

^{AV}Striving to Attain Formalized “Sequence Stratigraphic” Nirvana

**By
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Abstract

Since the earliest days of stratigraphy, there has been a great deal of interest in identifying stratigraphic units that cross traditional lithostratigraphic boundaries in order to delineate coeval sedimentary facies (depositional environments). Early attempts to develop this methodology were based on defining and correlating stratal surfaces that a few insightful workers observed crossing traditional lithostratigraphic boundaries. This correlation methodology blossomed with the advent of seismic stratigraphy and the observation that seismic reflections followed stratal surfaces and unconformities. Thus the informal chronostratigraphic methodology of correlating stratal surfaces is actually the cornerstone of sequence stratigraphy.

Over the last 25 years, there have been numerous attempts (allostratigraphic units/synthem) to formalize sequence stratigraphy. Unfortunately, these attempts have not focused on defining stratal-bounded units, but on defining “Unconformity-bounded” Units. Because unconformity-bounded units exist only to the limits of their bounding discontinuities, and other commonly defined stratal surfaces are excluded as boundaries, these units serve limited practical purpose and have not gained a wide acceptance.

If sequence stratigraphy is to transition from an informal to more formal methodology under the stratigraphic code, then a paradigm shift and bigger tent is also needed. Perhaps a shift from “discontinuity-bounded” to more flexible “surface-bounded” (Epi-stratigraphic) units could provide the framework and space to allow the large variety of differing “sequence stratigraphic” methodologies to live, prosper, and function under the stratigraphic code. Under the proposed framework, a user-defined “Episequence”, derived from the Greek work Epipoles meaning enclosing or bounding surface could be the fundamental stratal-bounded unit in a formal classification.



Striving to Attain Formalized “Sequence Stratigraphic” Nirvana

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Nirvana



The supreme happiness that comes when all passion, hatred, and delusion die out and the soul is released from the necessity of further purification.

The Merriam-Webster Dictionary

Introduction



Over the last 60 years, there have been numerous attempts to formalize “Sequence Stratigraphic” Methodologies within the Stratigraphic Code

- **Formats (Forgotson, 1957)**
- **Sequences (Wheeler, 1958 & 1959)**
- **Chronosomes (Shultz, 1982)**
- **Synthem (Salvador, 1987)**
- **Allostratigraphy (NACSN, 1993)**
- **Sequences (Salvador, 2000)**

ISSC WORKING GROUP ON SEQUENCE STRATIGRAPHY (1995-1999)

AGREED ON:

- **Abandonment of the terminology of Unconformity-bounded Units (Synthems) and Allostratigraphic Units**
- **Adoption of the Term Sequence as the main term for Unconformity-related units**

Introduction



ISSC WORKING GROUP ON SEQUENCE STRATIGRAPHY (1995-1999)

COULD NOT AGREE ON:

- What is a Sequence?
- If Sequences should be based solely on unconformities of subaerial erosion/nondeposition and their genetically related marine correlative conformities, or other discontinuity surfaces
- If Unconformity-related Units should be carried beyond the limits of distinct discontinuity
- What is a discontinuity?
- If condensed sections represent discontinuities or slow continuous deposition

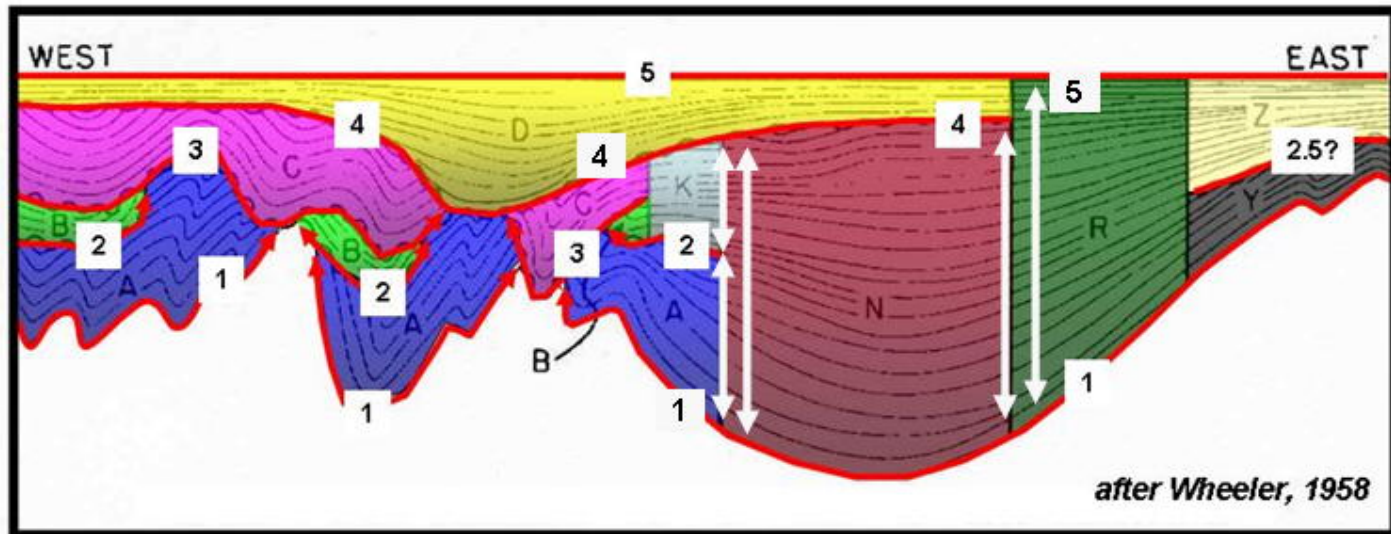
Conclusion

MAYBE WE SHOULD

- Forget about the focus on Unconformity-related Units
- Don't worry about what is a Sequence or what is a Discontinuity
- Get back to the basics
- Build on what we all can fundamentally agree on
- Map surfaces &
- Define surface-bounded stratigraphic units

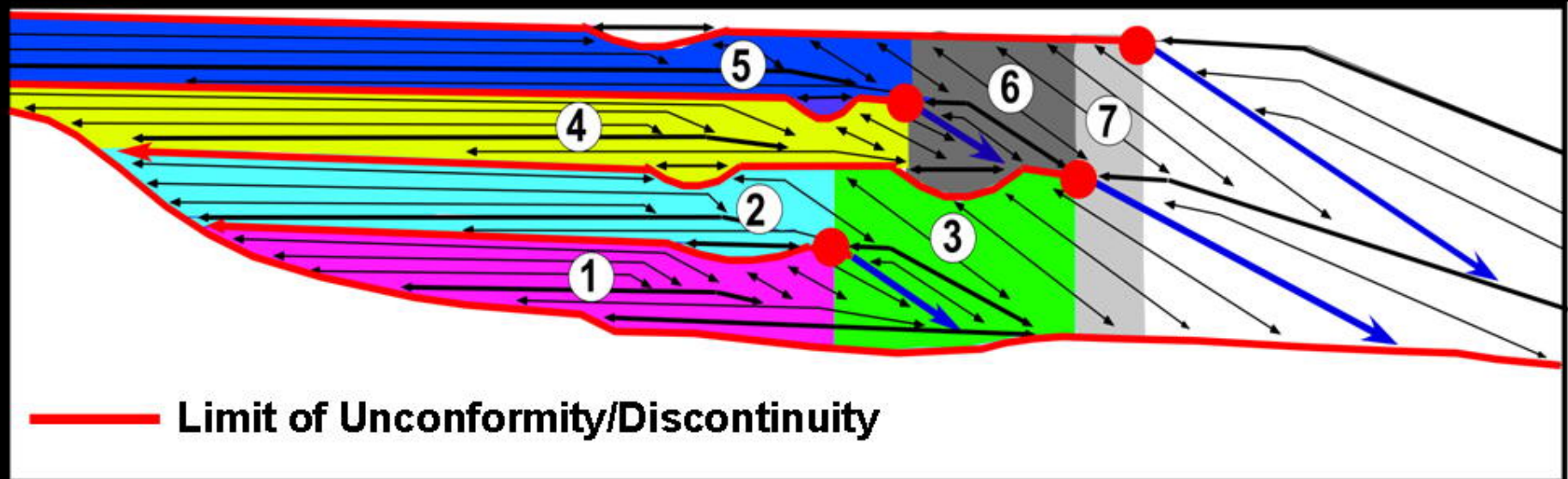
Unconformity-bounded Units

GENERALIZED CORDILLERAN MISSISSIPPIAN-TRIASSIC UBU'S



- Units extend only to limits of bounding unconformities
- As one Unconformity ends, New Unconformity-bounded Unit defined

“An unconformity-bounded unit is a body of rock bounded above and below by specifically designated discontinuities in the stratigraphic succession (angular unconformities, disconformities, and so on), preferably of regional or interregional extent. Being bounded by stratigraphic discontinuities is the single diagnostic criterion used to establish and recognize unconformity-bounded units: they should be extended only as far as both of its bounding discontinuities are identifiable.” (Salvador, 1987, p.232)



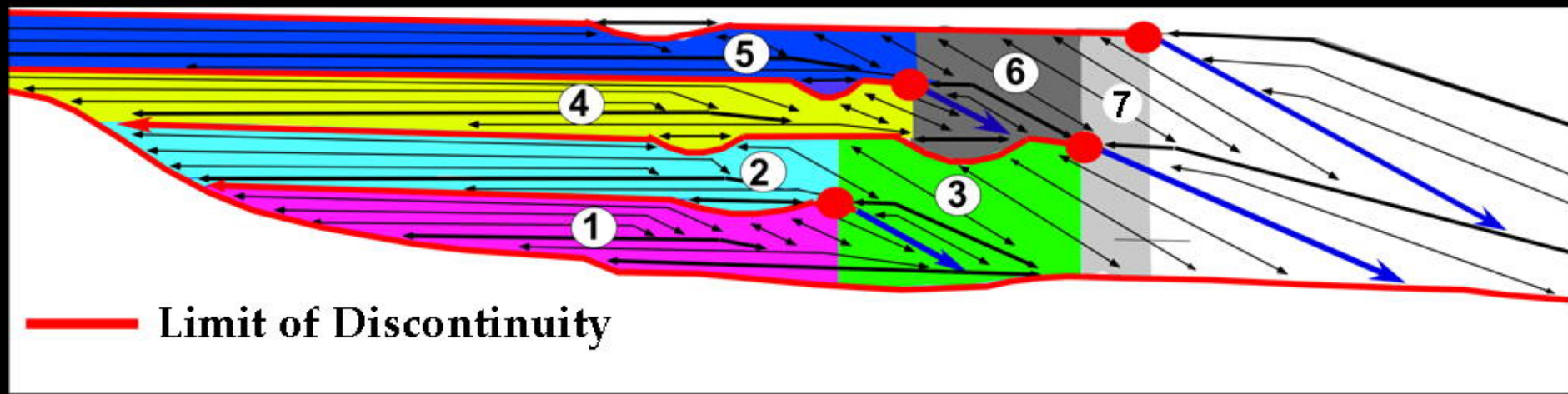
- Units extend only to limits of bounding unconformities
- As Unconformity ends, New Unconformity-bounded Unit defined

Allostratigraphic Unit

NACSN, 1983



A mappable stratiform body of sedimentary rock that is defined and identified on the basis of its bounding discontinuities. Allostratigraphic Units, in order of decreasing rank are allogroup, alloformation, and allomember. The fundamental unit is the alloformation (NACSN, 1983).



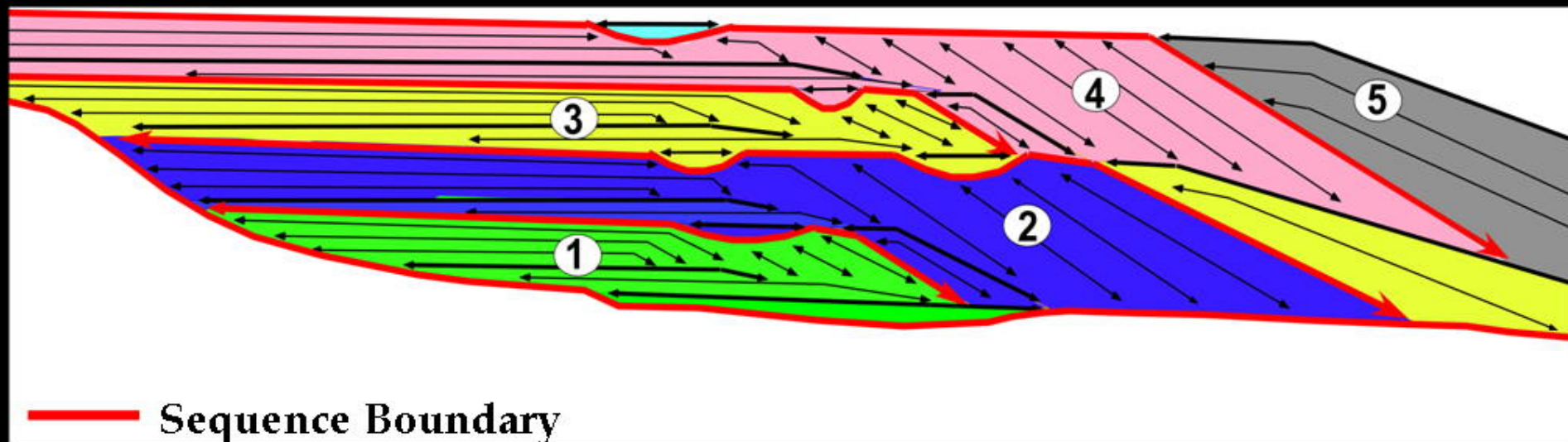
- Units extend only to limits of bounding discontinuities
- As discontinuity ends, New discontinuity-bounded Unit begins

