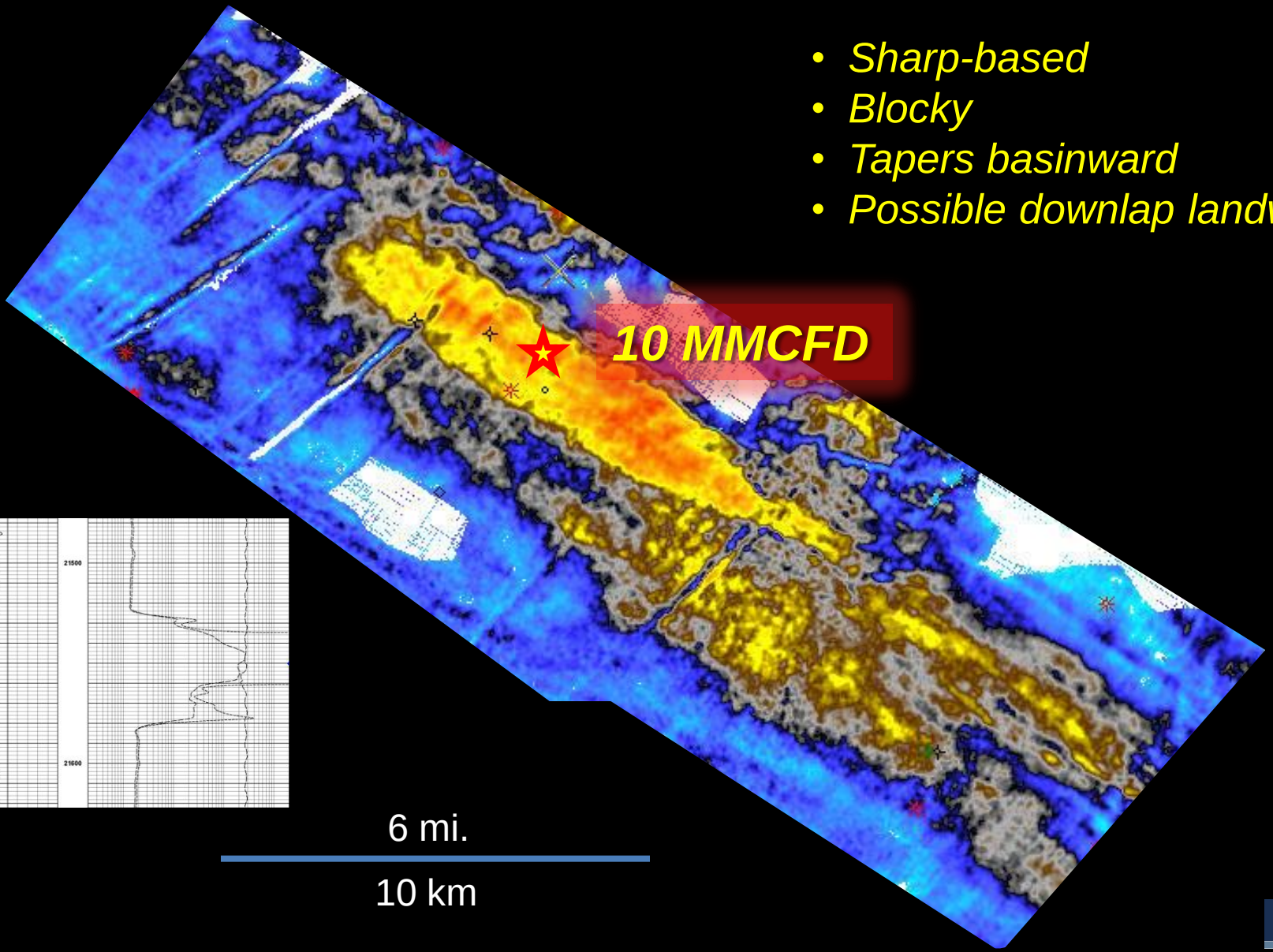


Isolated Sand bodies:

- *Lower relative accommodation*
- *Low sediment supply*
- *Tied to transgressions after lowstand*

Isolated Springer Shoal/“Bar”

