

# Sequence Stratigraphic Analysis of Mixed, Reefal Carbonate and Siliciclastic Systems\*

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## Abstract

Carbonate reefs are often juxtaposed with off-reef siliciclastic sediments and sequence stratigraphy provides the best methodology for correlating between the two disparate successions. A sequence analysis also allows the relationship between the carbonates and the siliciclastics to be understood in terms of base level change. The main sequence stratigraphic surfaces associated with reefs are unconformable shoreline ravinements (SR-U), maximum regressive surfaces (MRS), maximum flooding surfaces (MFS) and slope onlap surfaces (SOS). Off-reef siliciclastics usually contain only MRSs and MFSs. An SR-U within or capping a reefal succession correlates to an SOS on the reef flank and eventually to a facies contact between basinal carbonates and overlying siliciclastics. This facies contact is often misinterpreted as an MFS. The SR-U also correlates with a MRS which usually occurs near the top of the onlapping siliciclastic succession. A MFS can be traced from the reefal carbonates to near, or at, the top of the siliciclastic succession.

The conjoined reefal SR-U and the MRS high in the siliciclastics constitute a depositional sequence boundary. Such a boundary marks the start of transgression and approximates the start of base level rise.

Transgression allows carbonate deposition to be reinitiated on the reef and shuts off the siliciclastic supply. If the previously deposited siliciclastic sediments filled most of the off-reef area, a prograding carbonate ramp builds from the reef across the former inter-reef basins, downlapping on the MFS. If not, reef growth resumes until the next base level fall exposes the reef and brings back siliciclastic sediments which continue to fill the off-reef basin.

Off-reef siliciclastic sediment can vary from deep water turbidites, through slope shales to shallow shelf sandstones, depending on the proximity of, and the rate of supply from, the siliciclastic source area. Regardless of the specific siliciclastic facies occurring in the off-reef area, the same types of sequence stratigraphic surfaces are present and their correlation allows the depositional history to be determined.

In most situations, reef growth occurs during base level rise and is terminated during base level fall. The associated siliciclastic sediments are deposited almost entirely during base level fall and onlap the SOS on the carbonate slope. This sequence stratigraphic model is equivalent to Wilson's model of reciprocal sedimentation.

### References

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# Sequence Stratigraphic Analysis of Mixed, **Reefal Carbonate** and **Siliciclastic** Systems

**Ashton Embry**  
**Geological Survey of Canada**



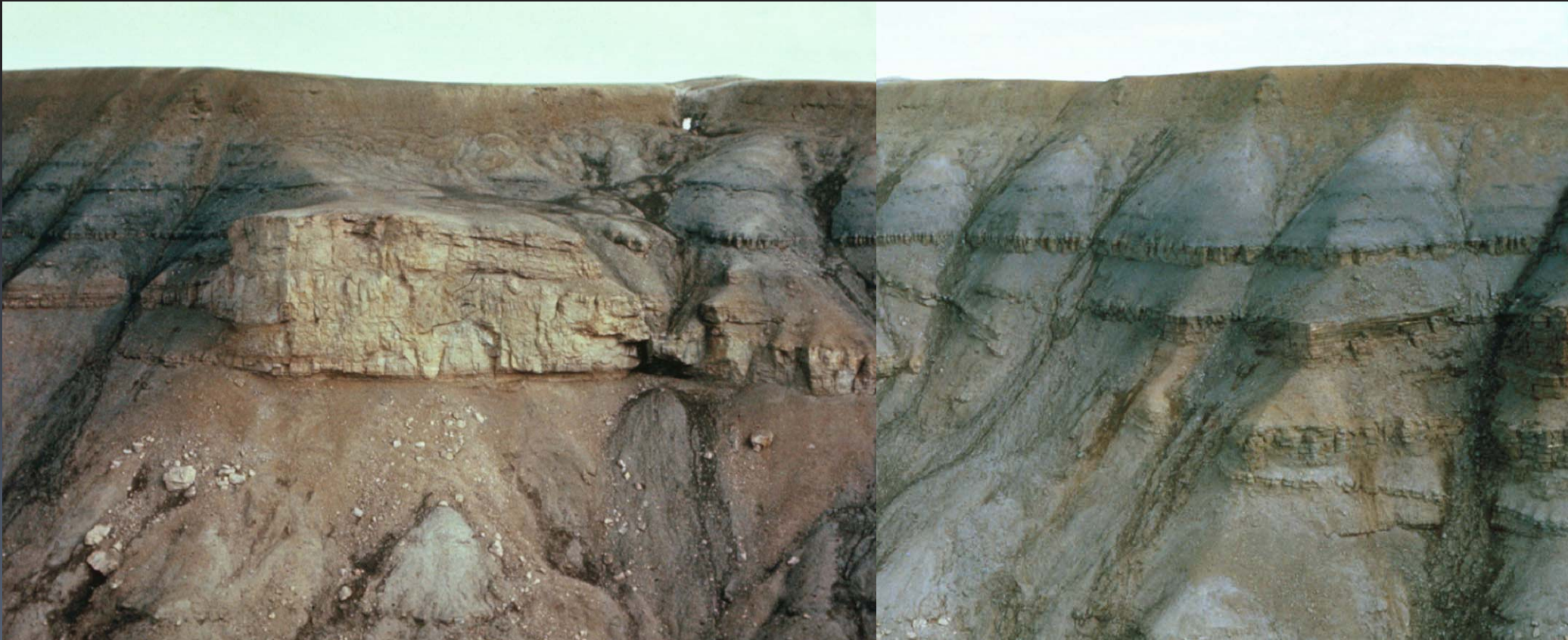
# Outline

- Sequence Stratigraphy
- Sequence Surfaces for Siliciclastics
- Sequence Surfaces and Sequence Boundaries for Reefs
- Sequence Surfaces and Sequence Boundaries for Mixed Reef and Siliciclastic Successions
- Correlating a Reef/Siliciclastic Succession



**REEF**

**SILICICLASTICS**



How do we use sequence stratigraphy to correlate from a reef to off-reef siliciclastics?

Where is the sequence boundary?

# SEQUENCE STRATIGRAPHY

Consists of :

- The recognition and correlation of stratigraphic surfaces which represent depositional breaks or changes in depositional trend in the rock record.
- The description and interpretation of resulting, genetic stratigraphic units bound by those surfaces.

# SEQUENCE STRATIGRAPHY

- The depositional breaks and changes in depositional trend were generated by the interplay of sedimentation, erosion and shifting base level.
- These surfaces are recognized by sedimentological criteria and geometrical relationships between the surface and strata above and below the surface.

# USING SEQUENCE STRATIGRAPHY

- 1) For constructing an approximate chronostratigraphic, correlation framework to facilitate facies analysis and related endeavours.
- 2) For bounding individual sequence stratigraphic units for mapping and communication purposes.

# USING SEQUENCE STRATIGRAPHY

- 3) For allowing the sedimentary record to be interpreted in terms of base level changes.
- 4) In conjunction with facies analysis, for providing a framework and theoretical basis for interpreting depositional history and paleogeographic evolution.



# The Five Material-Based Surfaces of Sequence Stratigraphy

Unconformities (time barriers) or low diachroneity surfaces (approx. time surfaces)

- 1) Subaerial Unconformity (SU)
- 2) Shoreline Ravinement Surface (SR)
- 3) Maximum Regressive Surface (MRS)
- 4) Maximum Flooding Surface (MFS)
- 5) Slope Onlap Surface (SOS)



# The Five Material-Based Surfaces of Sequence Stratigraphy

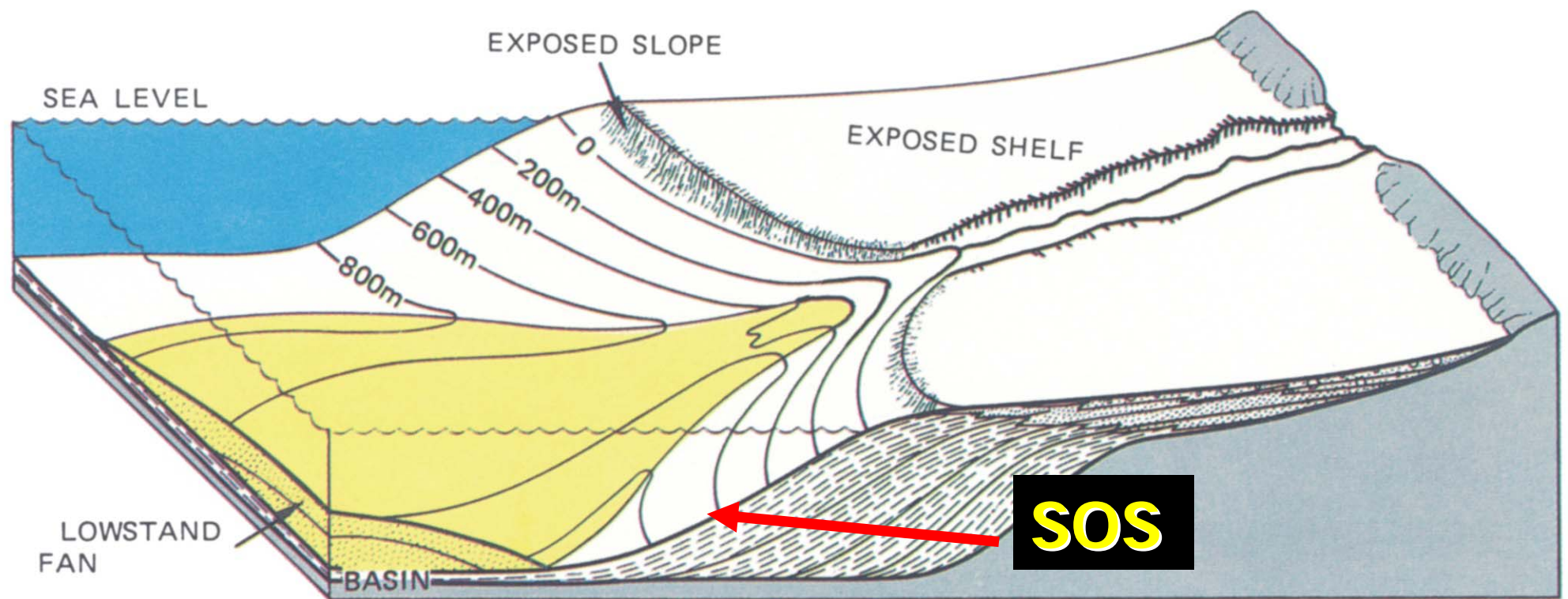
Unconformities (time barriers) or low diachroneity surfaces (approx. time surfaces)

- 1) Subaerial Unconformity (SU)
- 2) Shoreline Ravinement Surface (SR)
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- 4) Maximum Flooding Surface (MFS)
- 5) **Slope Onlap Surface (SOS)**

# Slope Onlap Surface

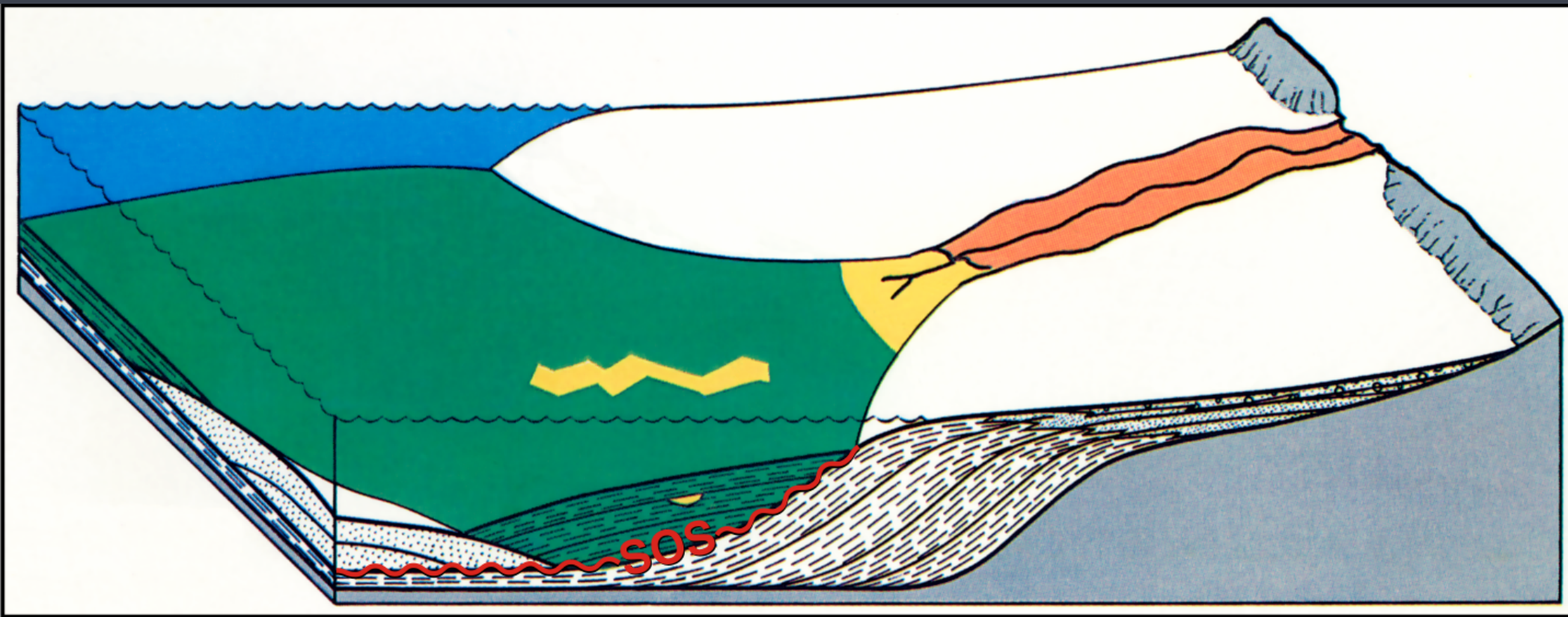
**An unconformable stratigraphic surface which is developed in marine slope strata and onto which there is demonstrable onlap by marine strata.**