Depositional Sequence

Mitchum and others, 1997



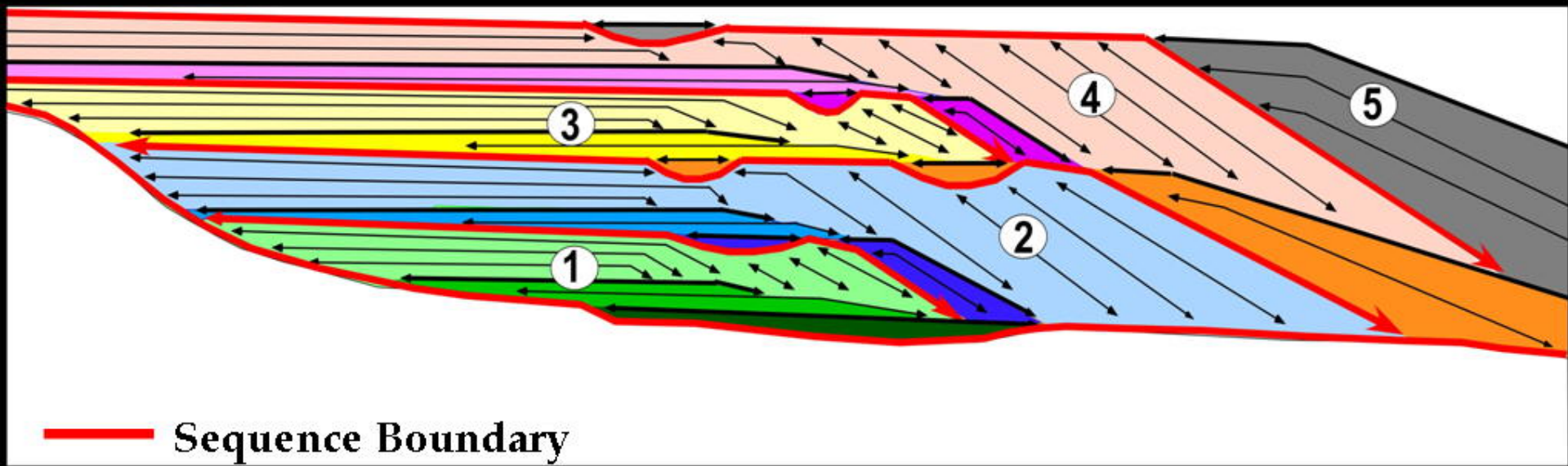
“....A relatively conformable succession of strata bounded at its top and base by unconformities or their correlative conformities.”



- **Stratal Unit Extends Beyond Limit of Unconformity.**
- **Sequence Boundaries defined by unconformities & their correlative conformities.**
- **The concept of the Correlative Conformity is a major step change for creating 3-d surface-bounded volume of strata**

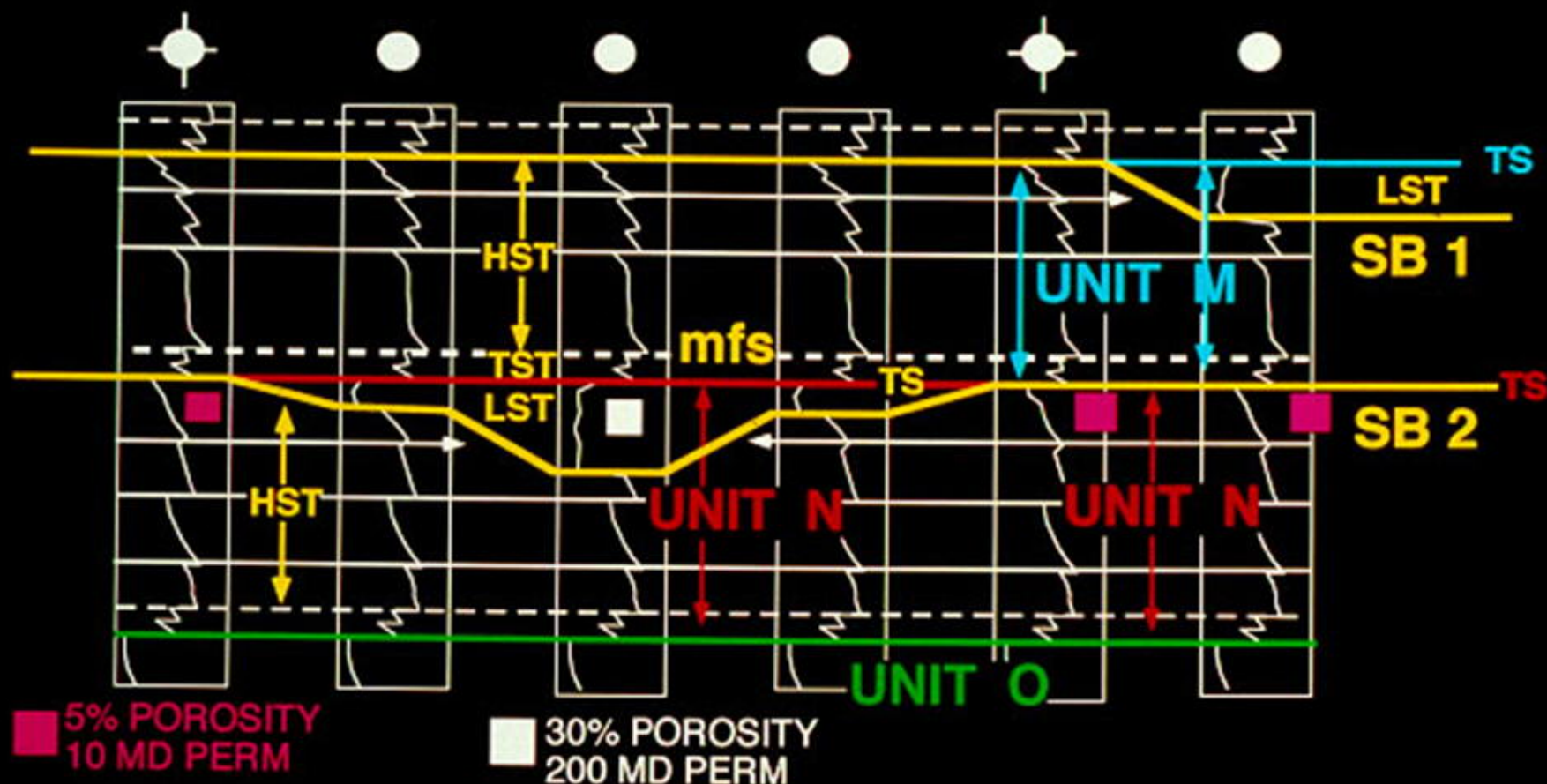
Depositional Sequence

Van Wagoner & others (1988, 1990)



- Hierarchy of Stratal Surfaces (bed, bedset, parasequence, parasequence set, etc.)
- Depositional Sequences contain 3 distinct stratal compartments (Systems Tracts)
- Key Stratal Surfaces (Sequence Boundaries, Transgressive & Maximum Flooding Surfaces) define systems tracts
- Transgressive and maximum flooding surfaces are not disconformities (surfaces)

Utility of Depositional Sequences

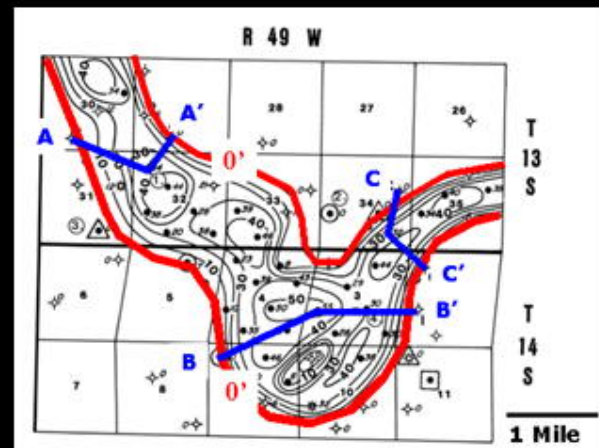
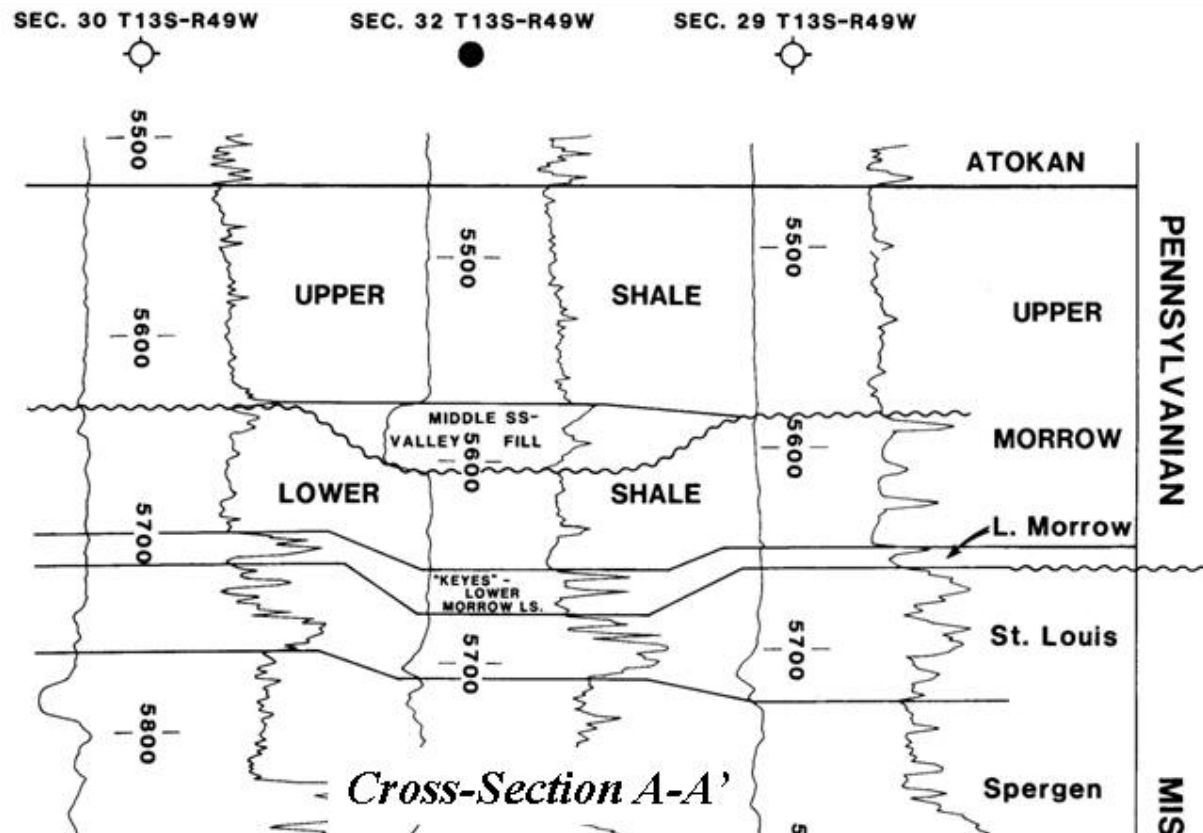


Explaining and predicting the Distribution of Reservoir Quality
Paralic Sands within Classic Lithostratigraphic Units

Utility of Depositional Sequences



Distribution of The Middle Morrow Sandstone at Sorrento Field, Kansas

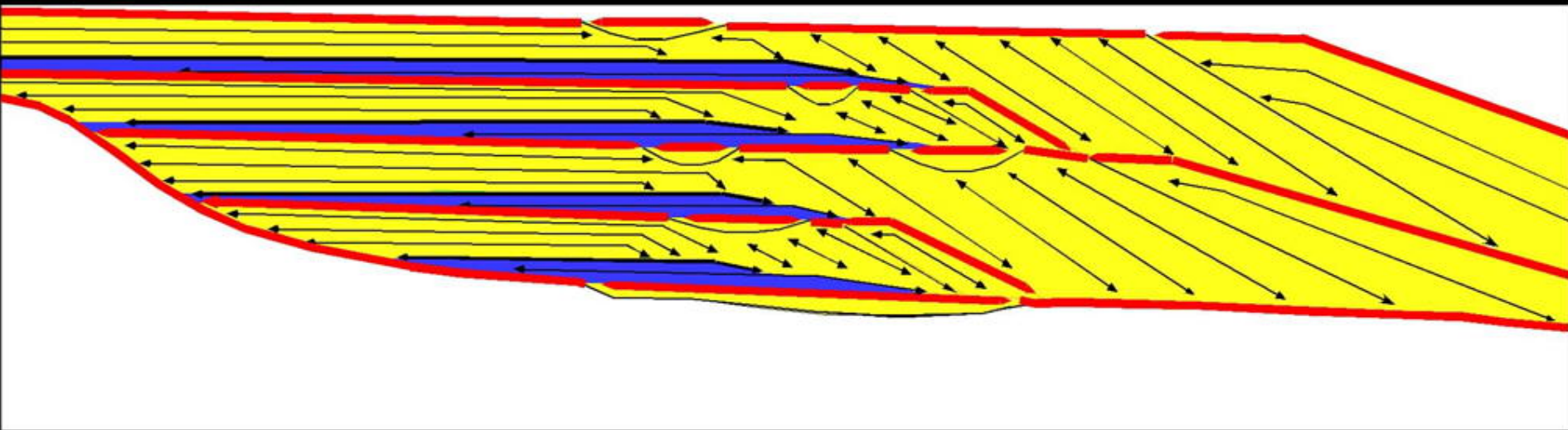


After Sonnenberg, MacKenzie, & McKenna (1991)