- *Sharp-based*
- *Blocky*
- *Tapers basinward*
- *Possible downlap landward?*



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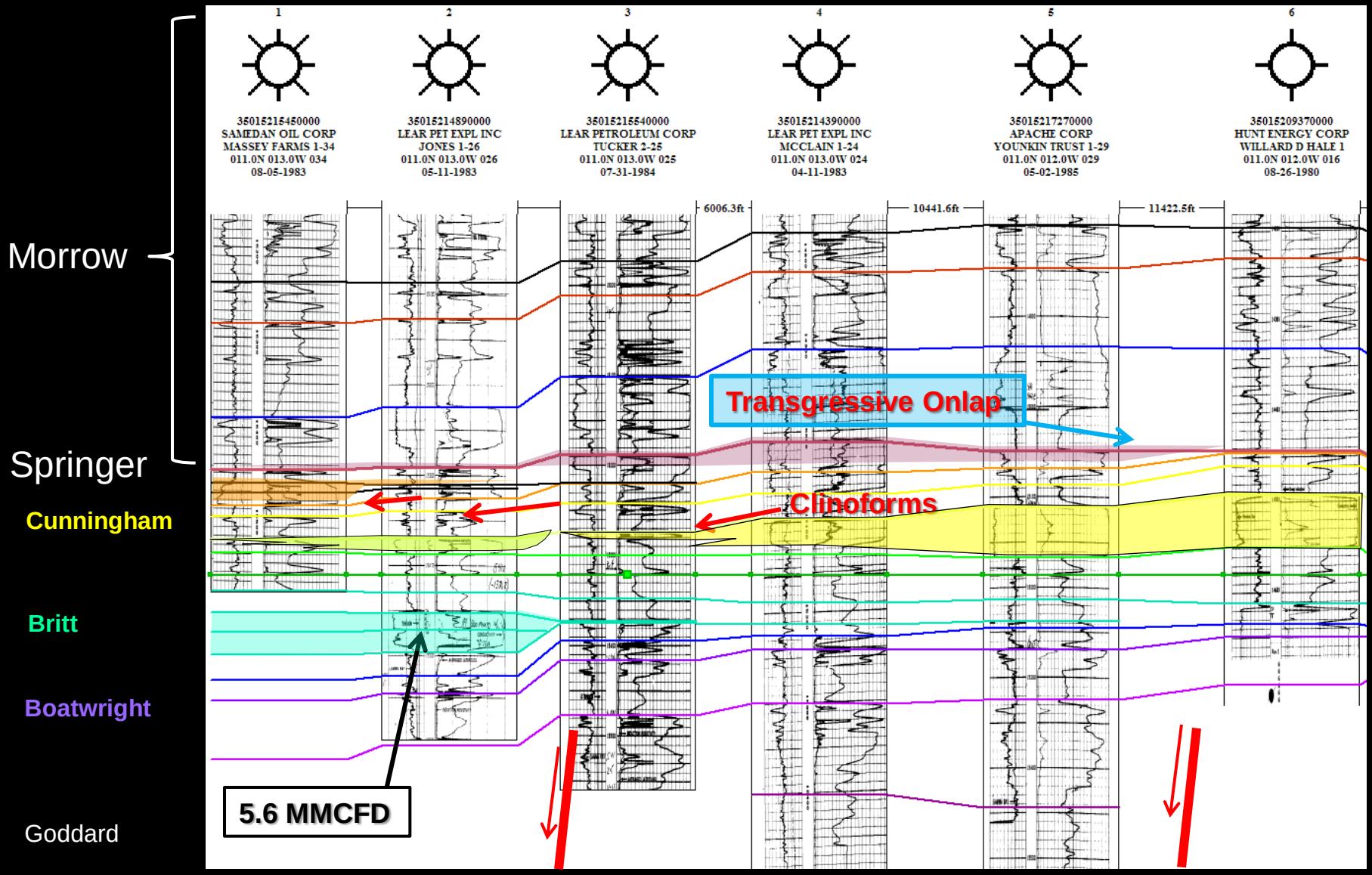
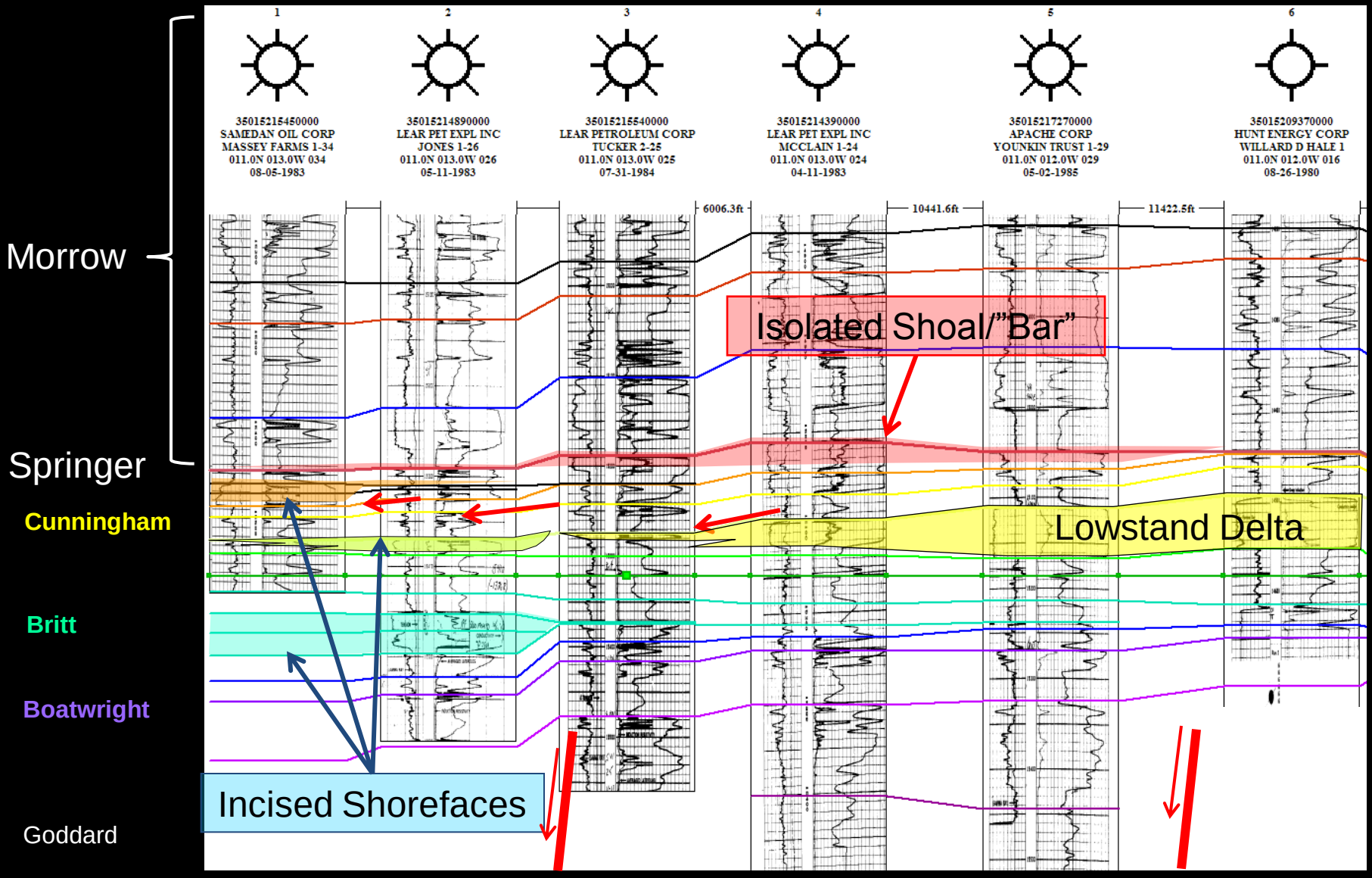
Isolated Springer Sands: Strat Section Accommodation & Transgressive Erosion