# SOS Forms When the Shoreline Reaches the Shelf Edge and Much of the Slope Becomes Starved

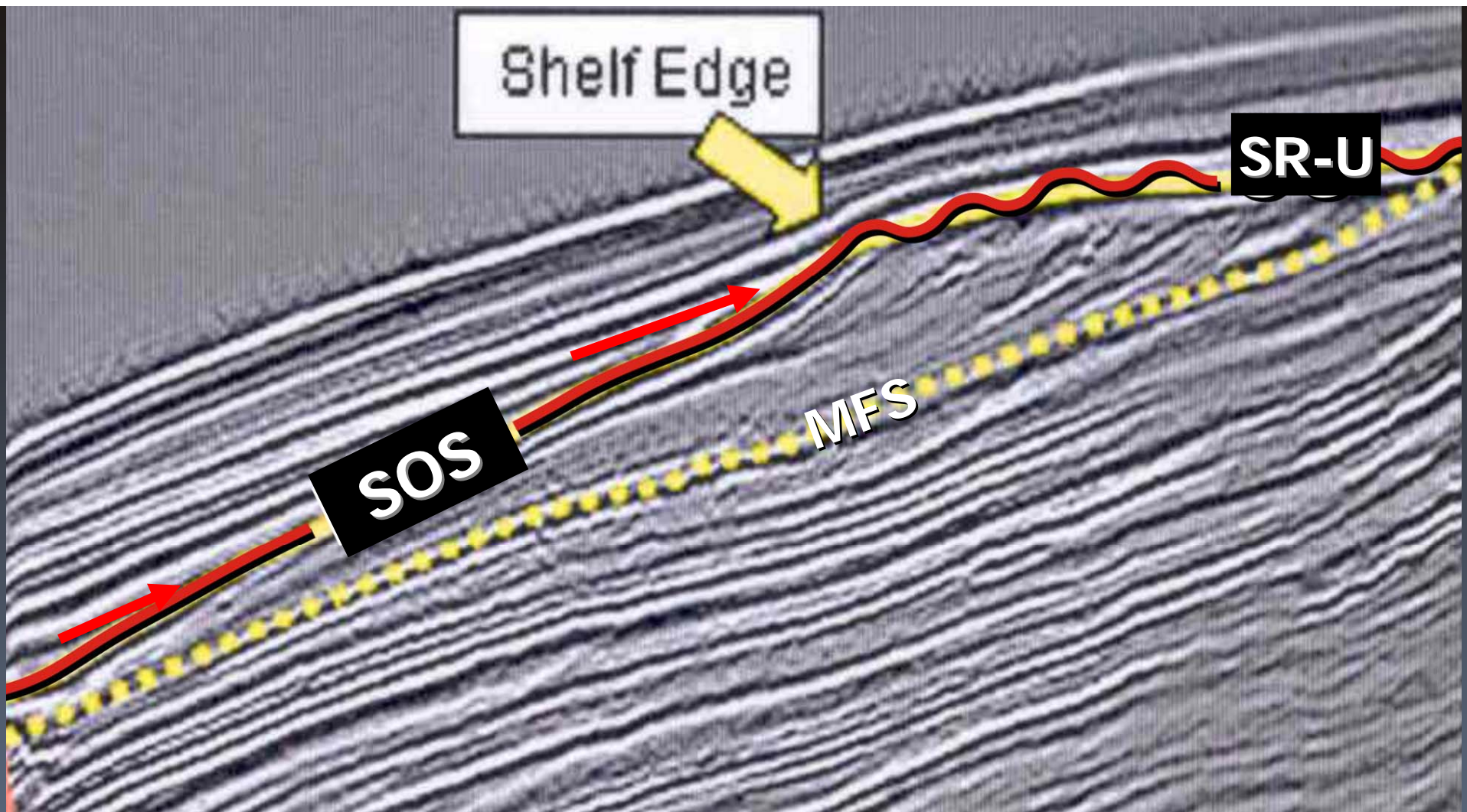


Posamentier and Vail, 1988

**SOS is overlapped by slope deposits  
during both base level fall and  
base level rise**







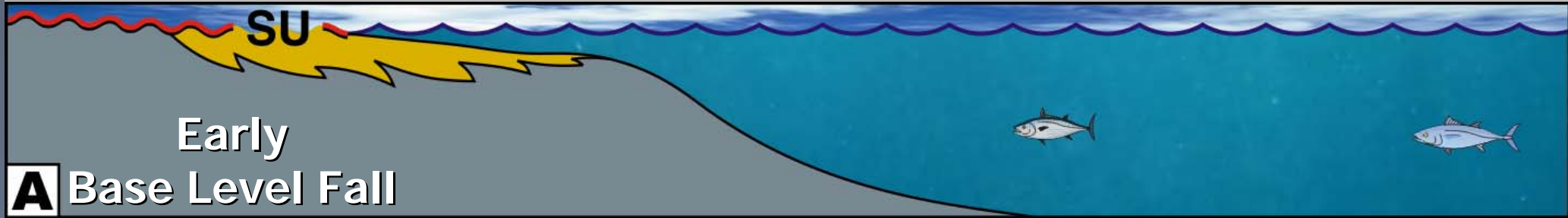
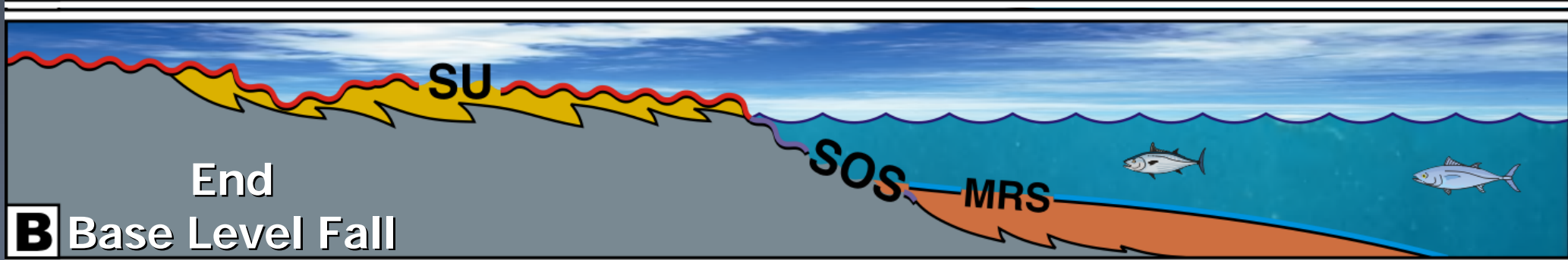
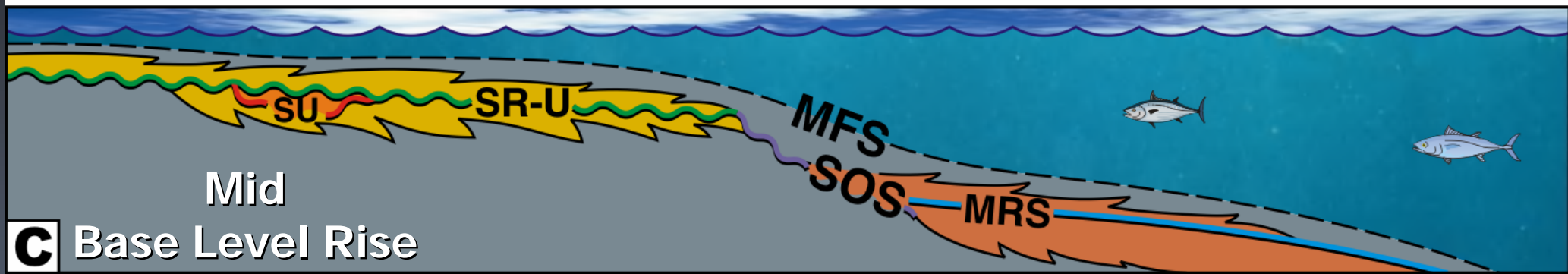
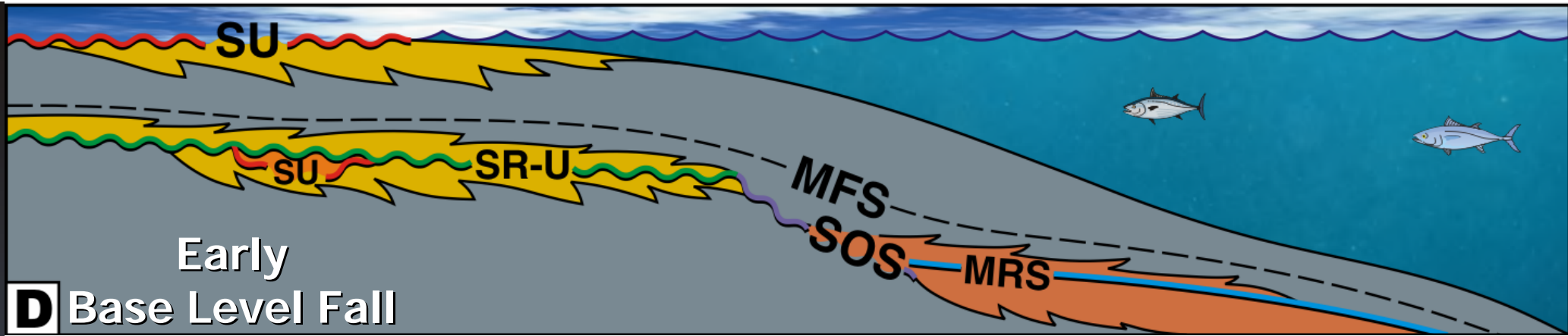
# Slope Onlap Surface (SOS) Quaternary Strata, Gulf of Mexico

# Inductive Model for Material-Based SURFACES OF SEQUENCE STRATIGRAPHY

Base Level	Events	Surfaces	
	Start Regression	Maximum Flooding Surface	
	Start Transgression	Maximum Regressive Surface	Shoreline Ravinement
	Base Level Fall	Slope Onlap Surface	Subaerial Unconformity



# Sequence Stratigraphic Surfaces in **Siliciclastics**



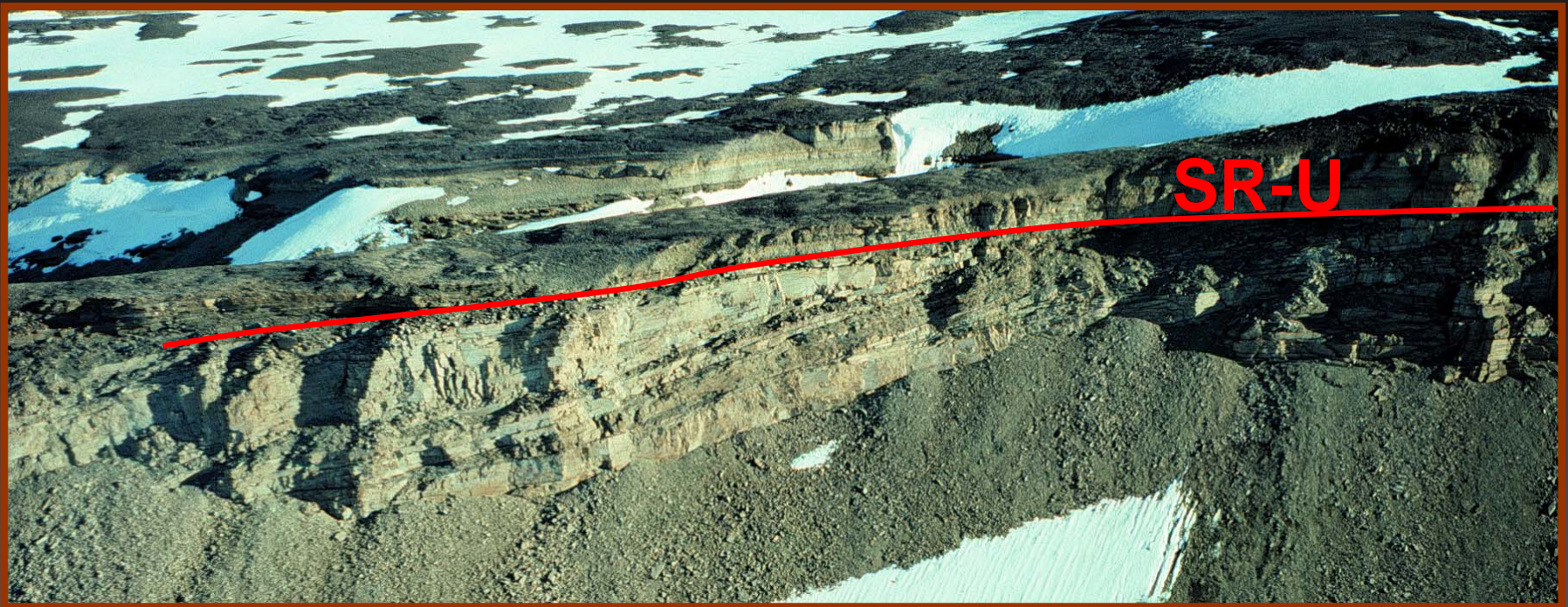
Subaerial Unconformity . . . . . **SU**  
 Shoreline Ravinement - Unconformable . . . . . **SR-U**  
 Slope Onlap Surface . . . . . **SOS**