Can Be Used to Explain and Predict the Irregular Distributions of
Classic Lithostratigraphic Units
(The Concept of Incised Valleys)

T-R Sequences

(Embry, 1993)



Transgressive Deposits



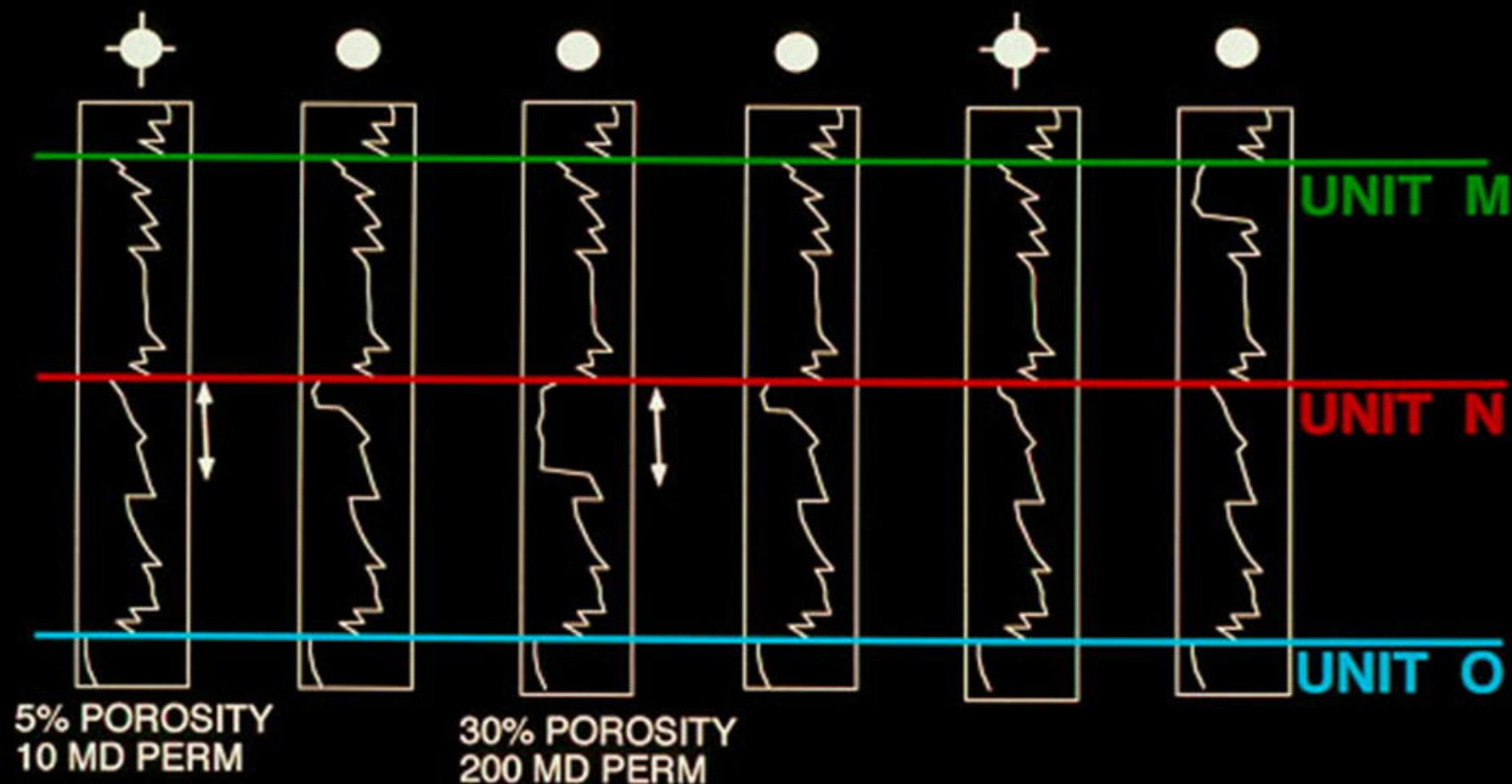
Regressive Deposits



T-R Cycle Boundaries

- Stratigraphic Record Consists of Transgressive-Regressive Cycles (T-R Sequences)
- T-R Sequences are bounded by Transgressive Surfaces/Subaerial Unconformities/ & Correlative Conformity
- Based on a distinct mappable surface
- Primary Methodology Utilized by most geoscientists in the subsurface to subdivide Sand-prone Marginal-marine Successions

T-R SEQUENCES

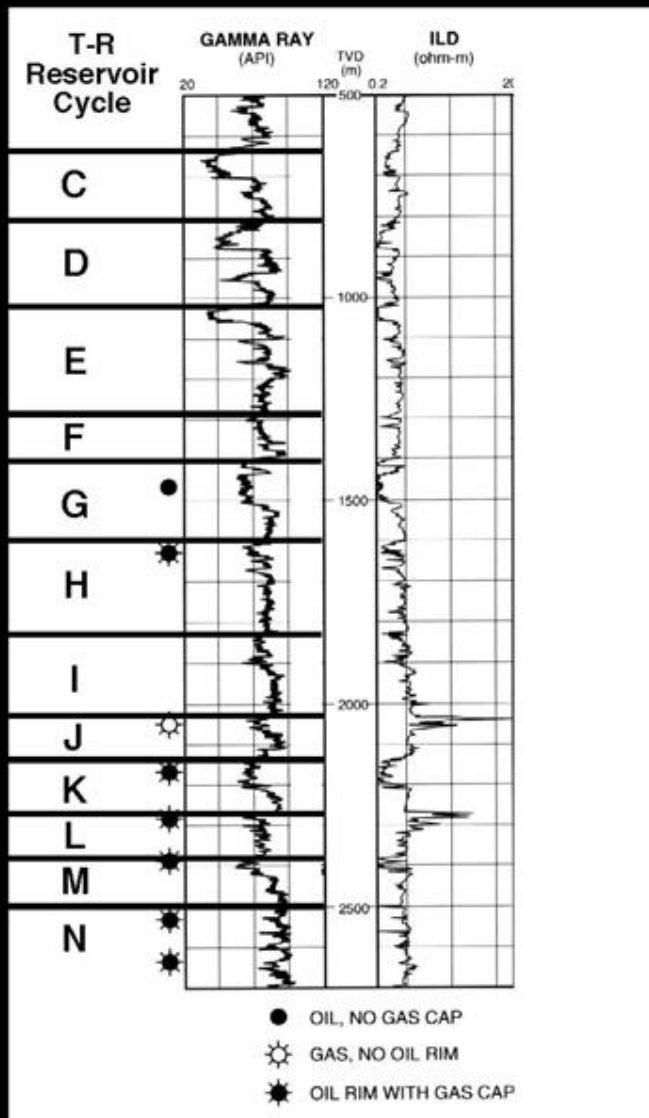


Transgressive (Flooding) Surfaces are commonly used as the Boundaries for Paralic Reservoirs Units in the subsurface and in outcrop