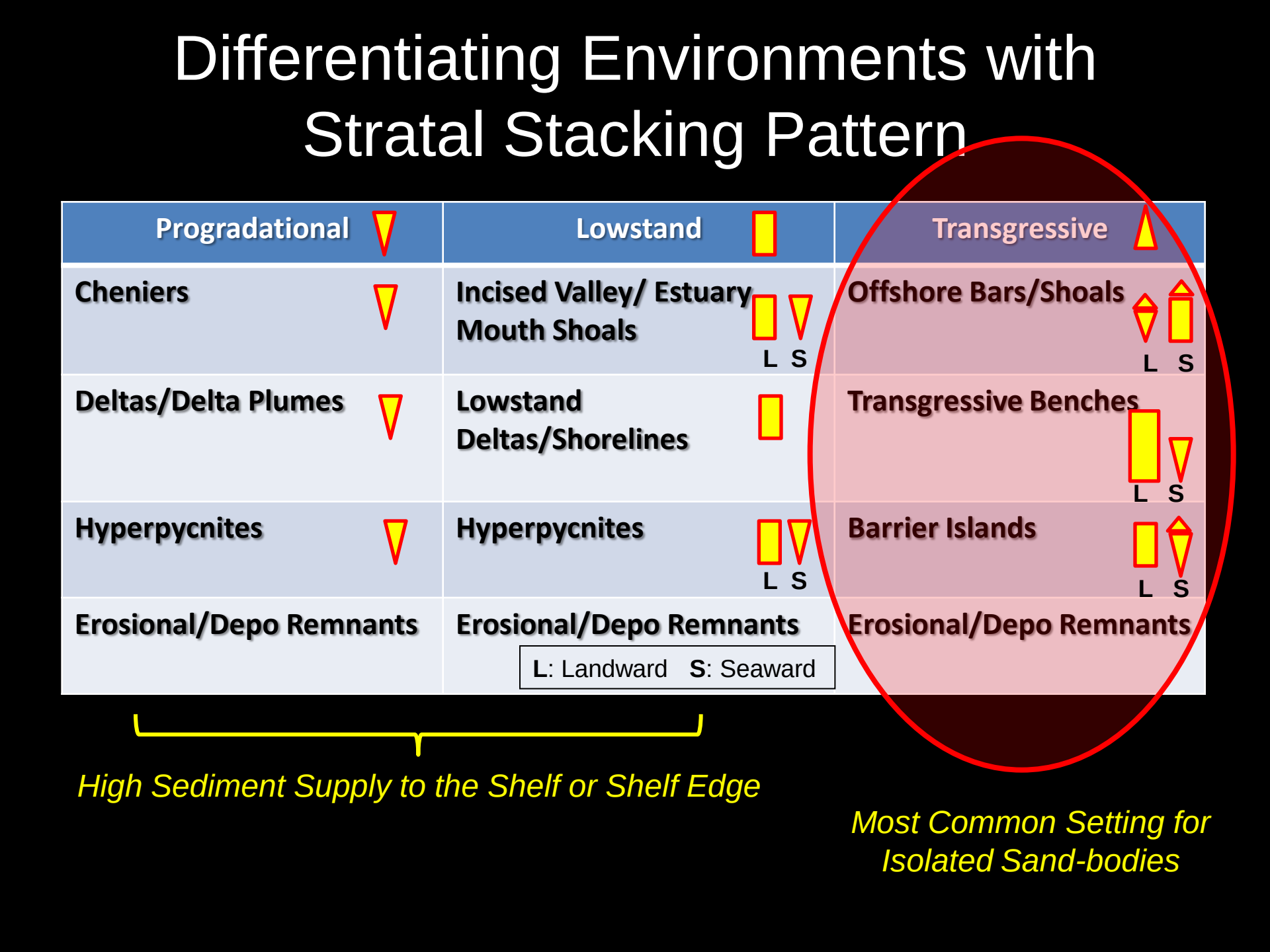


Isolated Springer Sands:
Shoals/"Bars" & "Incised Shorefaces"