Maximum Regressive Surface . . . . . **MRS**  
 Maximum Flooding Surface . . . . . **MFS**

 NON-MARINE	 OFFSHORE SHELF
 SHALLOW MARINE	 TURBIDITES

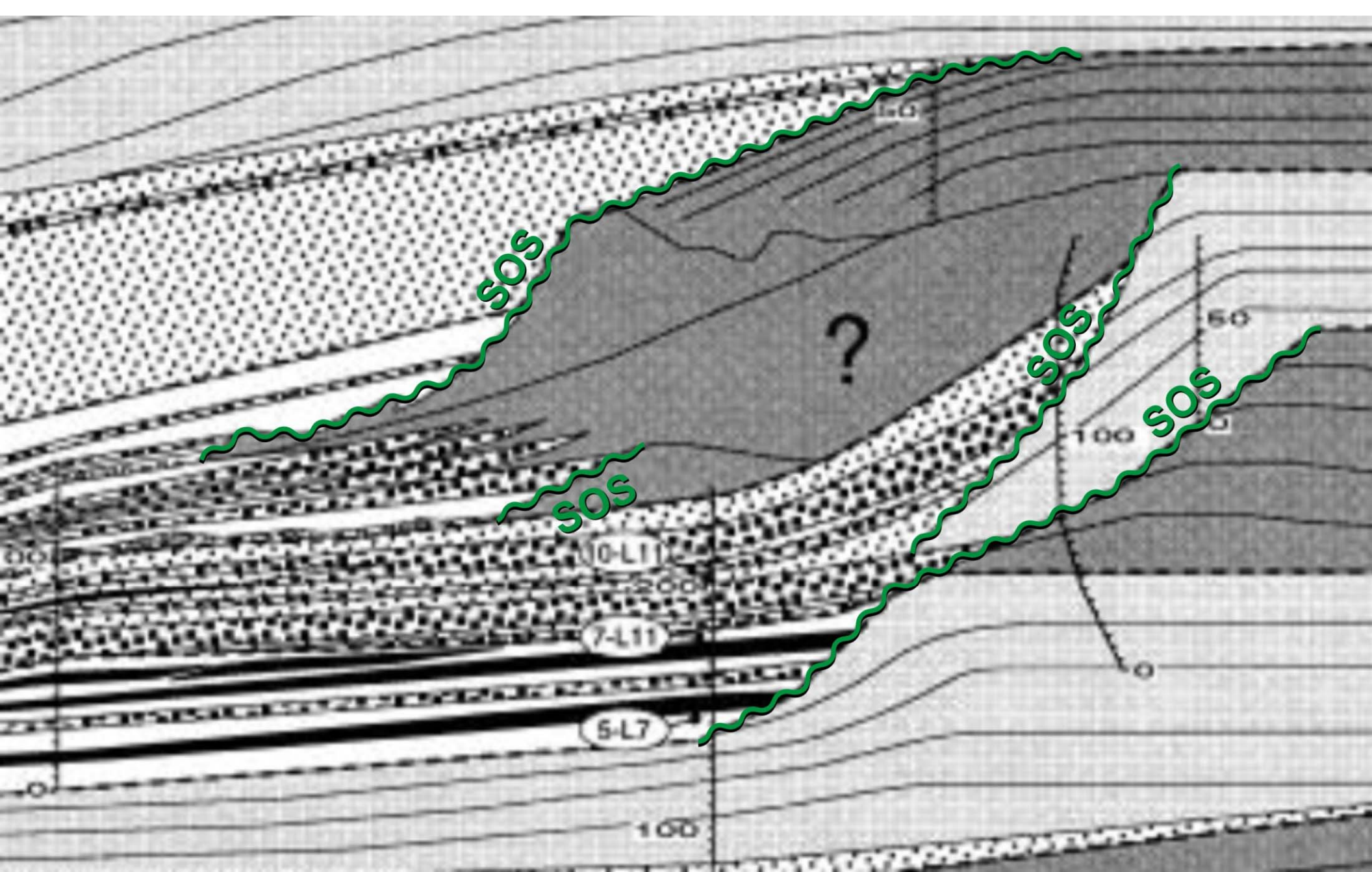
# Sequence Stratigraphic Surfaces in Carbonates





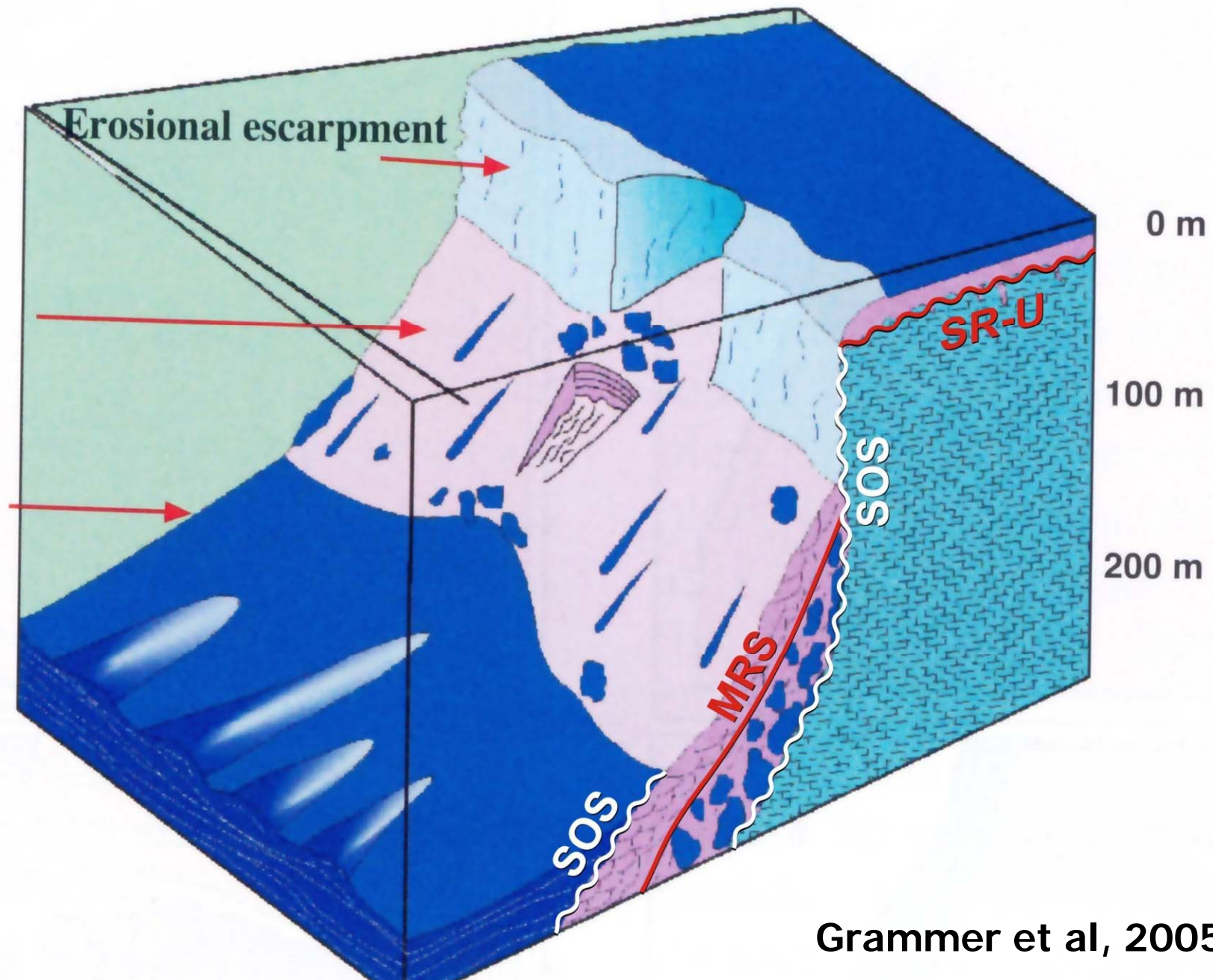
In most cases, the strata directly overlying an unconformity in carbonate strata are marine in origin. This indicates that a previously formed subaerial unconformity (SU) was modified during transgression. In such cases, the surface is best referred to as an Unconformable Shoreline Ravinement (SR-U).