T-R Sequences



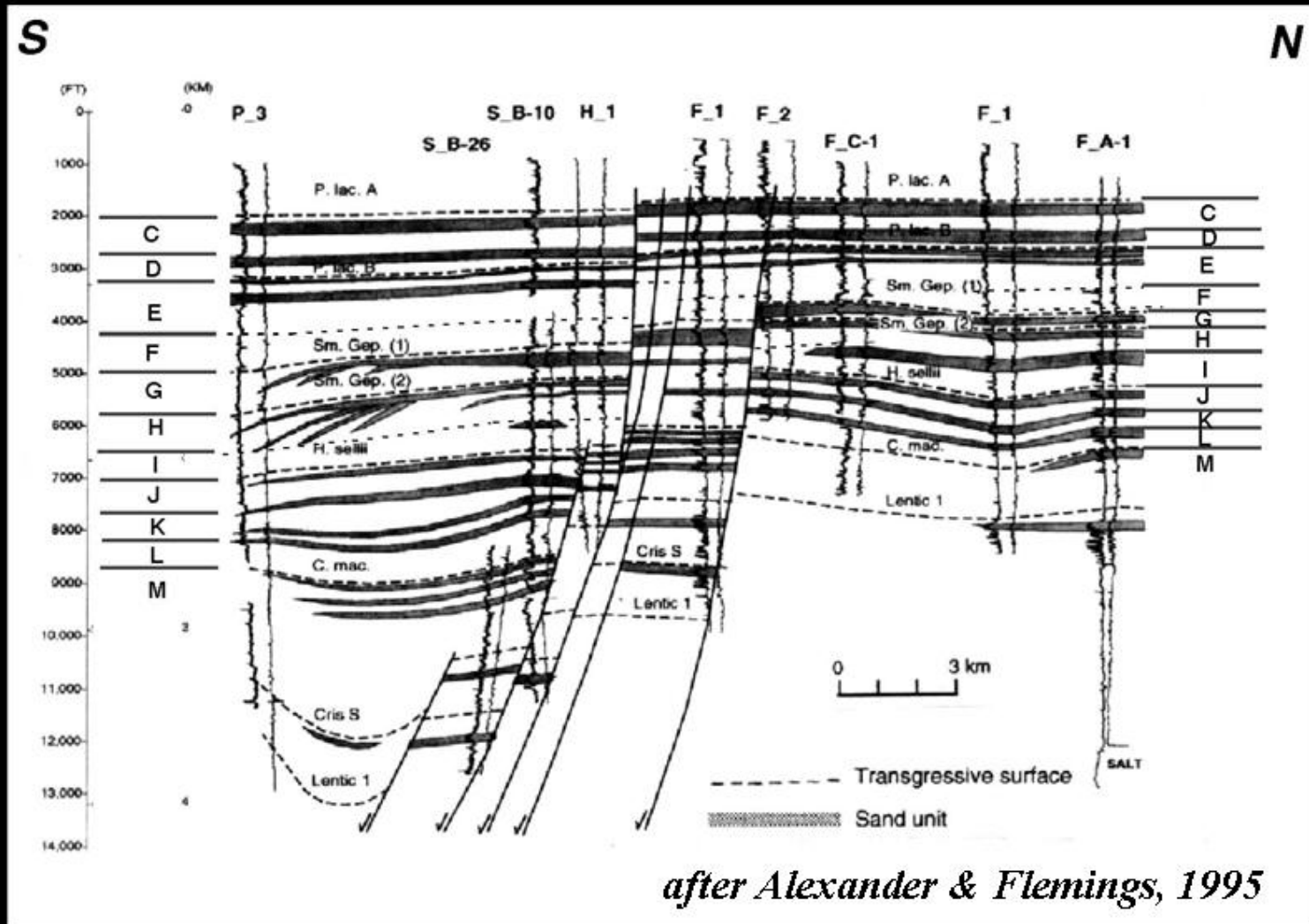
Eugene Island 330



**Transgressive
Surfaces form the
boundaries of most
Paralic Reservoir
Units in the Gulf of
Mexico**

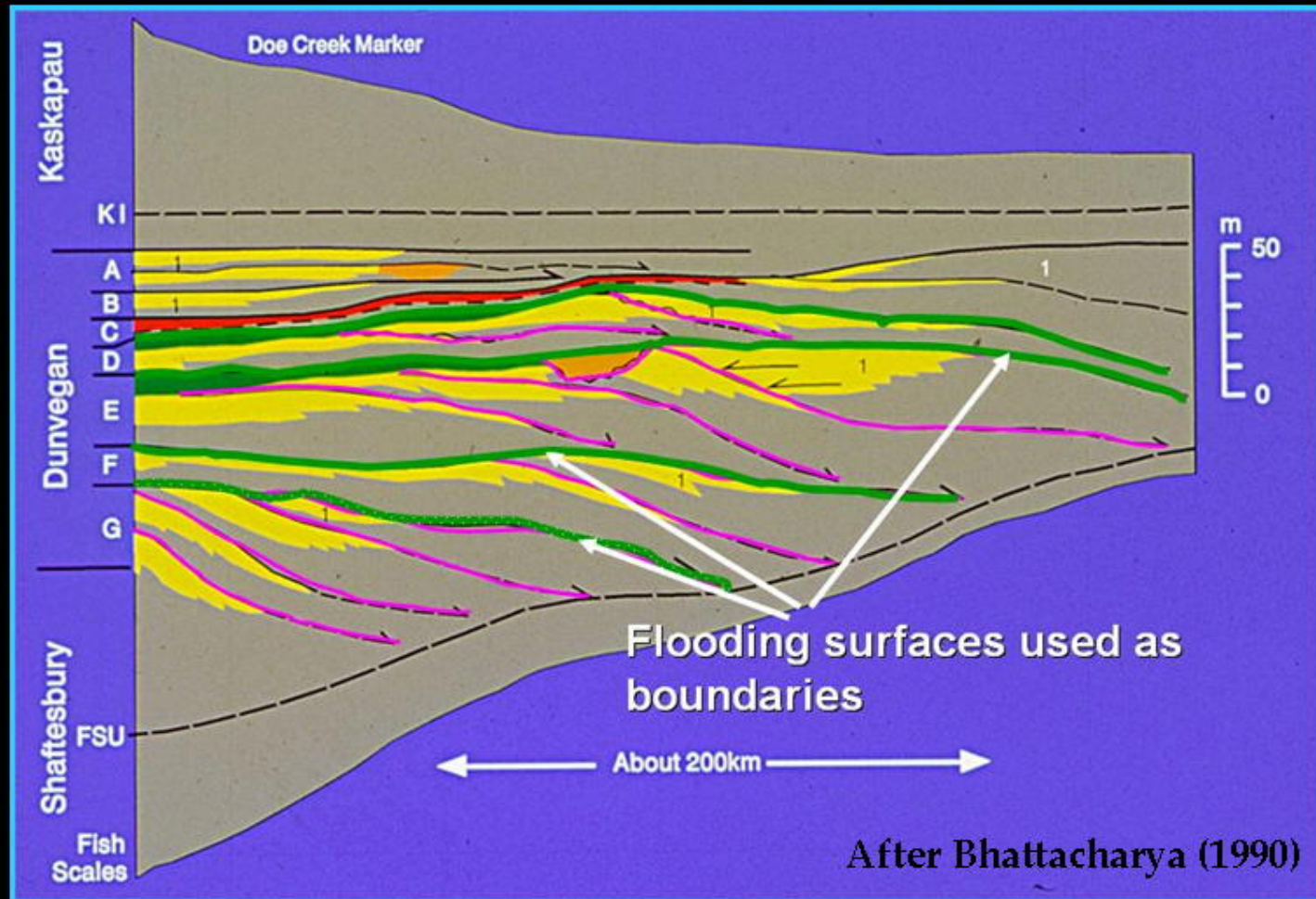
after Alexander & Flemings, 1995

Transgressive Surfaces



provide a framework for field-wide correlations

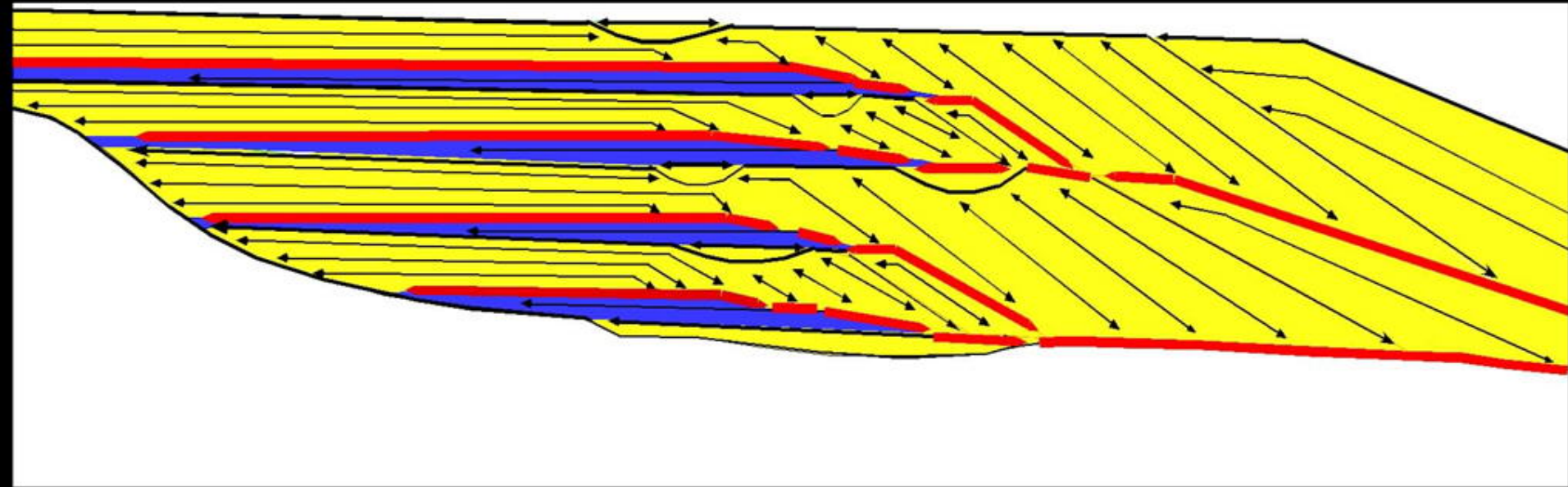
T-R Sequences



Transgressive (Flooding) Surfaces were used to define the members of the Cretaceous Dunvegan Formation in outcrop and in the shallow subsurface in Western Canada

Genetic (R-T) Sequences

(Galloway, 1989a&b)



Regressive Deposits



Transgressive Deposits



R-T Cycle Boundaries

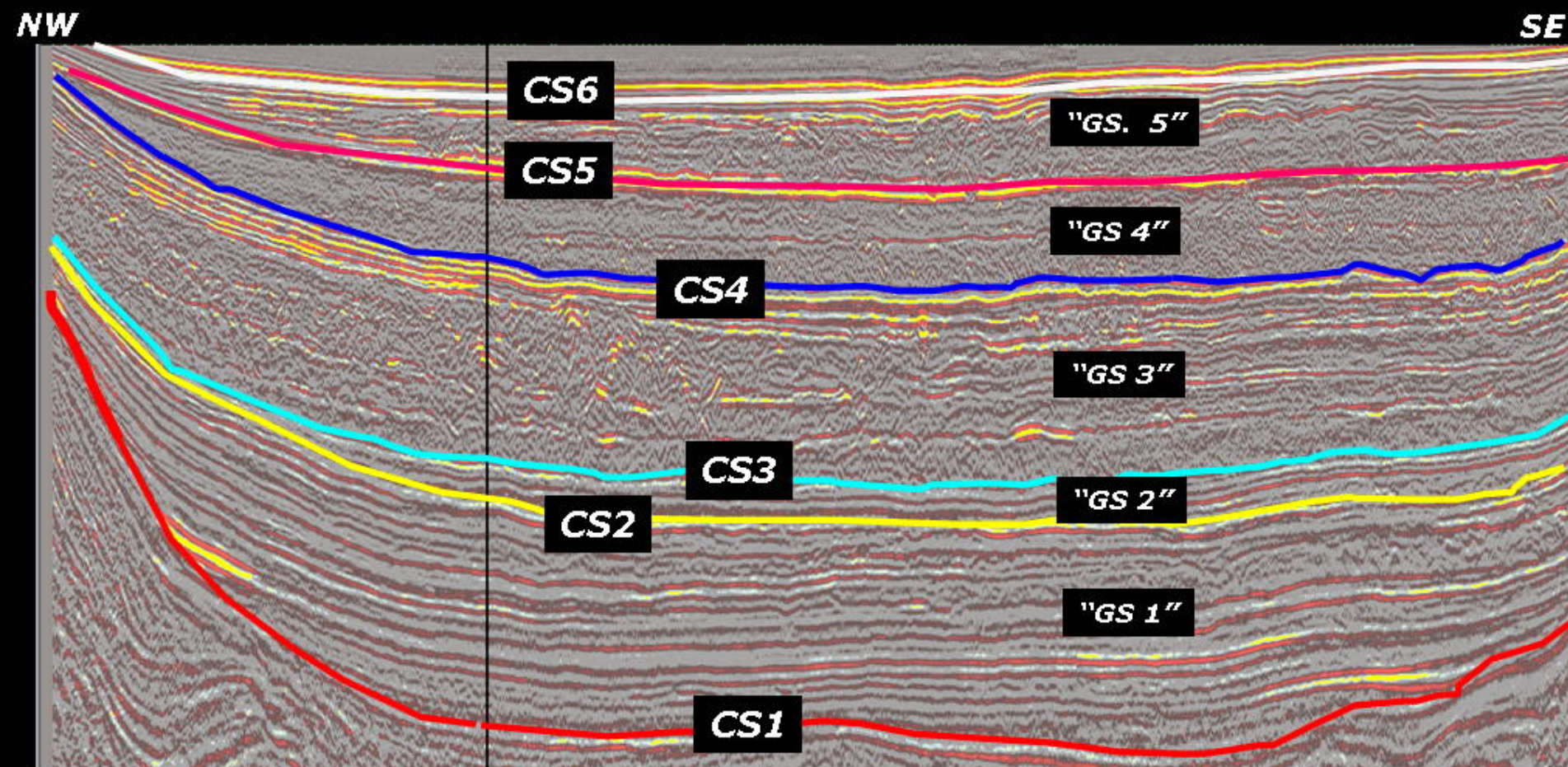
- Stratigraphic Record Consists of Regressive-Transgressive (R-T) Cycles (Genetic Sequences)
- Genetic Sequences are bounded by Maximum Flooding Surfaces
- These surfaces are distinctive (logs/fauna) and easily mappable (laterally continuous)
- In this paradigm, mfs's are discontinuities
- Traditional boundaries mapped on Seismic in Deep Water Basins around the World

Genetic (R-T) Sequences

Deep-water GOM



Condensed Sections produce the most continuous reflections in deep-water successions



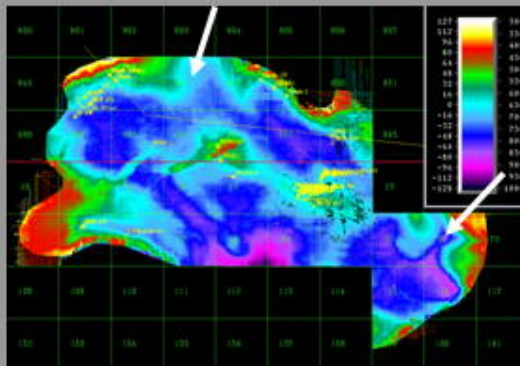
Genetic (R-T) Sequences

Deep-water GOM

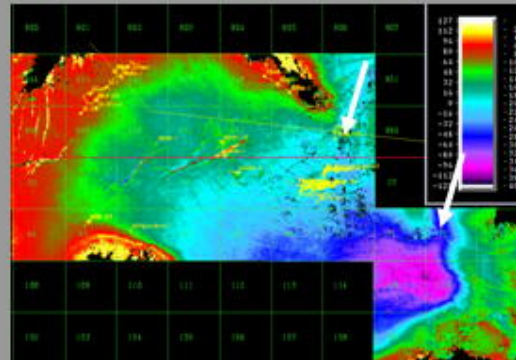


And allow the constructions of isochron maps which reveal subtle variations in basin configuration through time