Differentiating Environments with Stratal Stacking Pattern

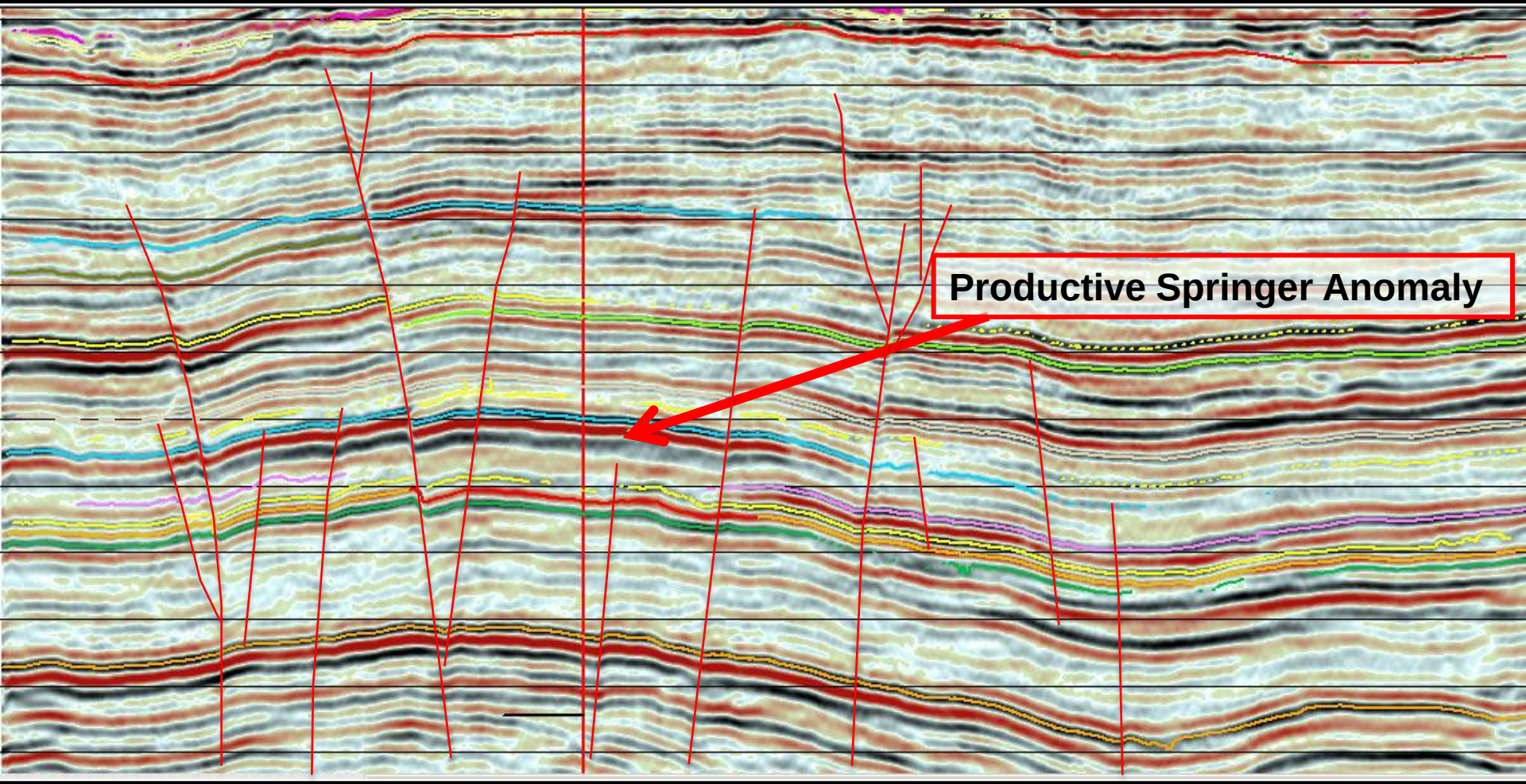
Progradational	Lowstand	Transgressive
Cheniers	Incised Valley/ Estuary Mouth Shoals	Offshore Bars/Shoals
Deltas/Delta Plumes	Lowstand Deltas/Shorelines	Transgressive Benches
Hyperpycnites	Hyperpycnites	Barrier Islands
Erosional/Depo Remnants	Erosional/Depo Remnants	Erosional/Depo Remnants