**Fairholme Gp (Late Devonian), Rocky Mtns,  
Slope Onlap Surfaces**

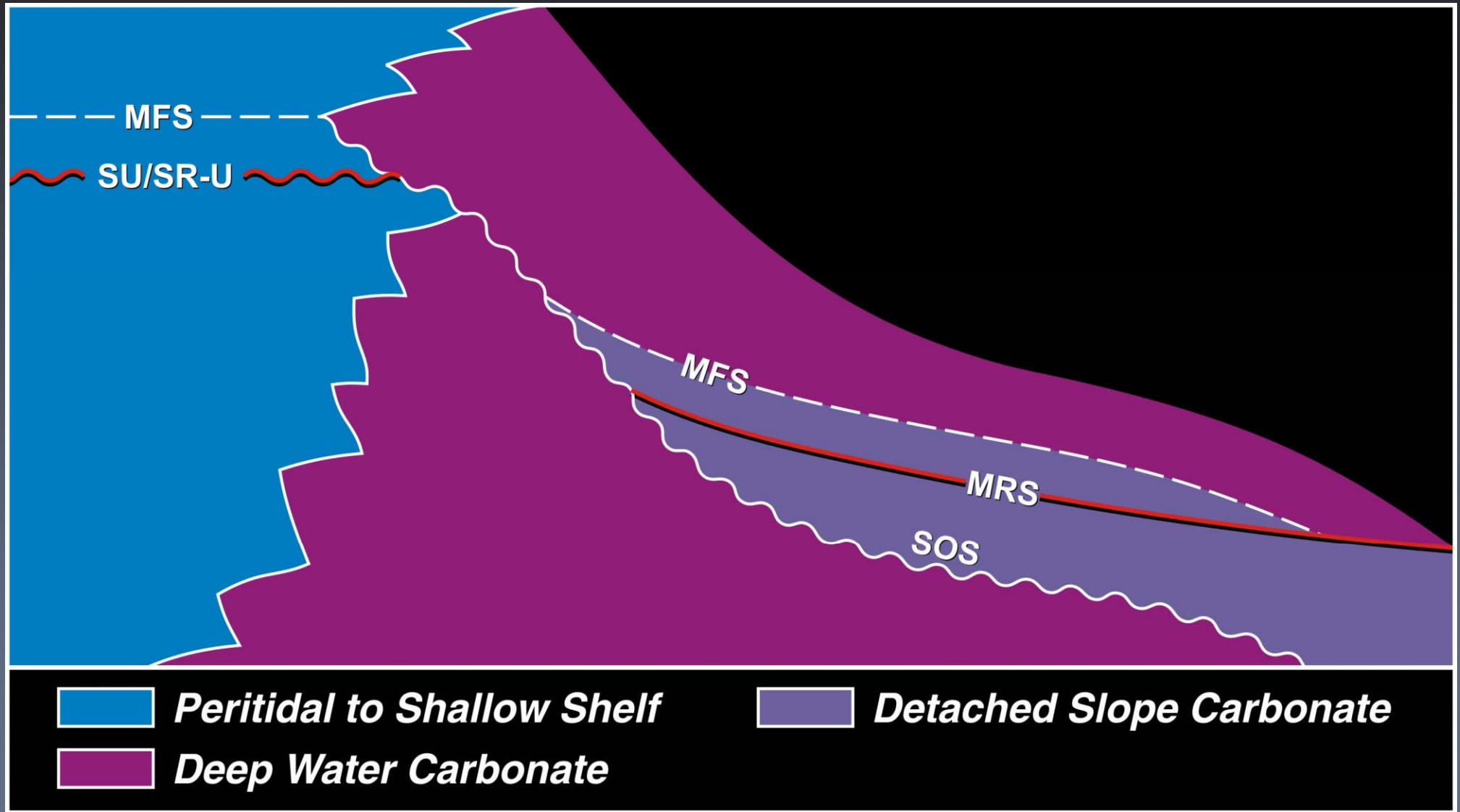
Whalen et al., 2000



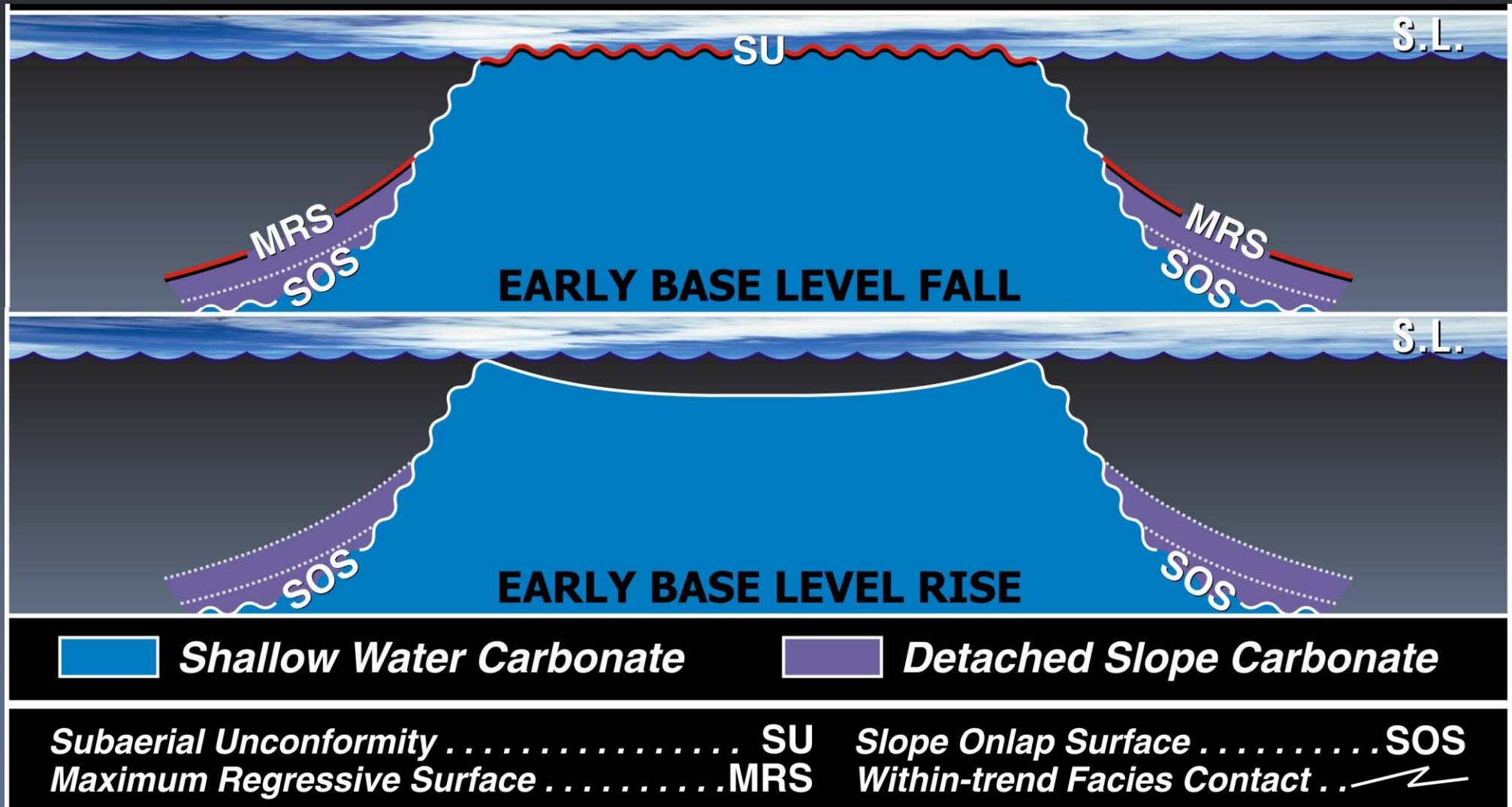
# Sequence Stratigraphic Surfaces Bahamas Bank



# Sequence Stratigraphic Surfaces Carbonate Platform/Slope/Basin



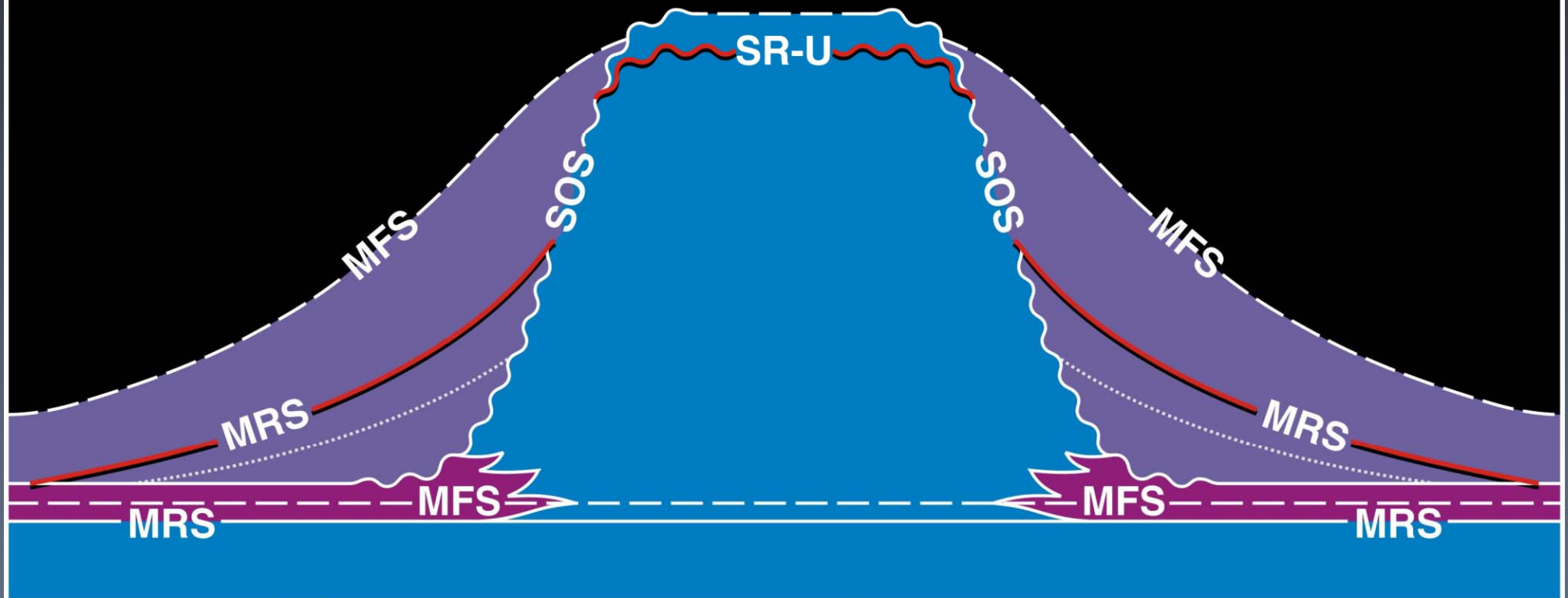
# Evolution of Sequence Stratigraphic Surfaces, Carbonate Reef



# Sequence Stratigraphic Surfaces Reefal Carbonate

*Unconformable Shoreline Ravinement . . SR-U*  
*Slope Onlap Surface . . . . . SOS*  
*Maximum Regressive Surface . . . . . MRS*

*Maximum Flooding Surface . . . . MFS*  
*Within-trend Facies Contact . . ↗*

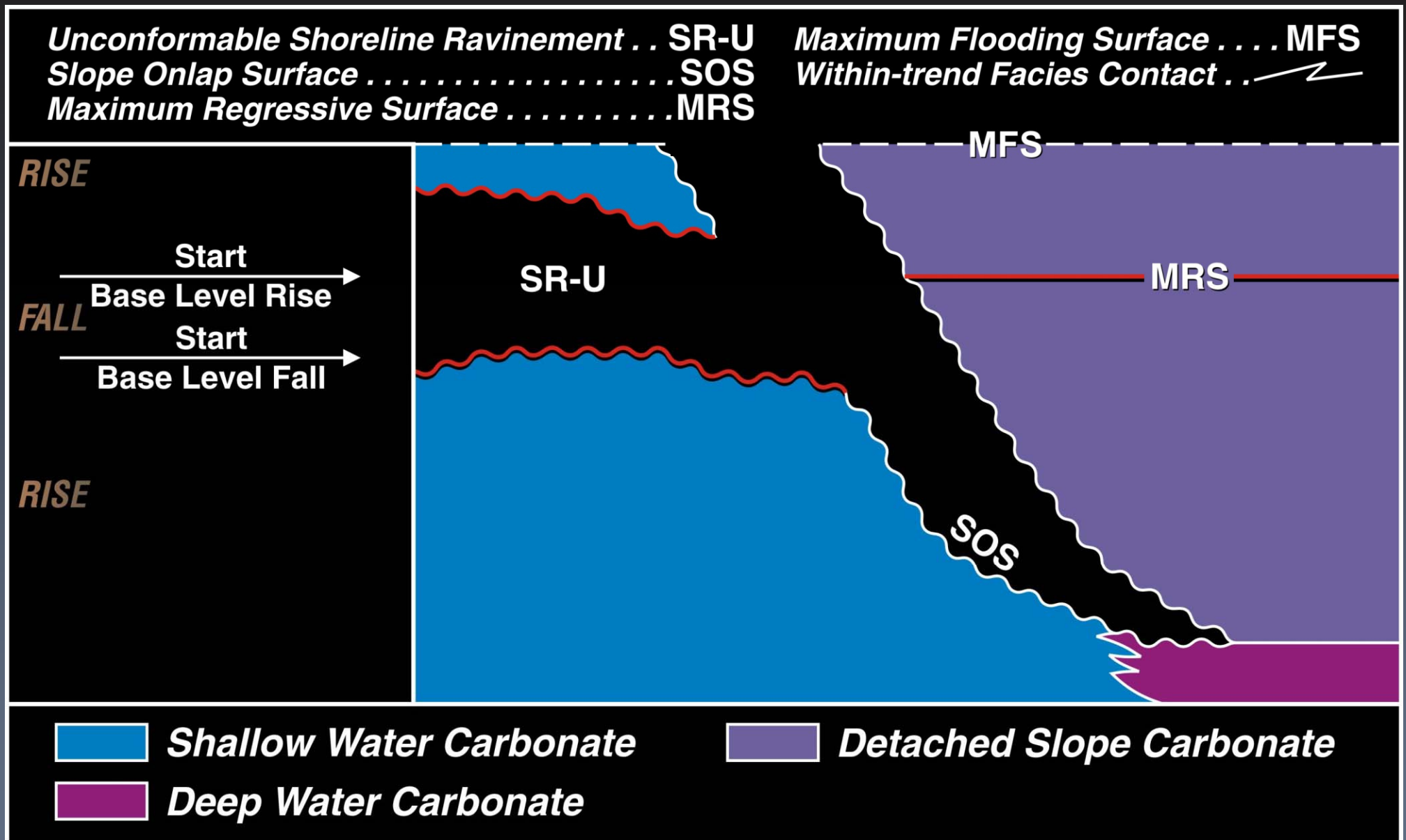


*Shallow Water Carbonate*

*Detached Slope Carbonate*

*Deep Water Carbonate*

# Wheeler Diagram



Sequence Stratigraphic Surfaces  
Reefal Carbonate

# Next Question

**Where's the  
Sequence  
Boundary**



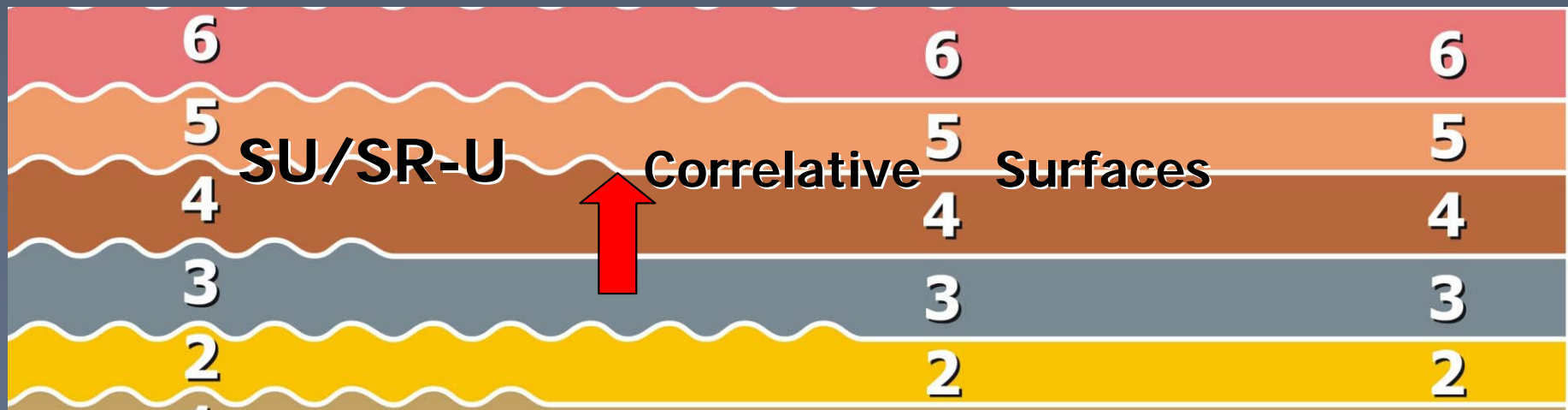
# Depositional Sequence

A depositional sequence is a stratigraphic unit **bound by subaerial unconformities and their correlative surfaces** (Van Wagoner et al, 1988).