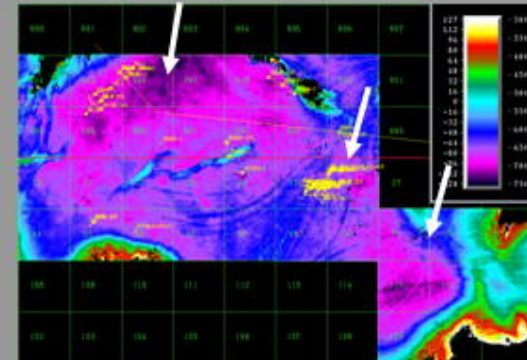
Genetic Sequence 1



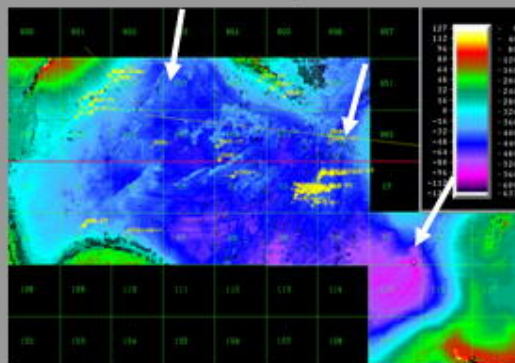
Genetic Sequence 2



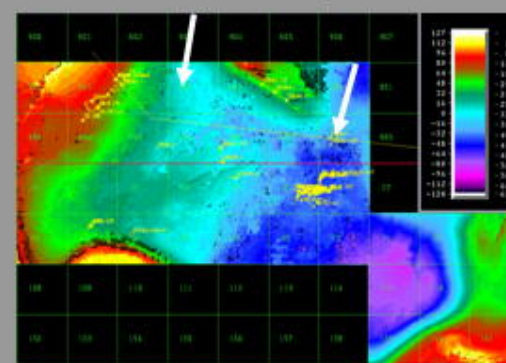
Genetic Sequence 3



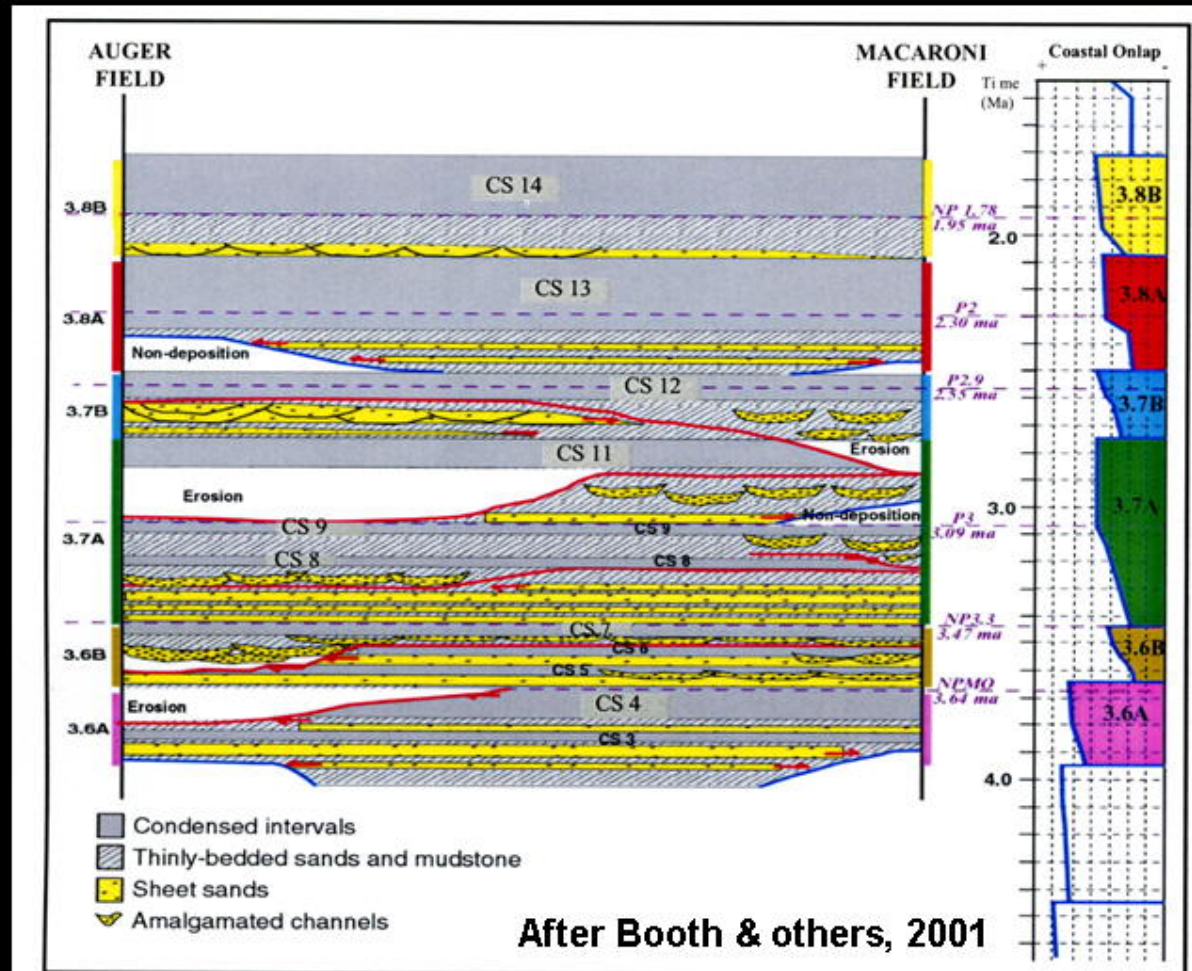
Genetic Sequence 4



Genetic Sequence 5



Genetic (R-T) Sequences

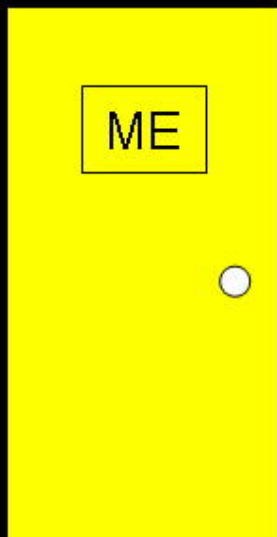


Condensed Sections provide the framework for stratal correlations throughout a basin

So, which is the best methodology ?

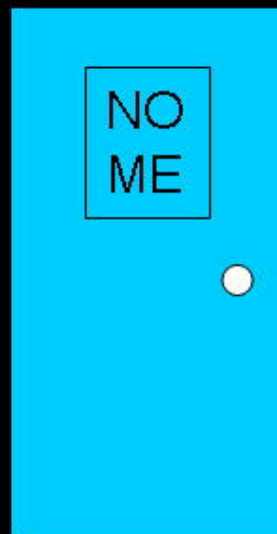


Door 1



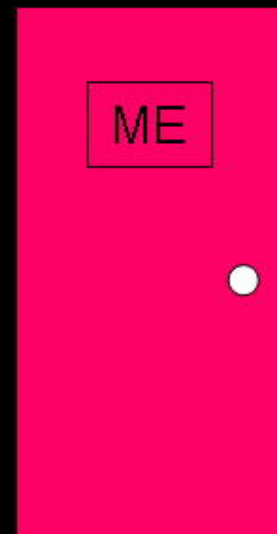
**Depositional
Sequence**

Door 2



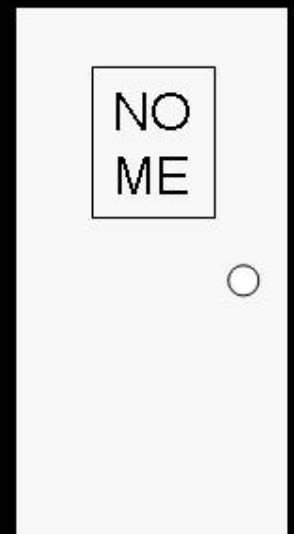
**TR
Sequence**

Door 3



**Genetic
Sequence**

Door 4

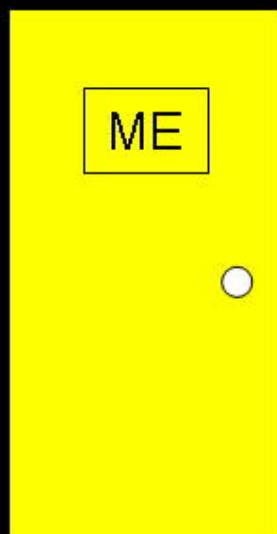


**UBU's/
Synthems/
Allostrat
Units**

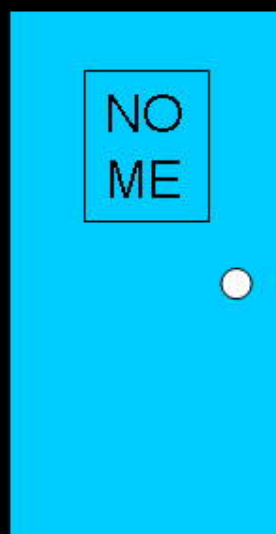
So, which is the best methodology ?



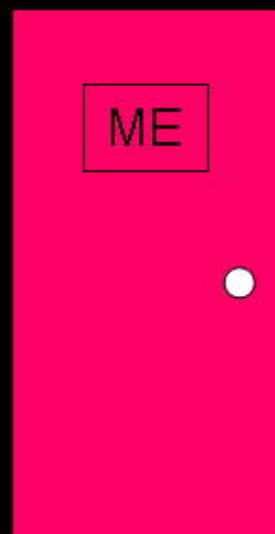
Door 1



Door 2



Door 3



Door 4



**Depositional
Sequence**

**TR
Sequence**

**Genetic
Sequence**

**UBU's
Synthems,
Allostrat
Units**

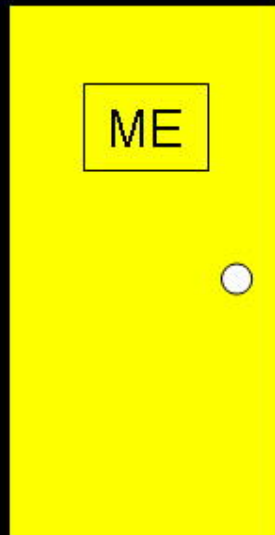
***Lacks
Correlative
Conformity***

*Depends on Depositional Setting
& Purpose*

Where does this leave us if we want to formalize a methodology of Unconformity Related Units?

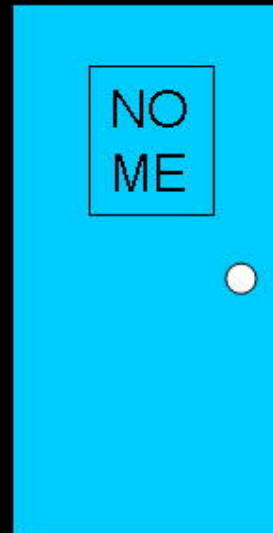


Door 1



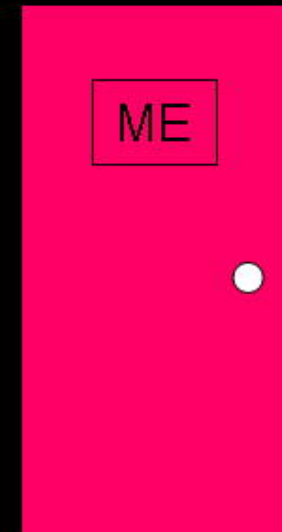
**Depositional
Sequence**

Door 2



**TR
Sequence**

Door 3



**Genetic
Sequence**

Unconformity-related Units



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AGREED ON:

- **Abandonment of the terminology of Unconformity-bounded Units (Synthems) and Allostratigraphic Units**
- **Adoption of the Term Sequence as the main term for Unconformity-related units**

Unconformity-related Units



ISSC WORKING GROUP ON SEQUENCE STRATIGRAPHY (1995-1999)

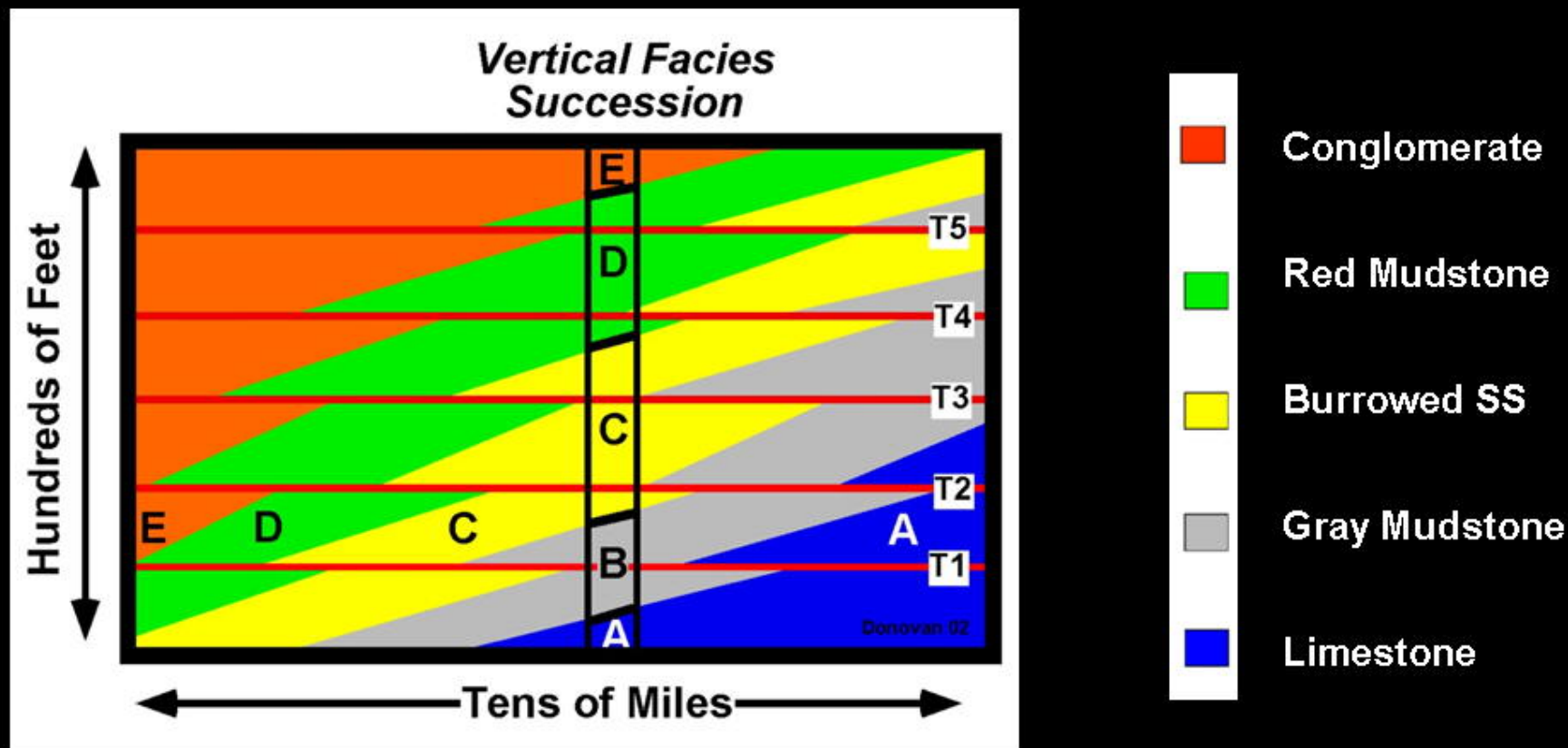
COULD NOT AGREE ON:

- What is a Sequence?
- If Sequences should be based solely on unconformities of subaerial erosion/nondeposition and their genetically related marine correlative conformities, or other discontinuity surfaces
- What is a discontinuity?
- If condensed sections represent discontinuities or slow continuous deposition

The Holy Grail



Walther's Law: Facies observed within a conformable vertical succession also occur as coeval lateral facies