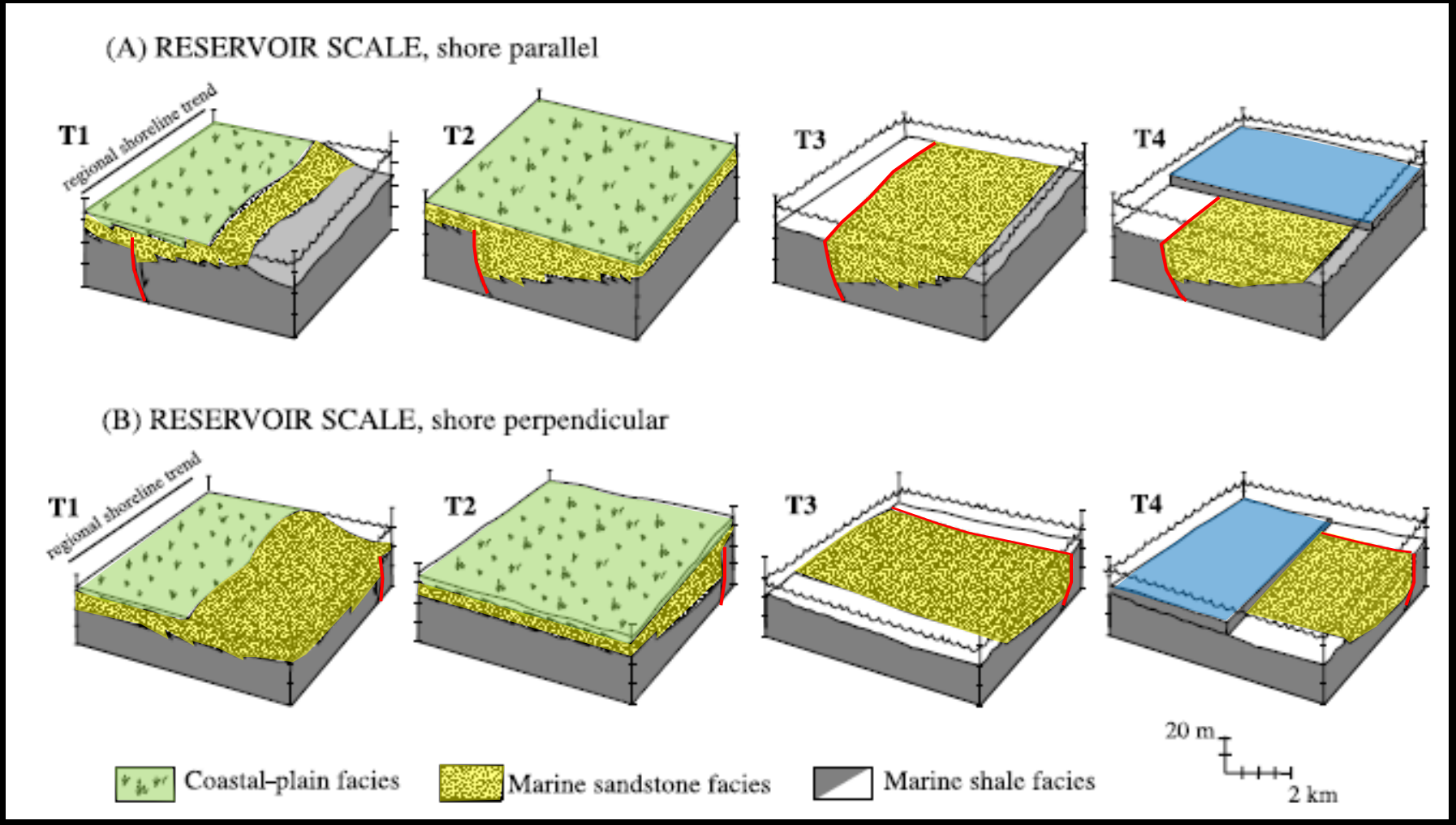
High Sediment Supply to the Shelf or Shelf Edge