# Correlative Surfaces

Correlative surfaces are sequence stratigraphic surfaces which join with the **end** of the SU/SR-U and with each other, so as to form a **single, continuous, through going boundary**.





Given that:

- 1) The correlative surfaces must adjoin to the basinward termination of the SU.
- 2) The Subaerial Unconformity reaches its maximum basinward extent at the end of base level fall (start base level rise).

**The correlative surfaces must develop at, or soon after, the start of base level rise to be able to join with the end of the SU/SR-U.**

**Acceptable**



Developed at or  
soon after start Rise



***Subaerial Unconformity***



***Correlative Surfaces***

The marginal unconformity (SU/SR-U) and the correlative surfaces must adjoin so as to form one continuous boundary.

**Acceptable**



Developed at or  
soon after start Rise

**Not  
Acceptable**



Developed  
during Fall



*Subaerial Unconformity*



*Correlative Surfaces*

The marginal unconformity (SU/SR-U) and the correlative surfaces must adjoin so as to form one continuous boundary.

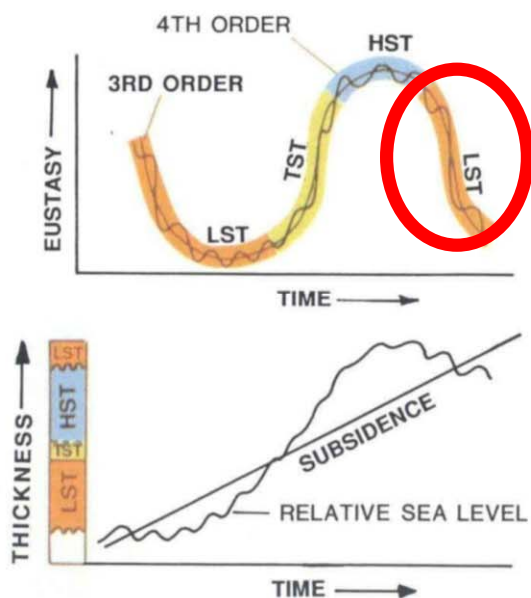
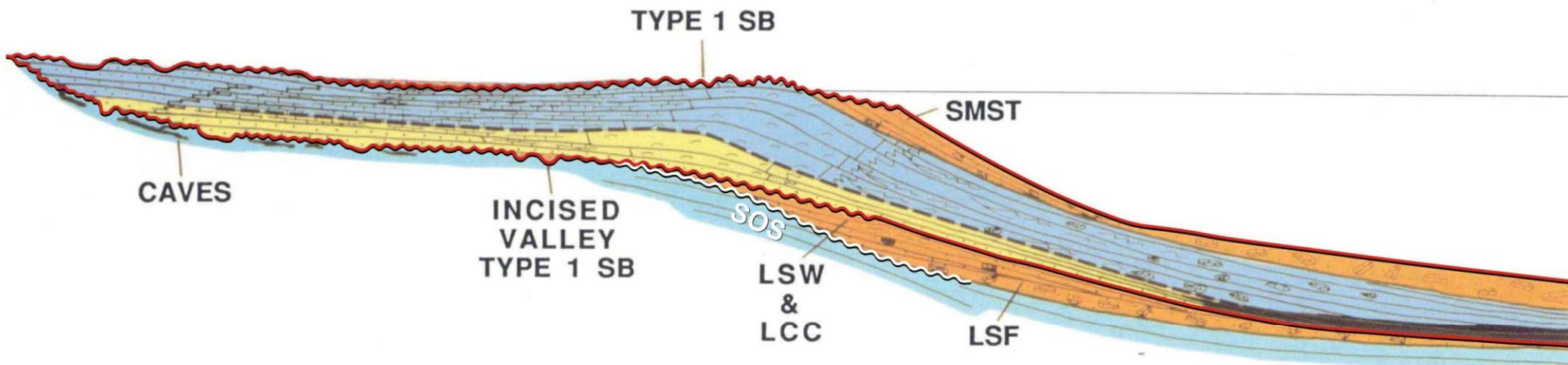
# Depositional Sequence Boundary Placement

Due to the requirement that the correlative surfaces portion of the SB develop at and soon after the start of base level rise:

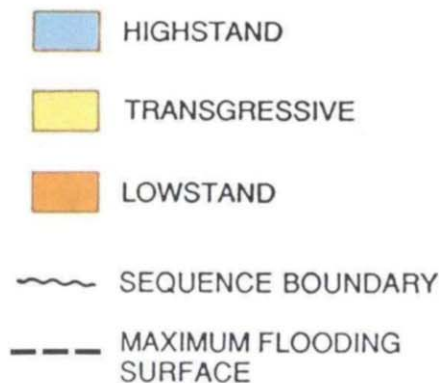
***"All sediments deposited during the previous base level fall must lie below the depositional sequence boundary."***



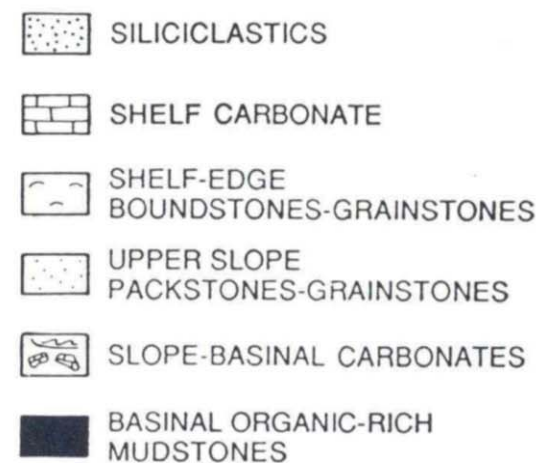
# DEPOSITIONAL SEQUENCE MODEL HUMID CARBONATE-SILICICLASTIC RIMMED SHELF



## SYSTEMS TRACTS



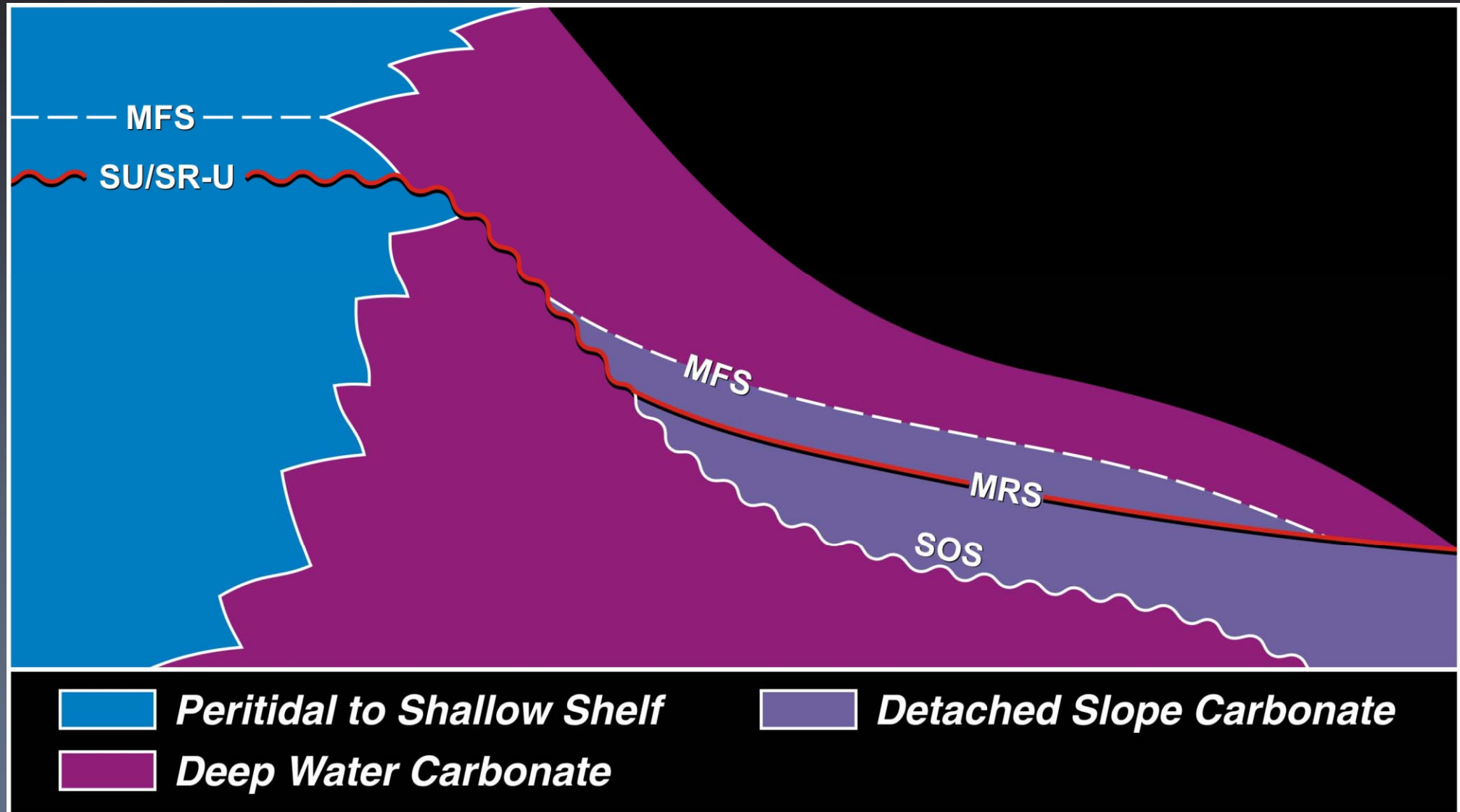
## LITHOFACIES



Handford and Loucks, 1993

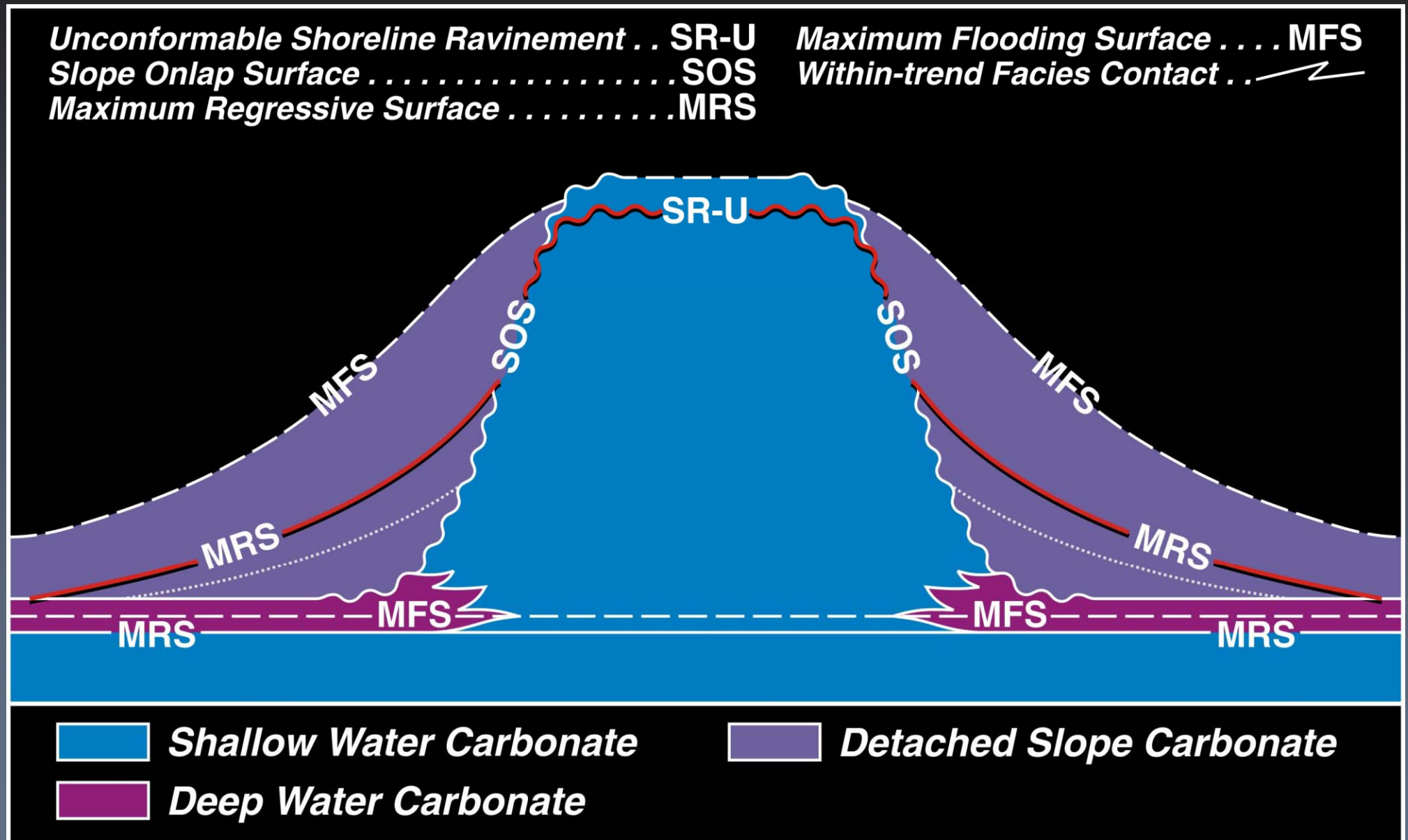
# Depositional Sequence Boundary Placement