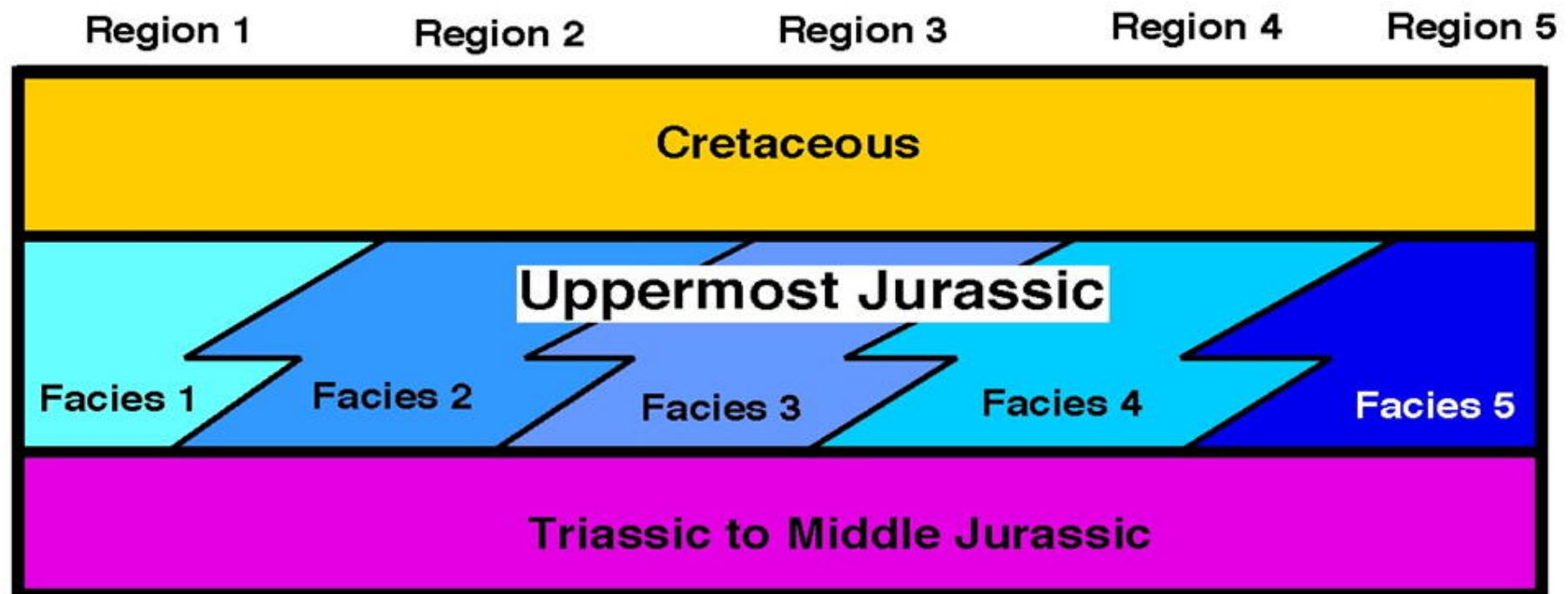


A methodology which allows the identification of coeval facies, documents the time-transgressive nature of classic litho-stratigraphic units, and provides geoscientists with an additional way to analyze and subdivide the stratigraphic record.

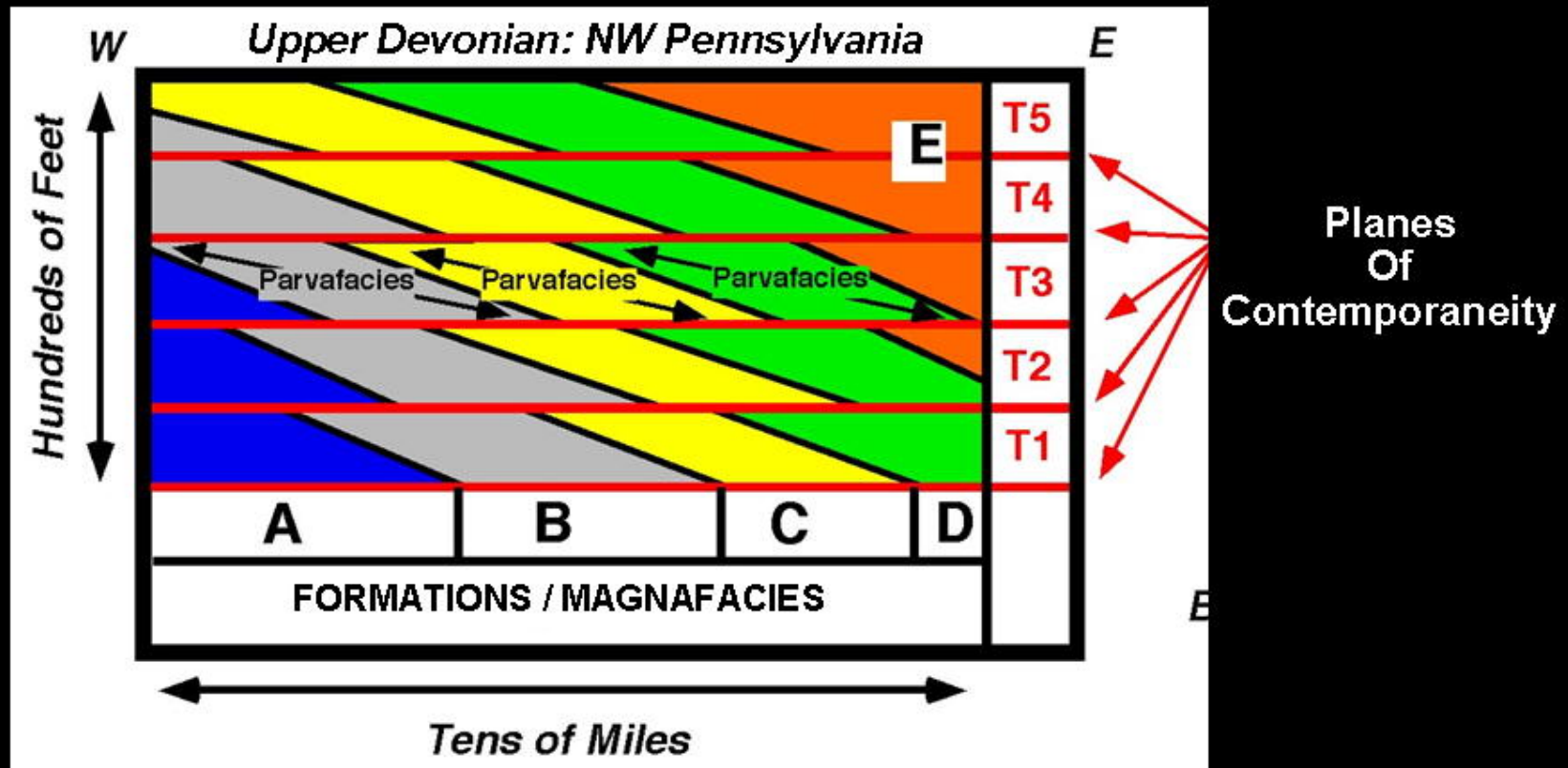
Amanz Greesly (1831)



- Swiss Geologist working in the Jura Mtns (France/Swiss border)
- Identified Lateral Lithologic & Fossil Variations along bedding surfaces
- Termed these coeval lateral variations “facies” from the Latin word aspect
- Interpreted these facies variations as a mosaic of environments along a depositional profile

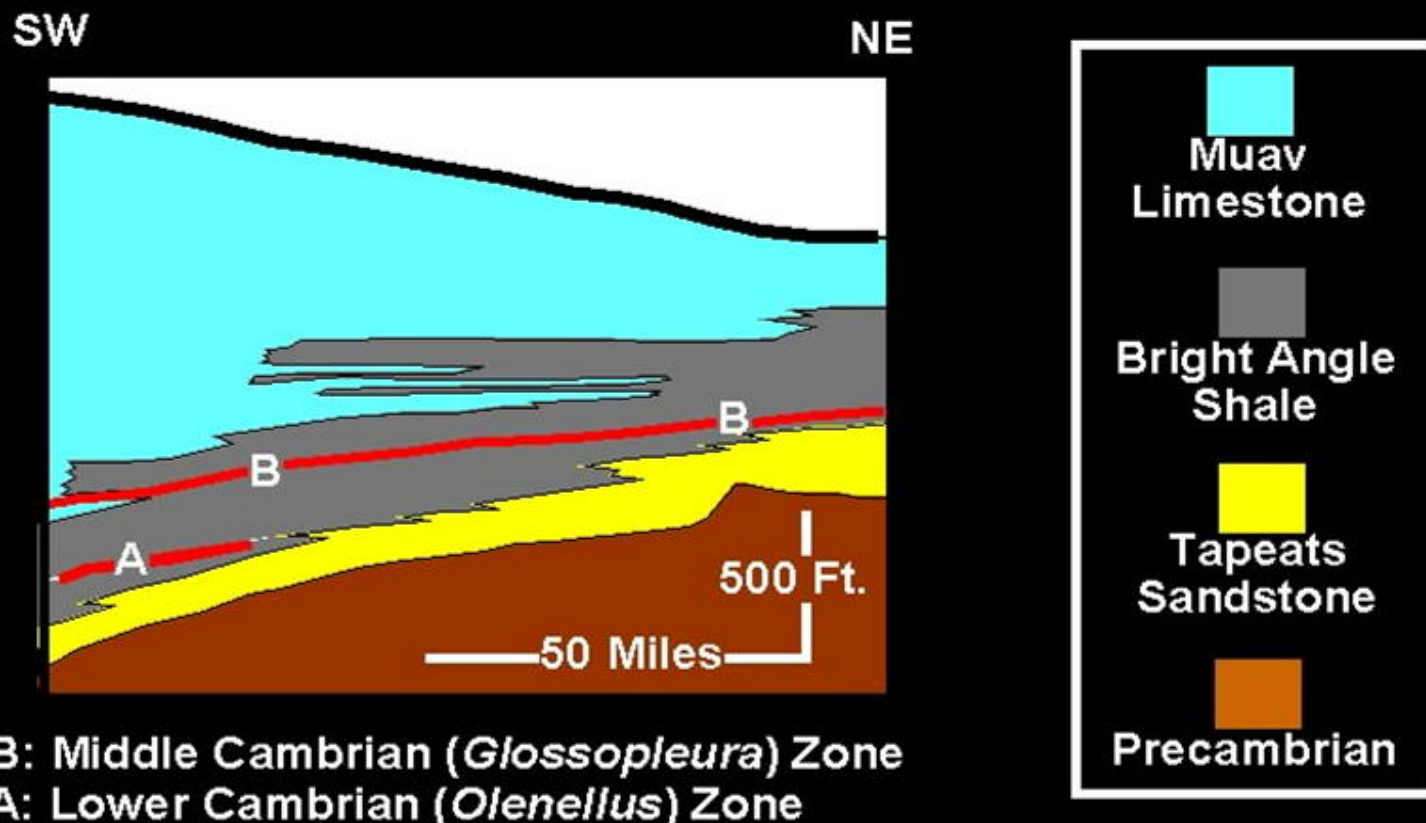


K.E. Caster (1934)



- Caster Identified & Traced Key Stratal Surfaces Across Study Area
- Found Stratal Surfaces Obliquely Intersect Formations (Magnafacies Belts)
- Interpreted Stratal Surfaces as Planes of Contemporaneity
- Planes of Contemporaneity Bound Groups of Parvafacies (The Parts of each Formation which were deposited during a given period of time)
- Formations are Time-Transgressive

McKee (1949)

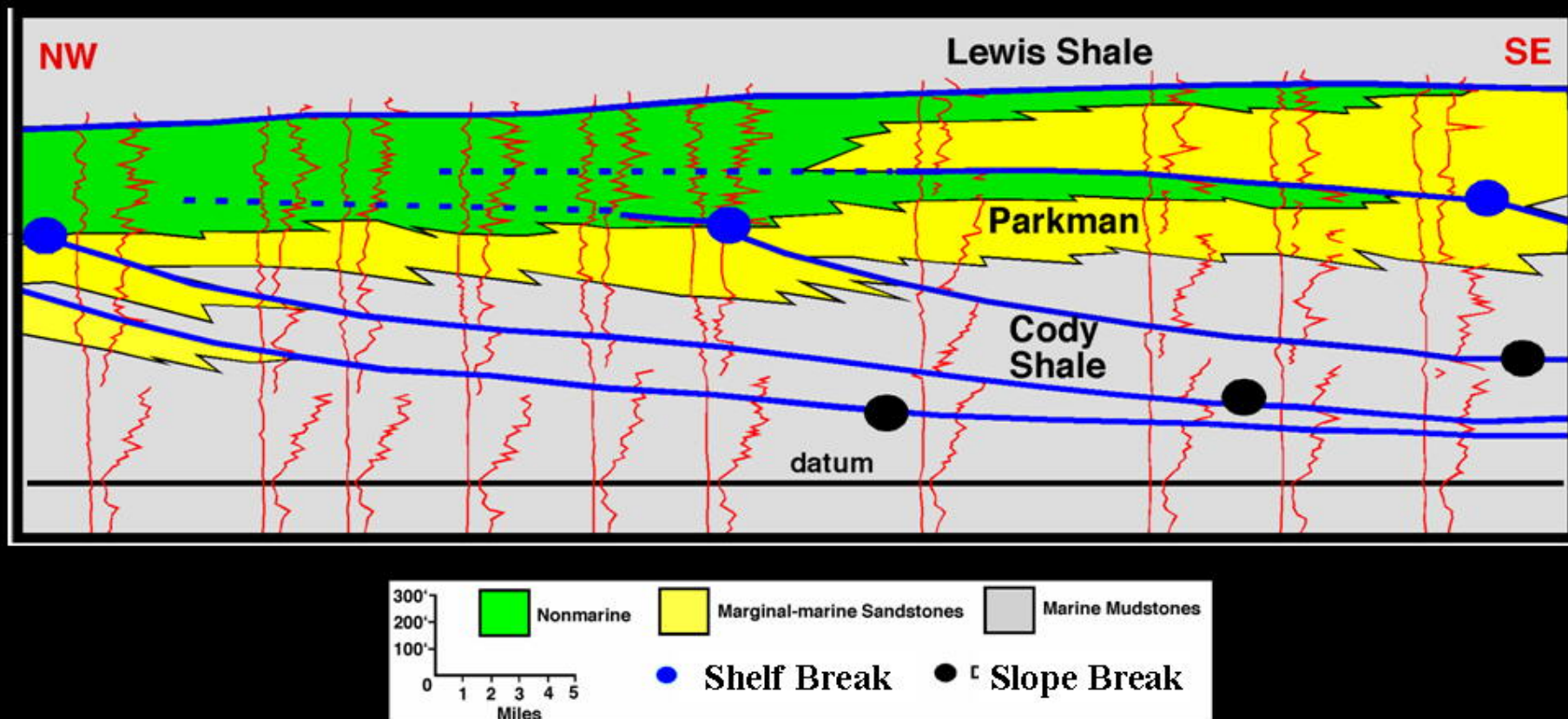


- McKee's research, which integrated faunal and stratal correlations, revealed that the Cambrian formations in the Grand Canyon were time-transgressive.
- Tapeats/Bright Angel Contact in SW part of Canyon was Early Cambrian in age, the same lithostratigraphic transition to NE was Middle Cambrian in age & equivalent to Bright Angle/Muav contact to west.