Most Common Setting for Isolated Sand-bodies

Springer Anomaly Structural Section: Structural Inversion



Erosional/Accommodation Remnants

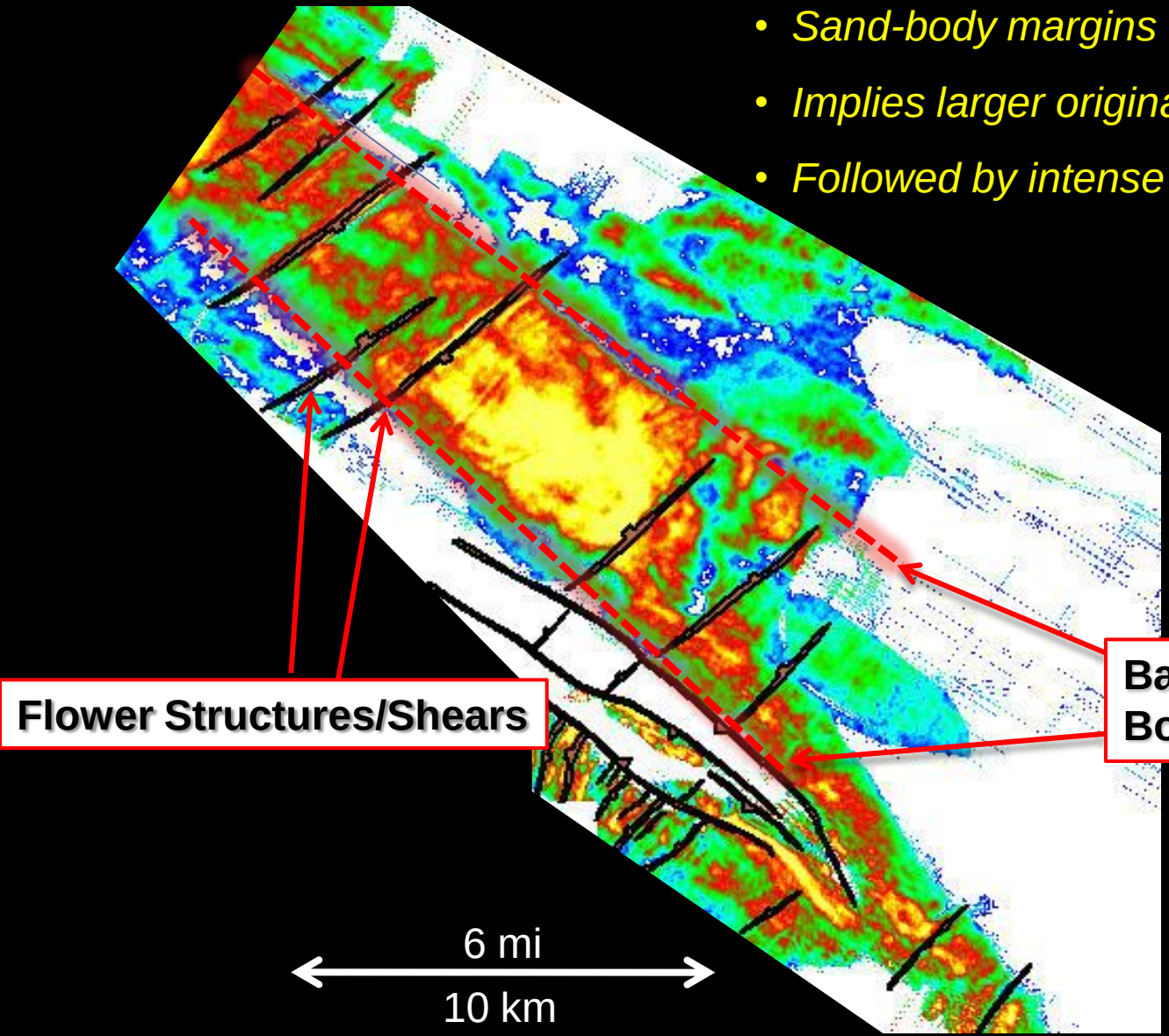


Martinsen, 2003

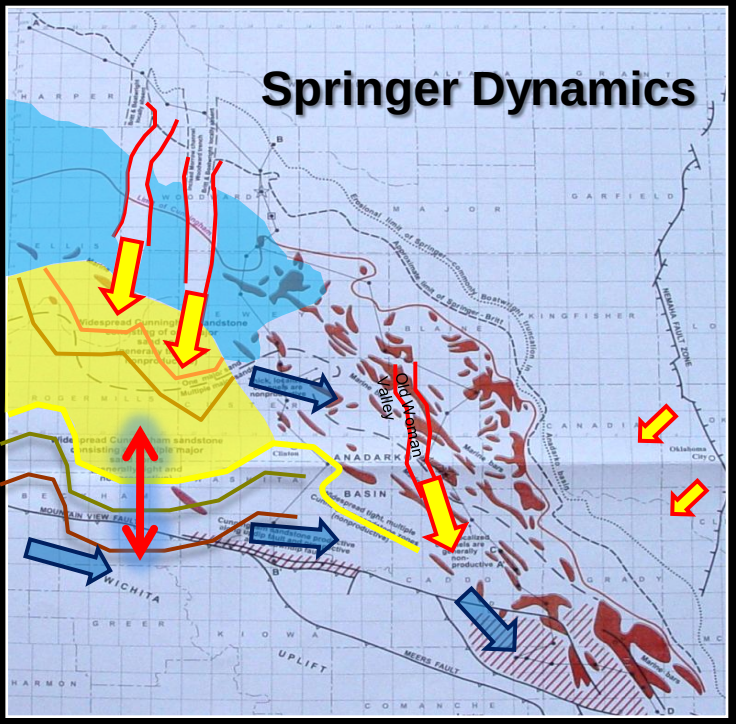
Synsedimentary Tectonics & Subsequent Transgressive Erosion:
Different preserved geometries, orientations & thickness = Strat Traps

Synsedimentary Tectonic Control on Preservation:

- *Shears truncate/attenuate sand preservation*
- *Sand-body margins also structurally controlled*
- *Implies larger original sand distribution*
- *Followed by intense transgressive erosion*