# Sequence Stratigraphic Surfaces Carbonate Platform/Slope/Basin



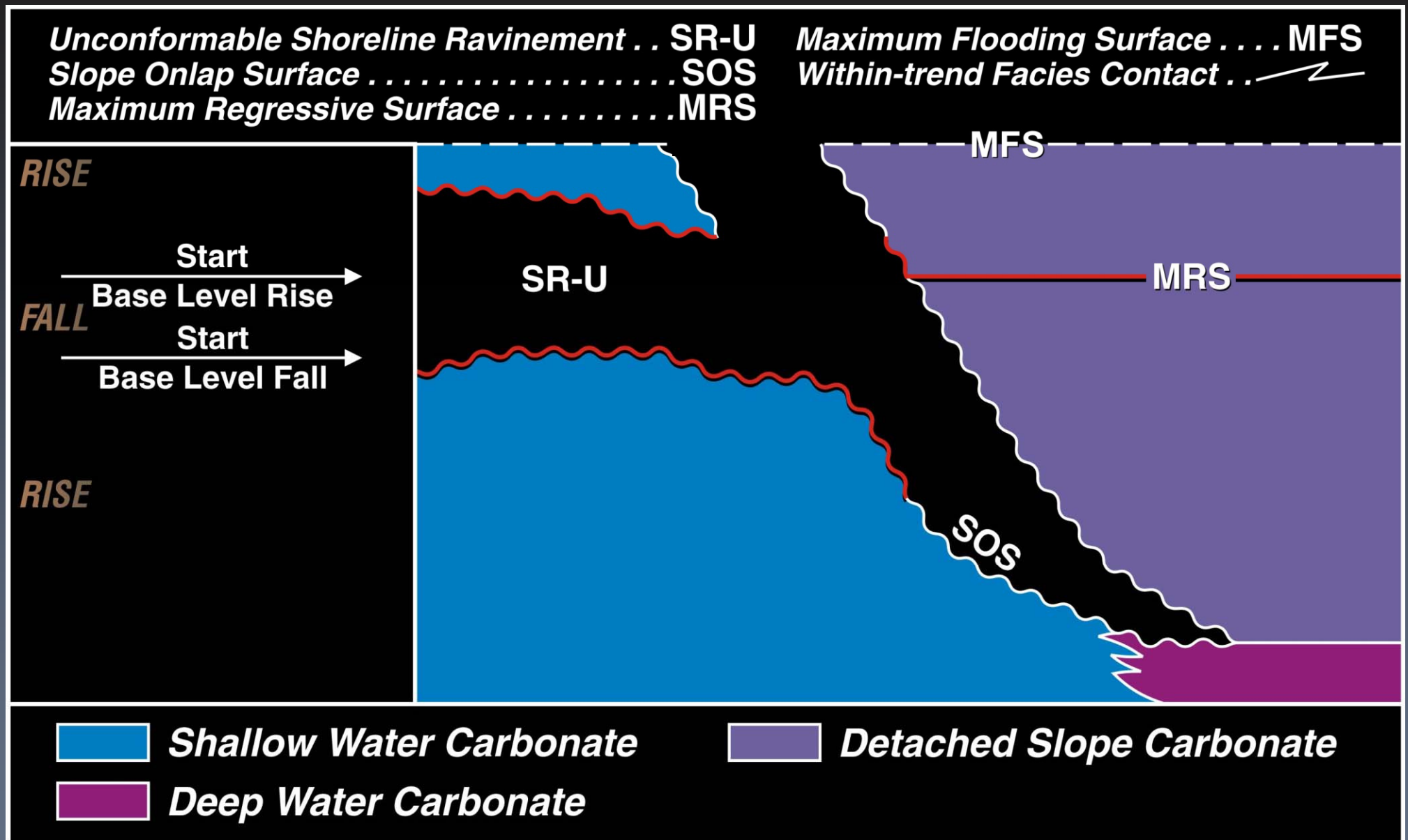
Depositional Sequence Boundary Placement

# Reefal Carbonate



# Depositional Sequence Boundary Placement

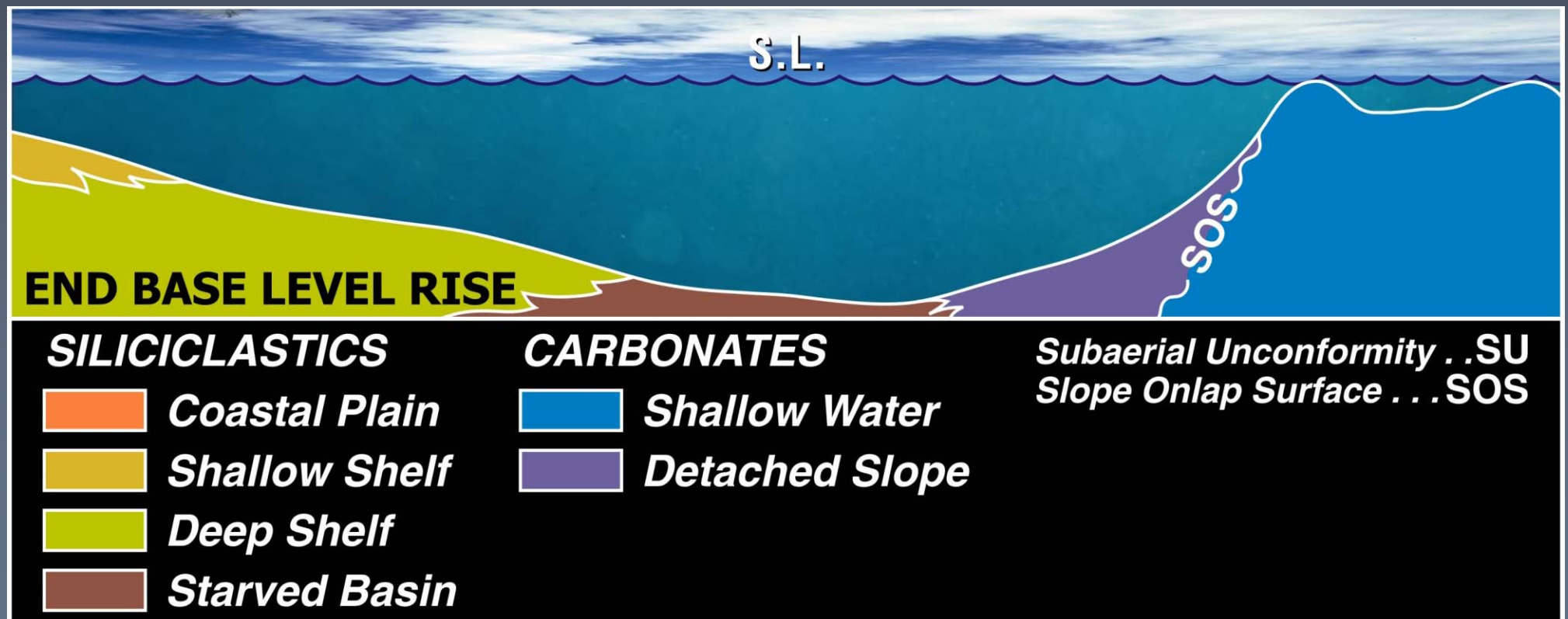
# Wheeler Diagram



Depositional Sequence Boundary Placement

**Sequence  
Stratigraphic  
Surfaces in Mixed  
Reefal Carbonates  
and Siliciclastics**







### SILICICLASTICS

- Coastal Plain
- Shallow Shelf
- Deep Shelf
- Starved Basin

### CARBONATES

- Shallow Water
- Detached Slope

Subaerial Unconformity . . SU  
Slope Onlap Surface . . . SOS



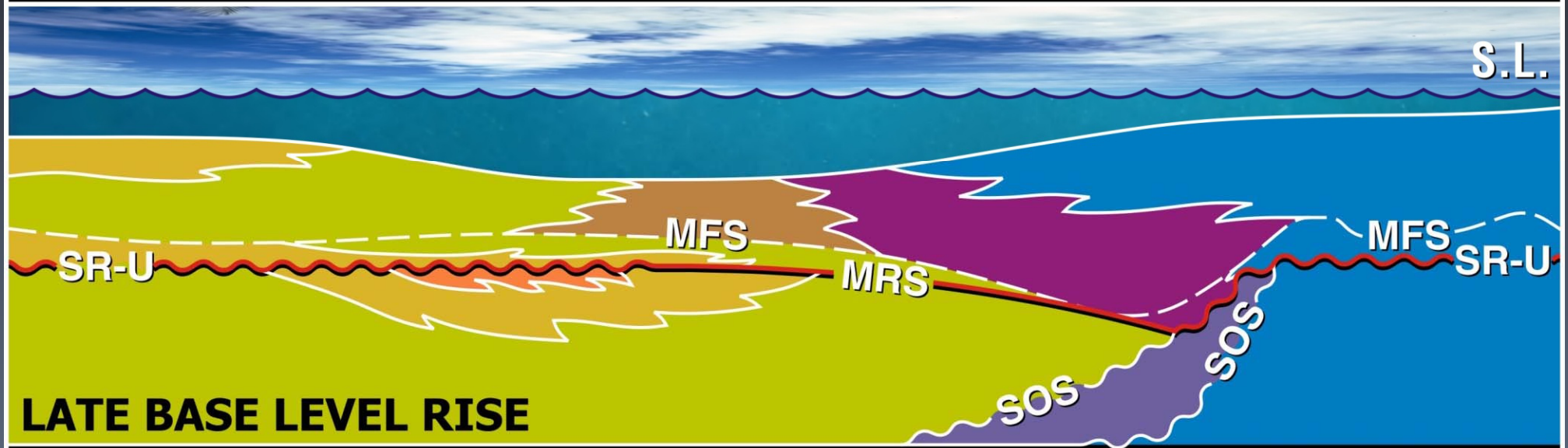


# Sequence Stratigraphic Model

## Mixed Reefal Carbonates and Siliciclastics

*Subaerial Unconformity . . . . . SU*  
*Unconformable Shoreline Ravinement . . SR-U*  
*Maximum Regressive Surface . . . . . MRS*

*Maximum Flooding Surface . . . . MFS*  
*Slope Onlap Surface . . . . . SOS*  
*Within-trend Facies Contact . . ↗*