Asquith (1970)

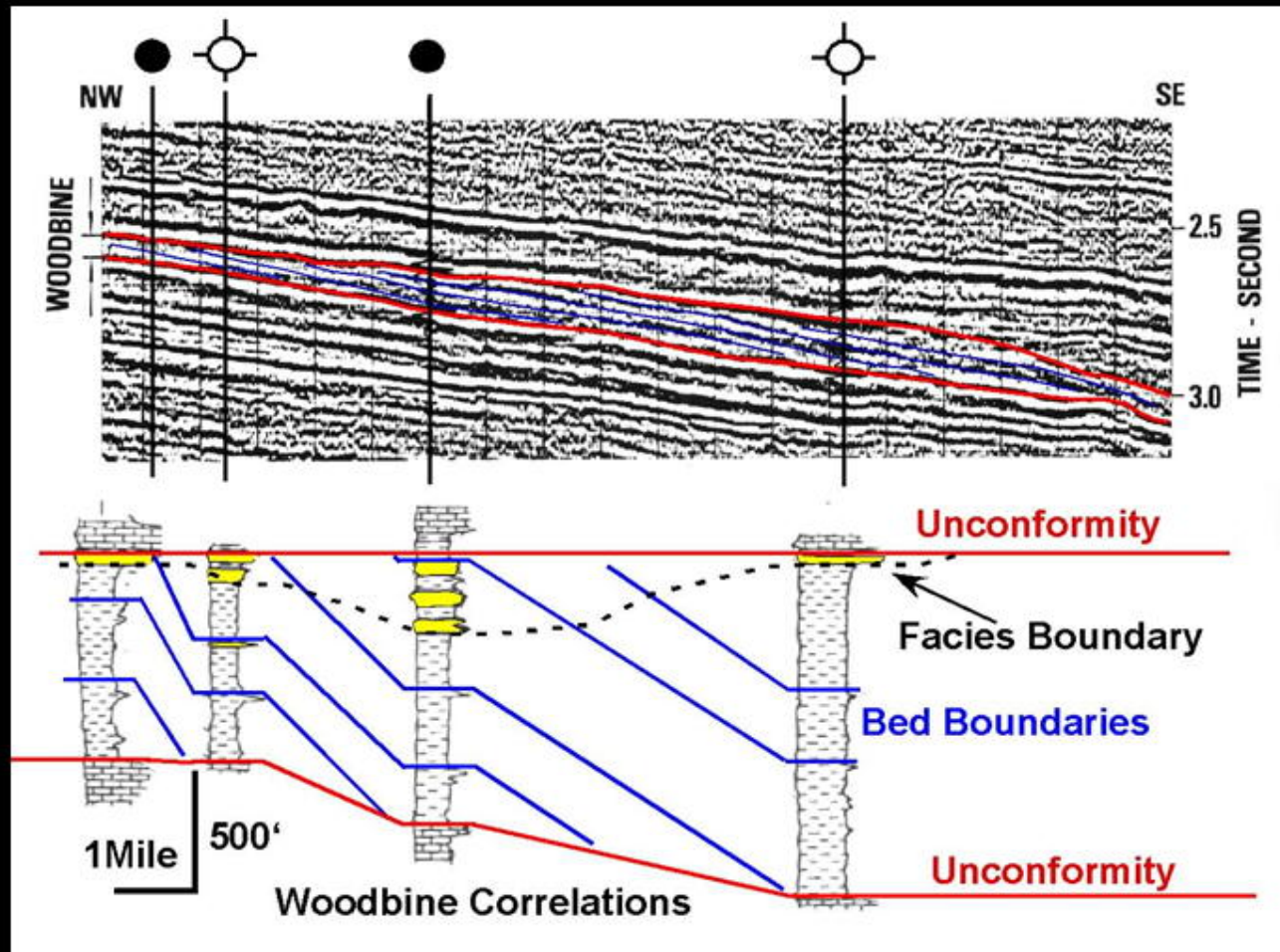


Parkman Sandstone Powder River Basin, Wyoming



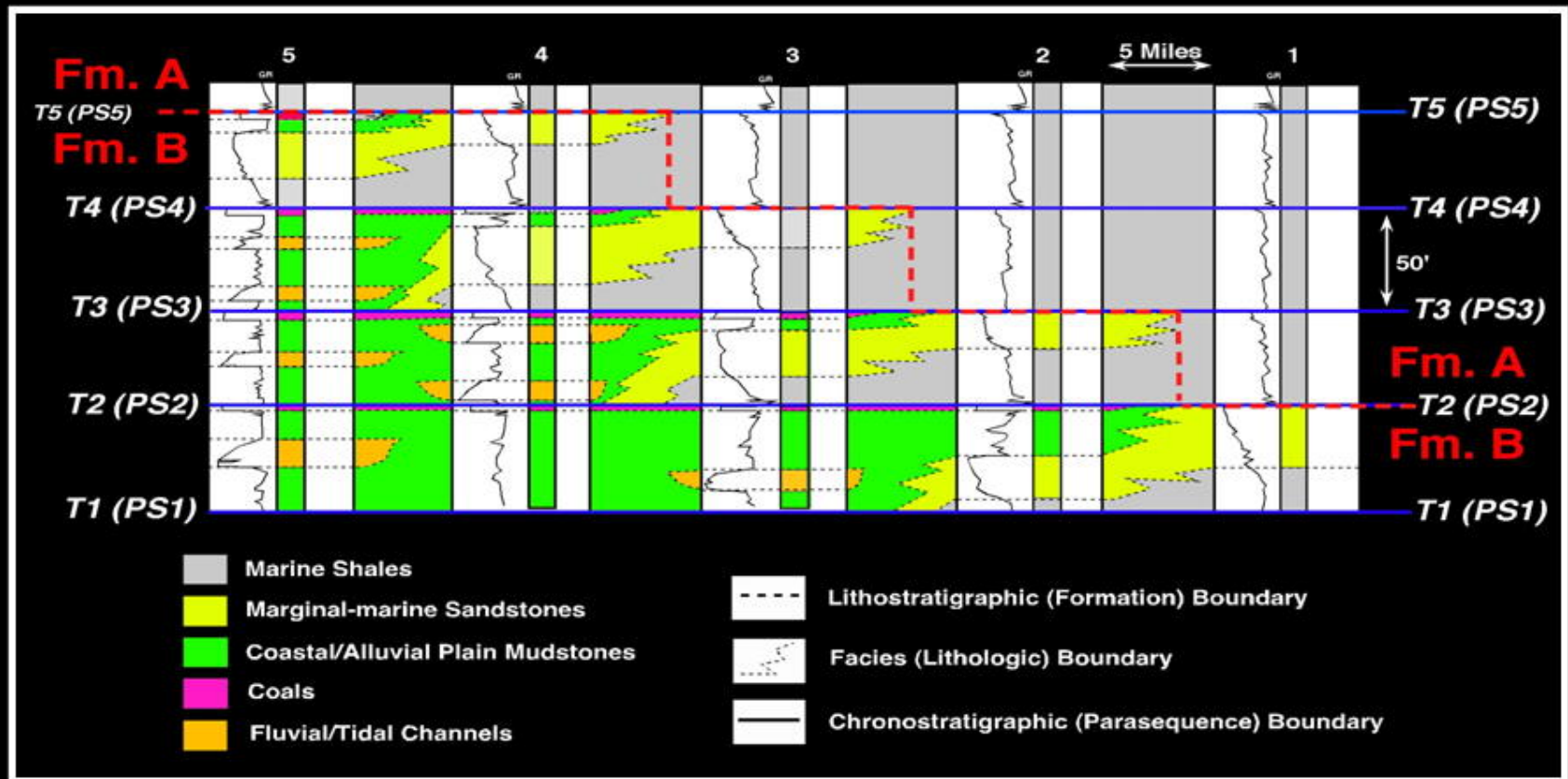
- **Stratal Surfaces (Log Markers) can be correlated on well-log cross sections**
- **Stratal Surfaces (markers) cross Lithostratigraphic Boundaries**
- **Stratal Surfaces are time-significant & can be used to define coeval units**

Seismic Stratigraphy: Vail & others (1977)



- Seismic Reflections Follow Physical Surfaces (Bedding Planes & Unconformities)
- These Physical Surfaces Have Chronostratigraphic Significance
- Framework to Identify Coeval Deposits

What is Sequence Stratigraphy?



Sequence stratigraphy is a methodology that uses a hierarchy of stratal surfaces to subdivide the stratigraphic record. This methodology allows the identification of coeval facies, documents the time-transgressive nature of classic litho-stratigraphic units, and provides geoscientists with an additional way to analyze and subdivide the stratigraphic record.

WHILE THERE IS NO CONSENSUS ON:

- What is a Sequence?
- If Sequences should be based solely on Sequence Boundaries
which are unconformities of subaerial erosion/ nondeposition
and their correlative conformities, or other discontinuity surfaces
- What is a discontinuity?
- If condensed sections represent discontinuities or slow continuous
deposition

**Contend that a fundamental step change is needed away from
unconformity-related or discontinuity bounded units, or even using the
term sequence, if we truly wish to formalize a “sequence stratigraphic”
methodology**

EPI-STRATIGRAPHIC UNITS

Maybe we can find consensus by realizing that the basic premise behind all “sequence stratigraphic” methodologies is actually correlating stratal surfaces and defining surface bounded stratigraphic units. Thus a methodology of Surface-bounded Stratigraphic (Epi-Stratigraphic) Units, with user-defined flexibility for choosing the type or types of stratal boundaries used to define Members, Formations, and Groups may provide the common ground for the various sequence stratigraphic methodologies to live, prosper, and co-exist under an informal or formal stratigraphic code.

epi: from Epipoles --- Greek for Surface

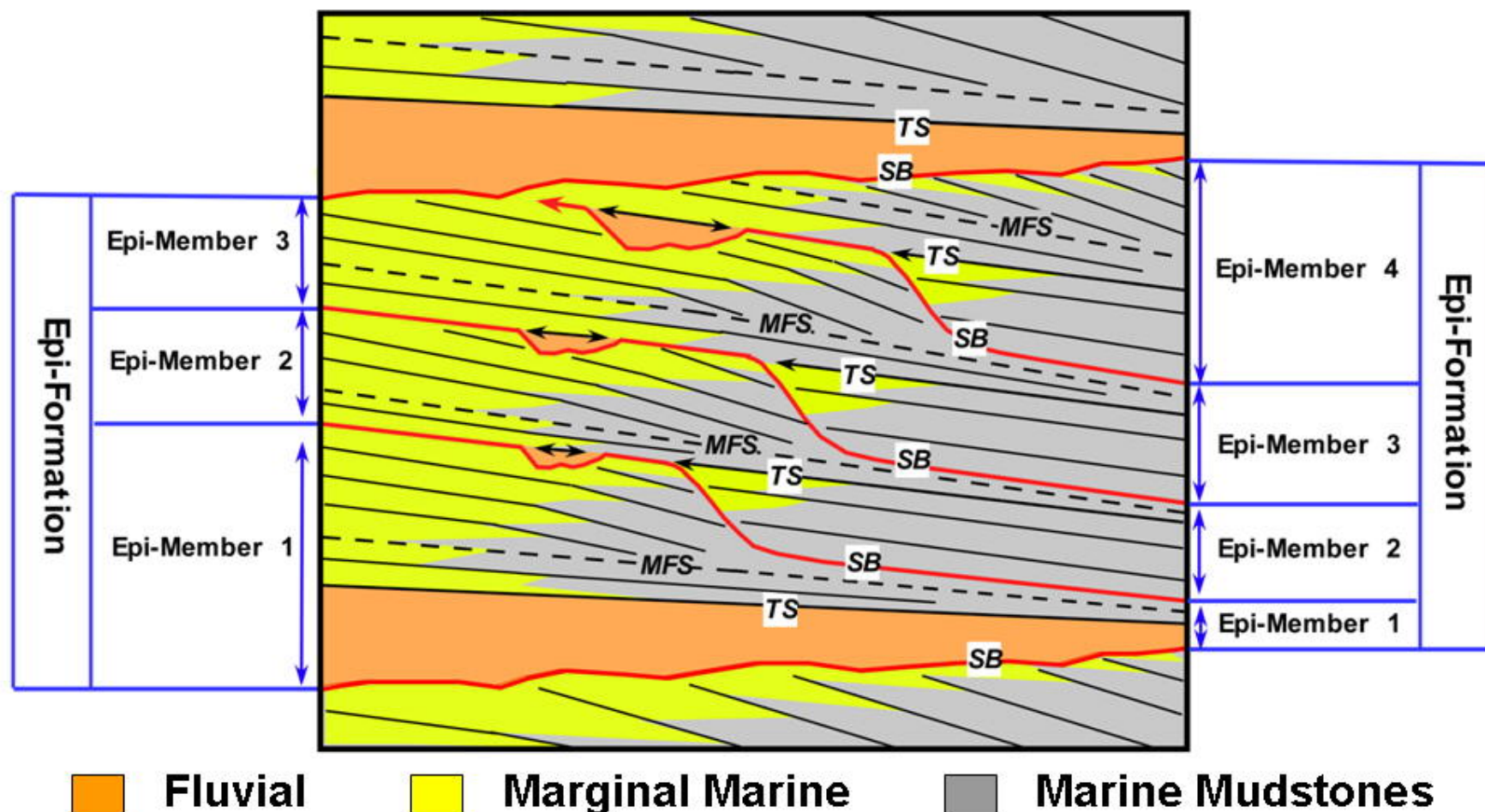
Hierarchy of Epi-stratigraphic Units

Formal Name	Informal Names
Epi-Super Group	Super or Mega Sequence
Epi-Group	Composite Sequence
Epi-Formation	Sequence Set
Epi-Member	Sequence (Depositional/TR/Genetic)
Epi-Compartment	System Tract
Epi-Unit	Parasequence, PAC, etc.
Epi-bed	