Conclusions



Lowstand Deltaic Headland = Sediment Supply

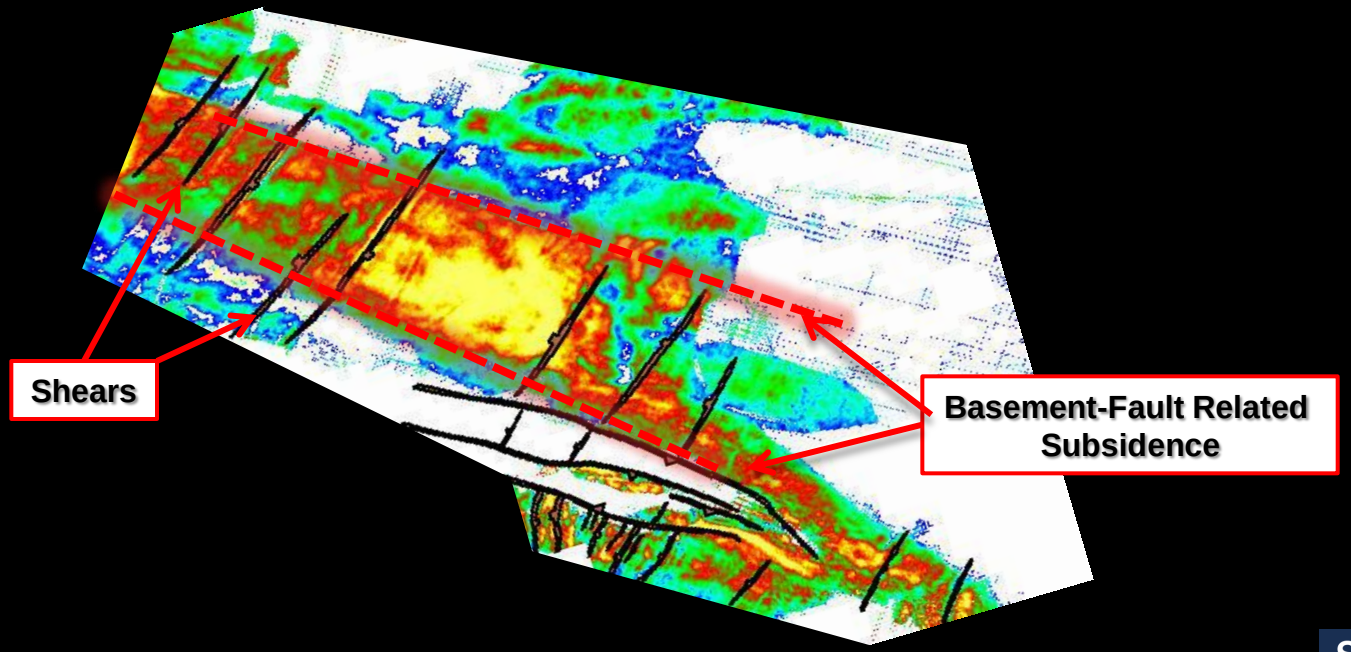
- *Major Longshore Transport (skews STS)*
- *Sheets & Isolated Sand Bodies*

Isolated Sand Body Reservoirs:

- *Occur After Significant Lowstands*
- *In Low-Accommodation Areas*
- *Low(er) Sediment Supply*
- *Transgression: Greatest erosion & transport*
- *Numerous Strat Traps Down Drift*
- *Benches & Shoals: Can be differentiated*

Conclusions

- *Locally: Intimate Interaction with Synsedimentary Tectonics*
- *Transgressive Erosion: Erosional/Accommodation Remnants*
- *Preserved Reservoir Vs. Original Deposit… Integrate tectonic story*
- *3D Seismic, Carefully Integrated with Geology... Highly effective*
- *Very Similar Relationships in Cretaceous WIS Isolated Sands*

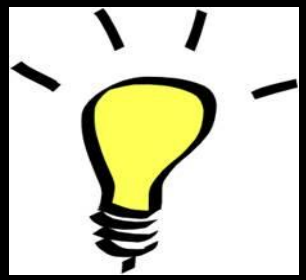


Acknowledgements

Dan Cook shared numerous insights on the Springer

Julie Hardie – permissions for seismic images from several 3D surveys held by SEI

Dennis Langlois – permissions for seismic images from a 3D survey by CGGVeritas



Rod Tillman & Randi Martinsen's decades of work with isolated shelf sandstones