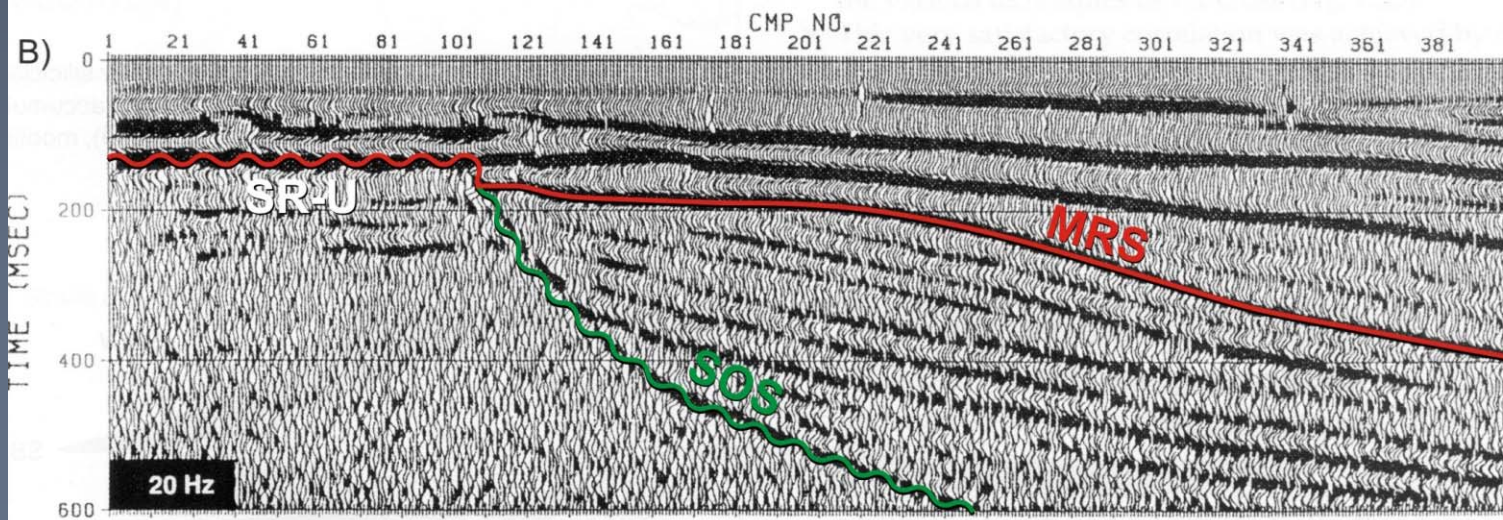
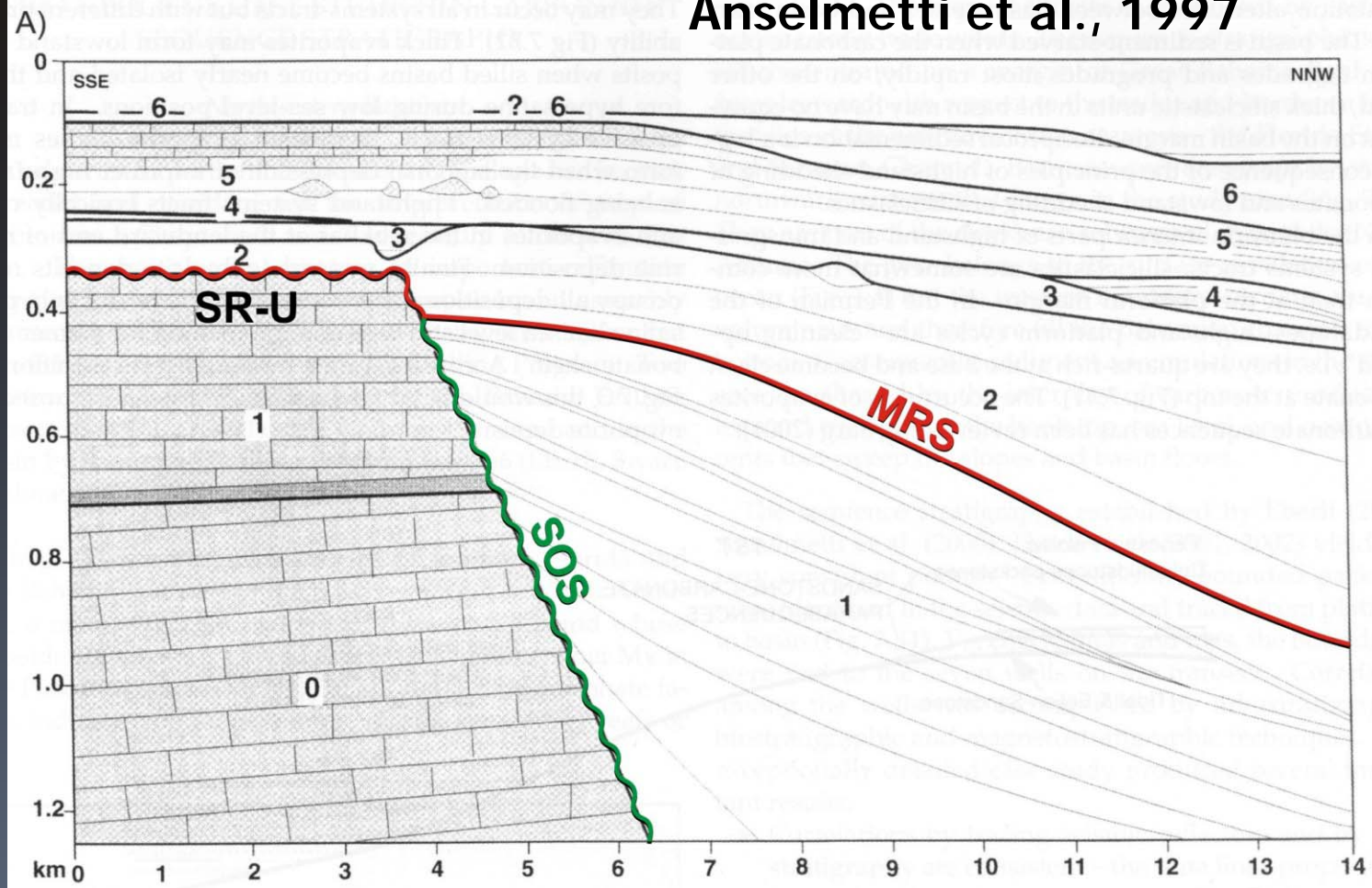
### SILICICLASTICS

- Coastal Plain*
- Shallow Shelf*
- Deep Shelf*

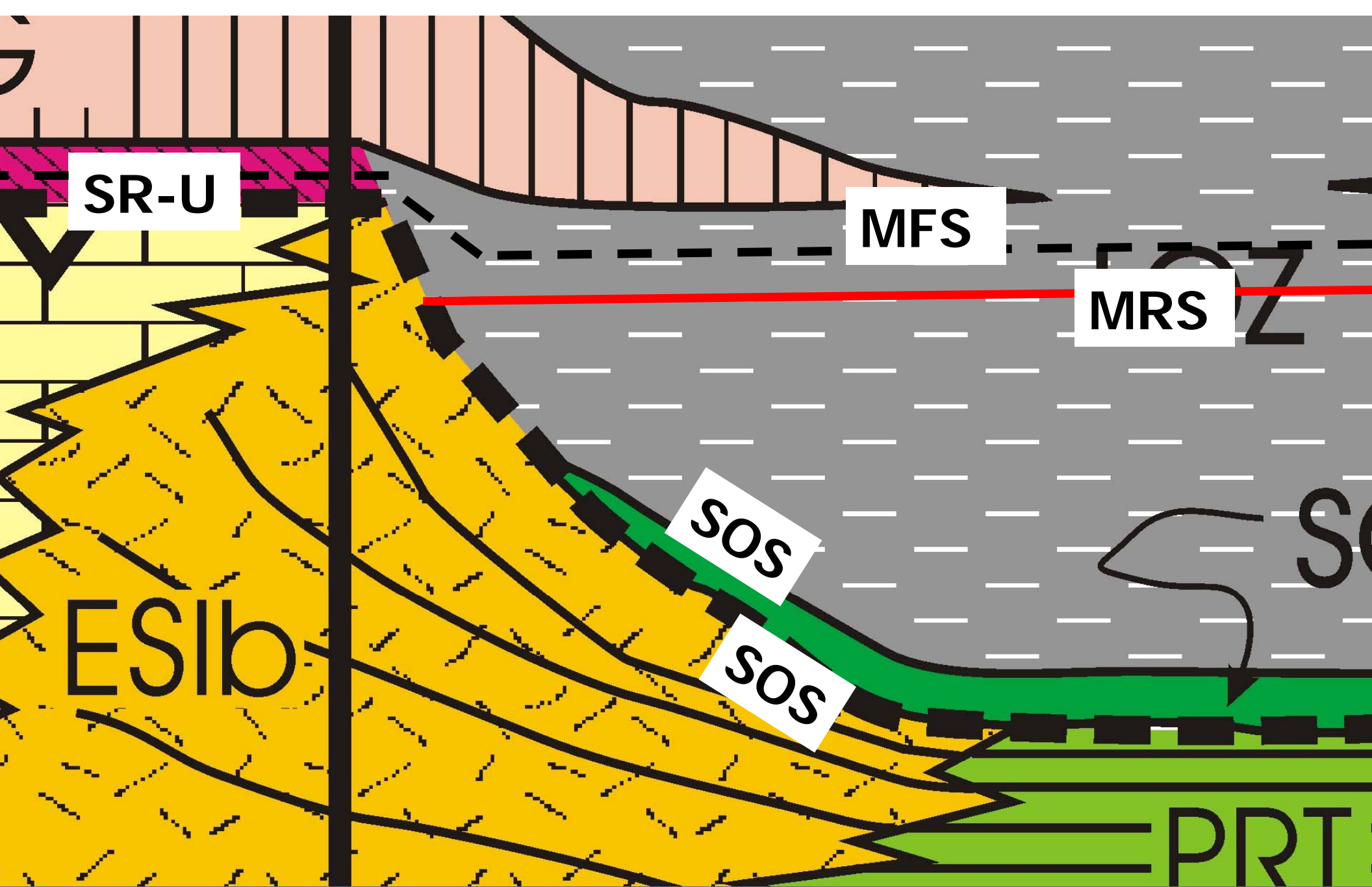
### CARBONATES

- Shallow Water*
- Detached Slope*
- Deep Water*
- Deep Water Marl*









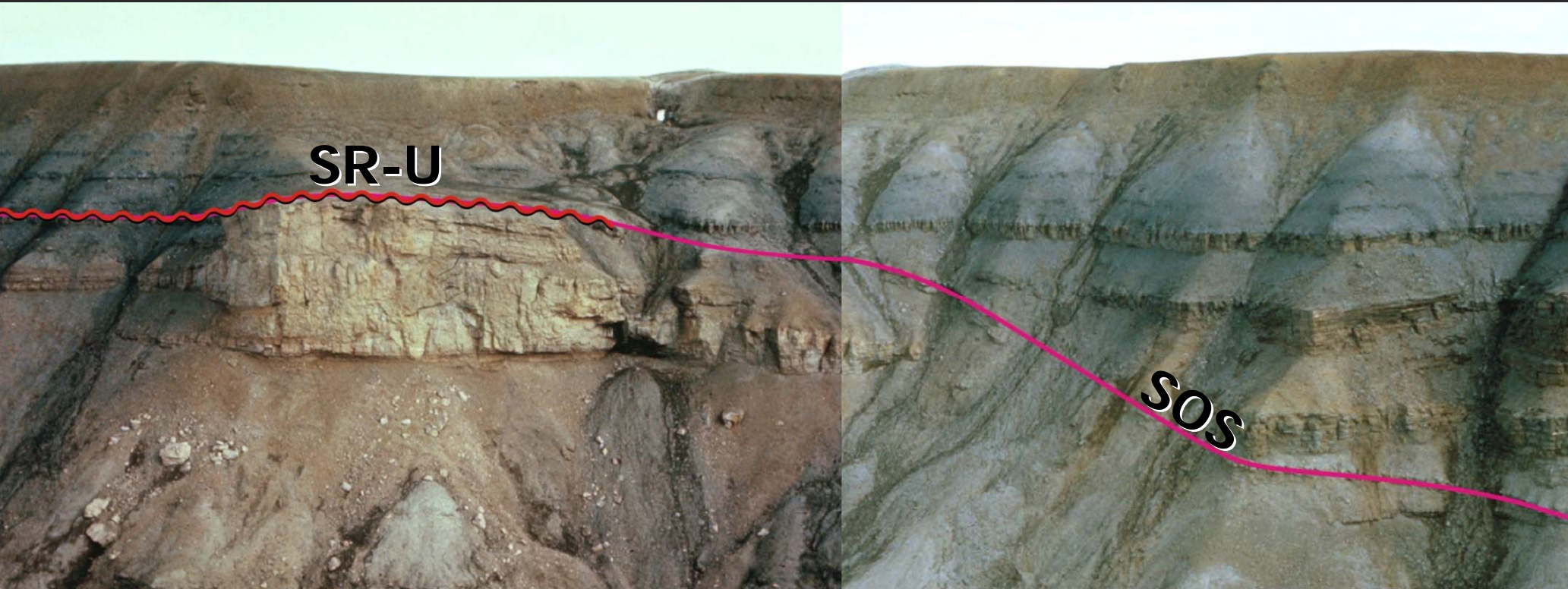
Ladinian Carbonate Platform, Lombardy Basin, Italy

Berra, 2007

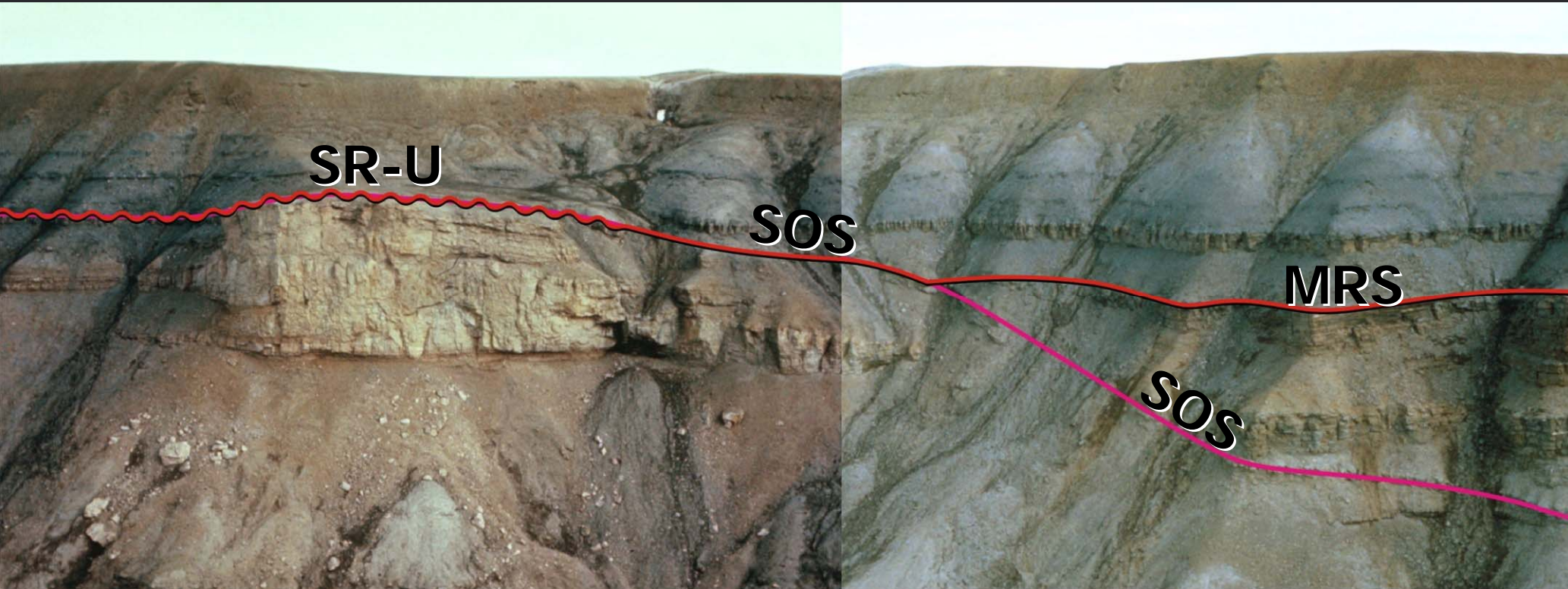


Correlating from **Reef** to **Siliciclastics**  
with Sequence Stratigraphy



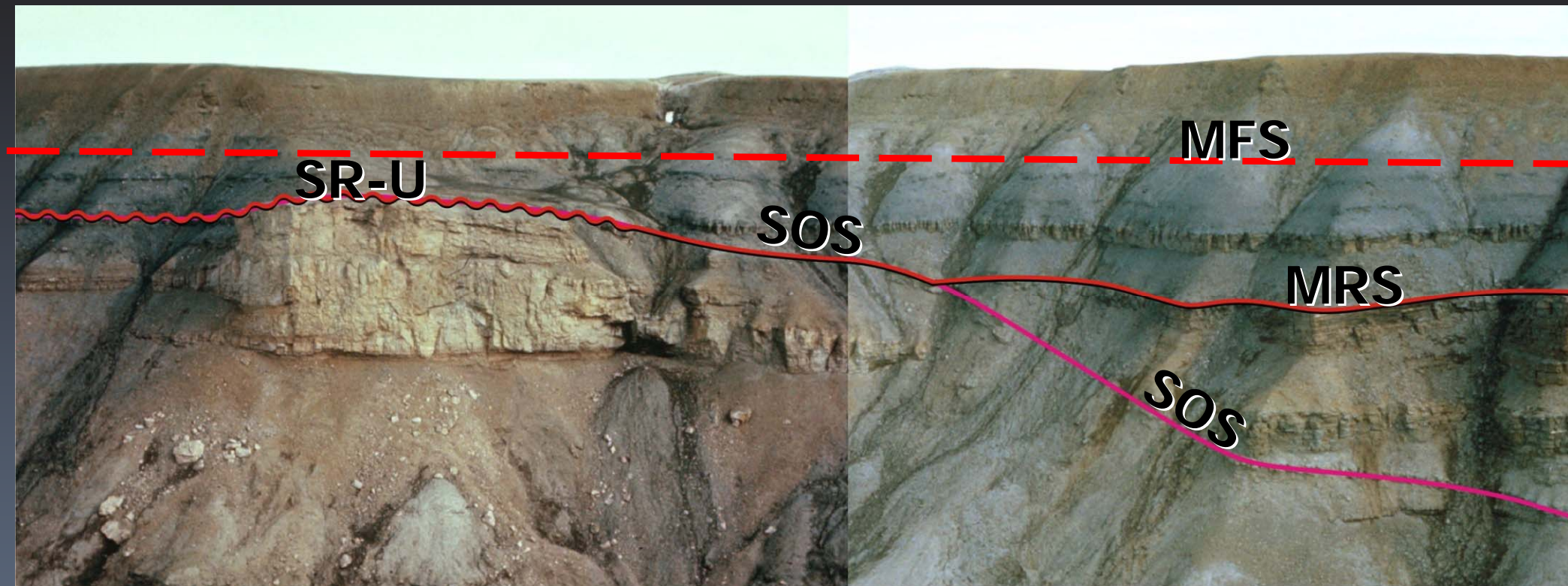


Correlating from **Reef** to **Siliciclastics**  
with Sequence Stratigraphy



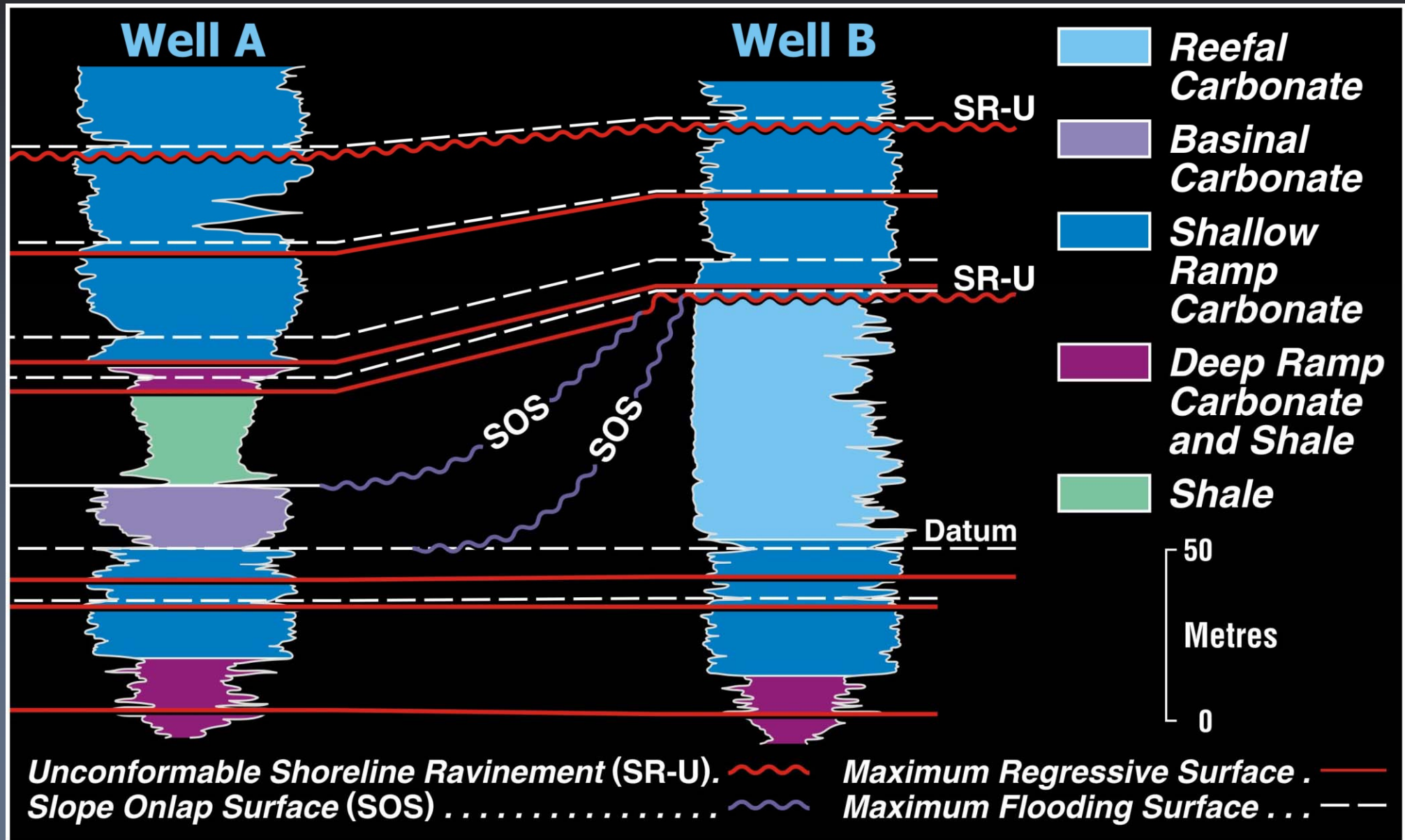
Correlating from **Reef** to **Siliciclastics**  
with Sequence Stratigraphy





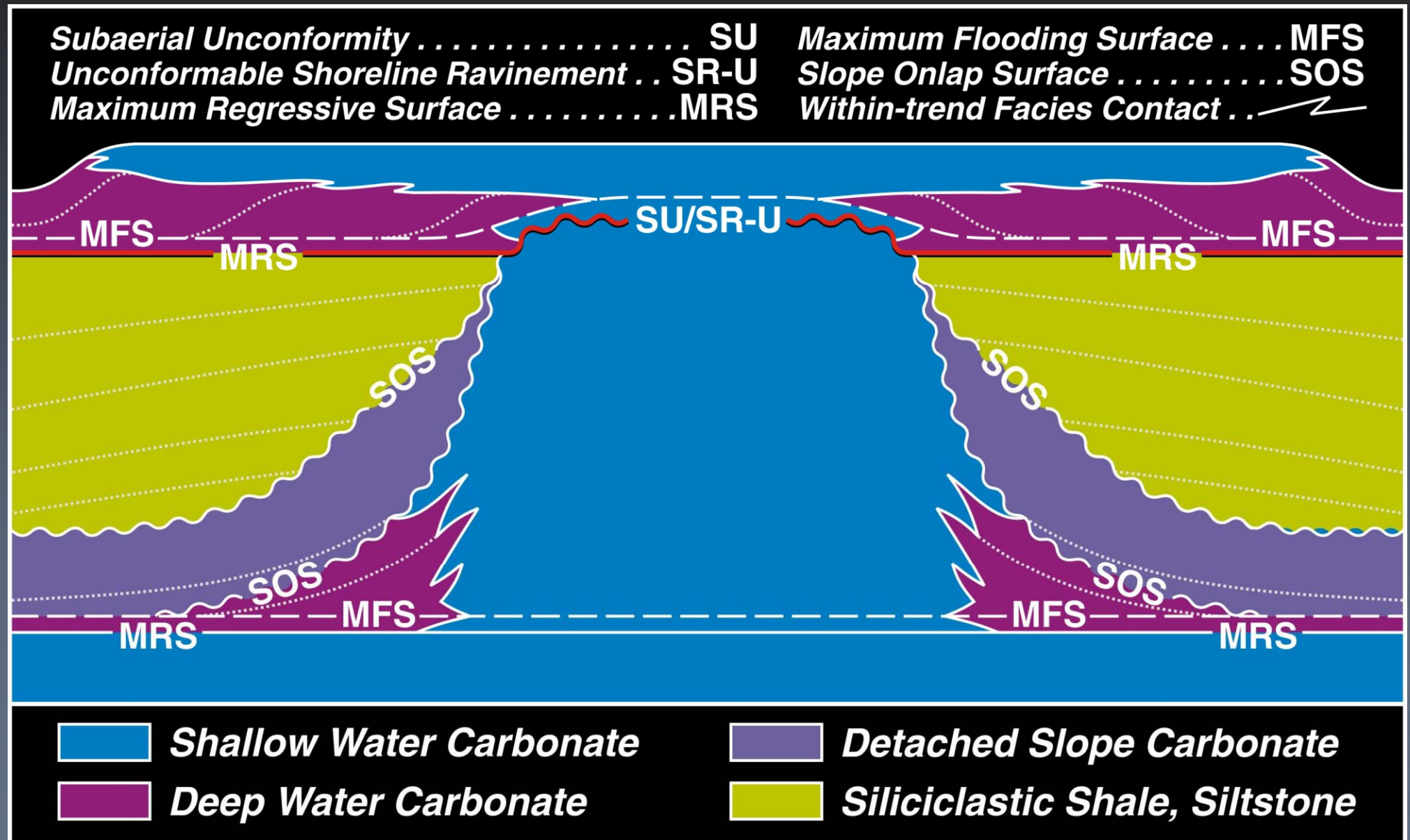
Correlating from **Reef** to **Siliciclastics**  
with Sequence Stratigraphy

# Subsurface Correlation from Reef to Siliciclastics with Sequence Stratigraphy





# Sequence Stratigraphic Surfaces – Reefal Carbonate and Adjacent Siliciclastics



**Thanks to: Geological Survey of Canada  
for continued support**





**Thanks to: Dave Sargent for  
assistance with slide preparation**