Epi-Stratigraphic Units



Depositional Sequence Paradigm

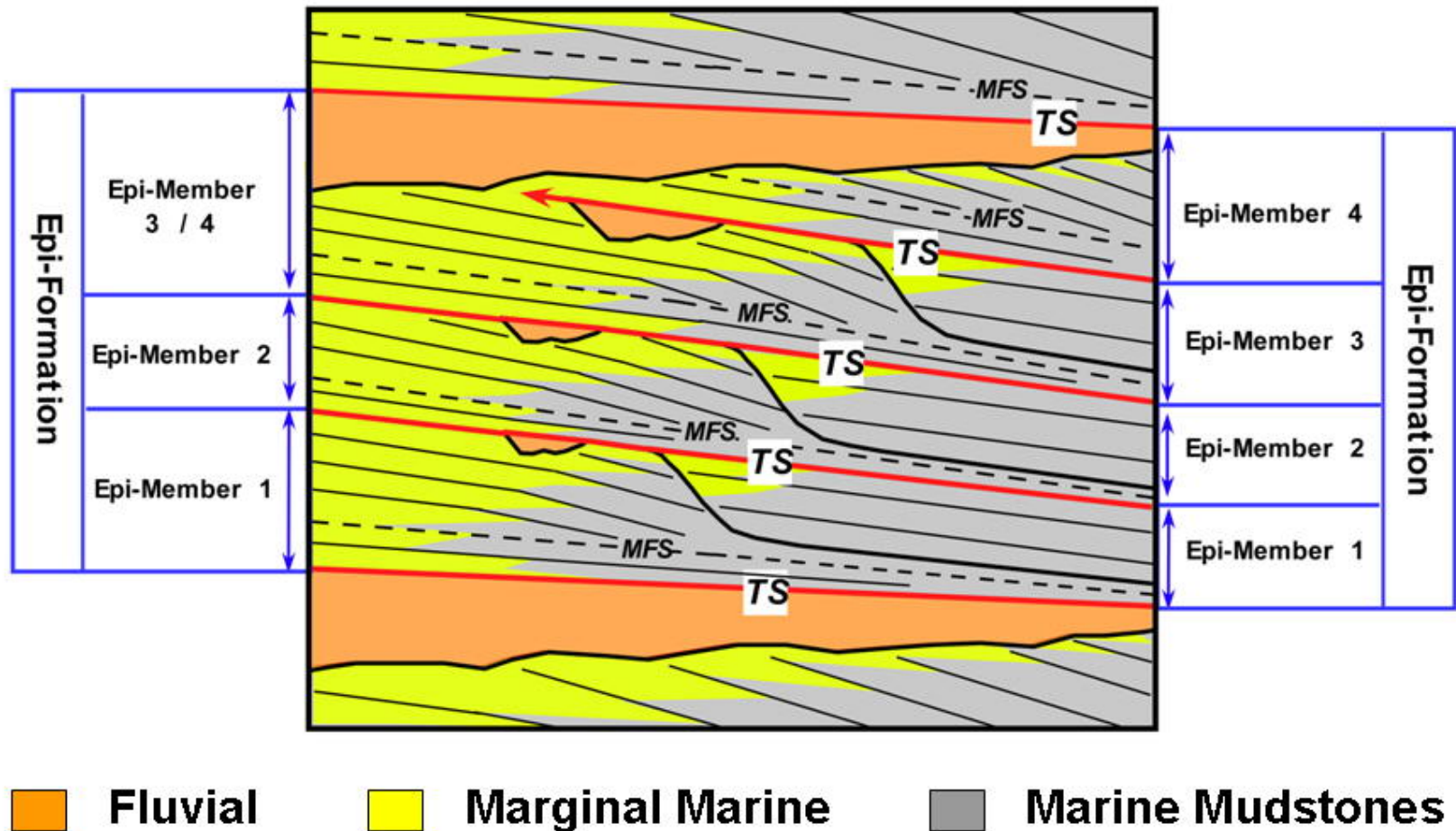


3-D Surface-bounded Stratigraphic Unit

Epi-Stratigraphic Units



T-R Sequence Paradigm

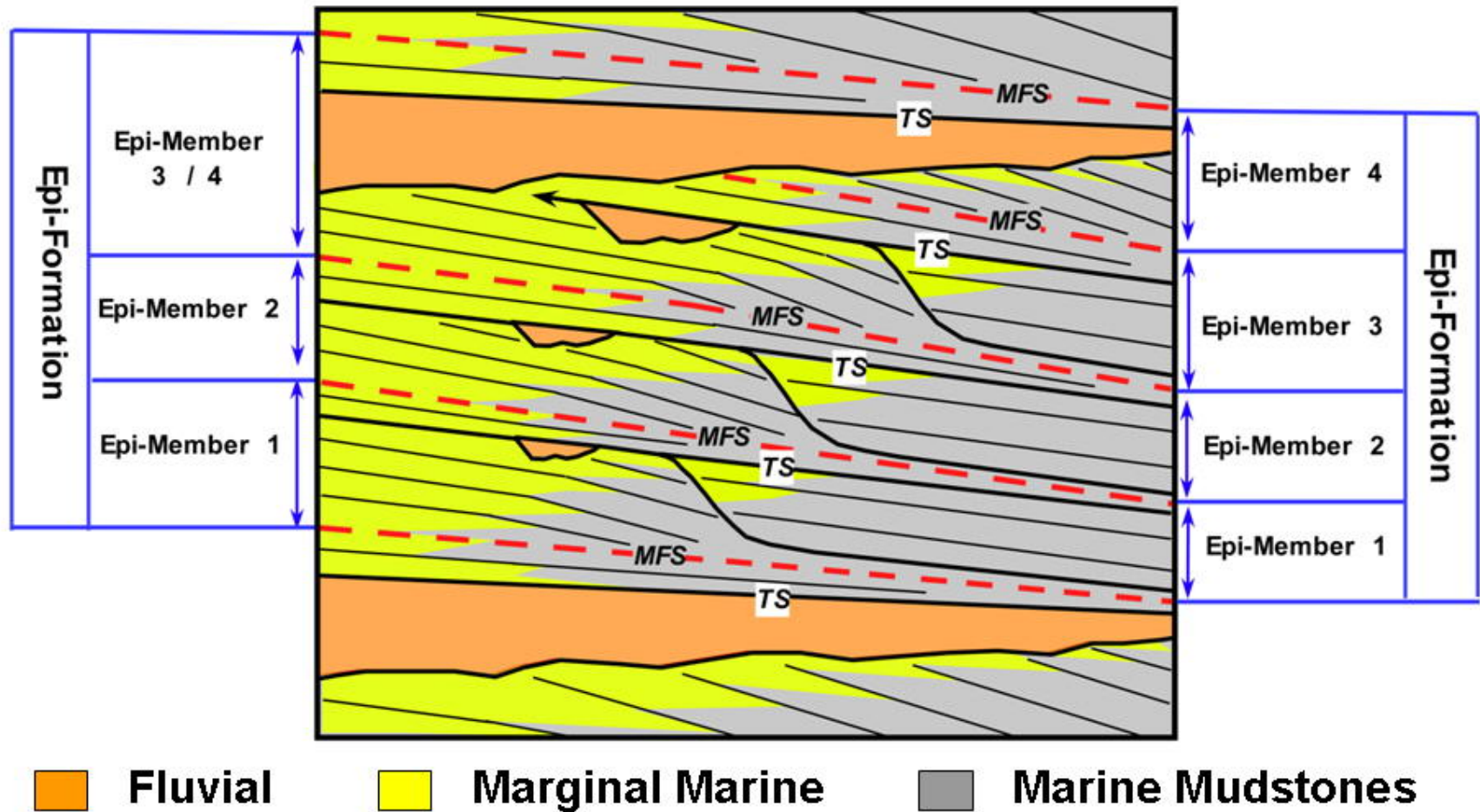


3-D Surface-bounded Stratigraphic Unit

Epi-Stratigraphic Units



Genetic Sequence Paradigm



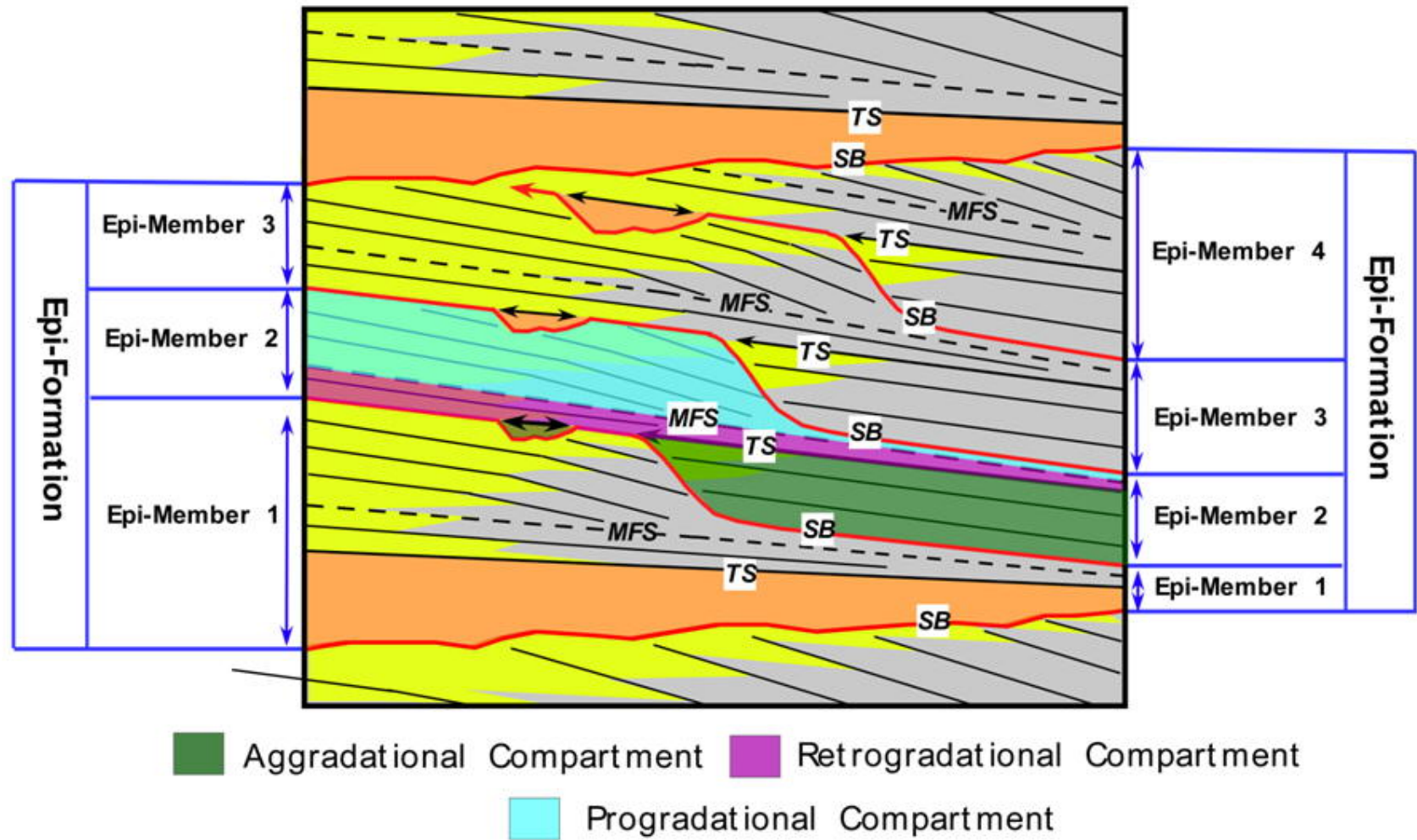
3-D Surface-bounded Stratigraphic Unit

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Epi-bed	

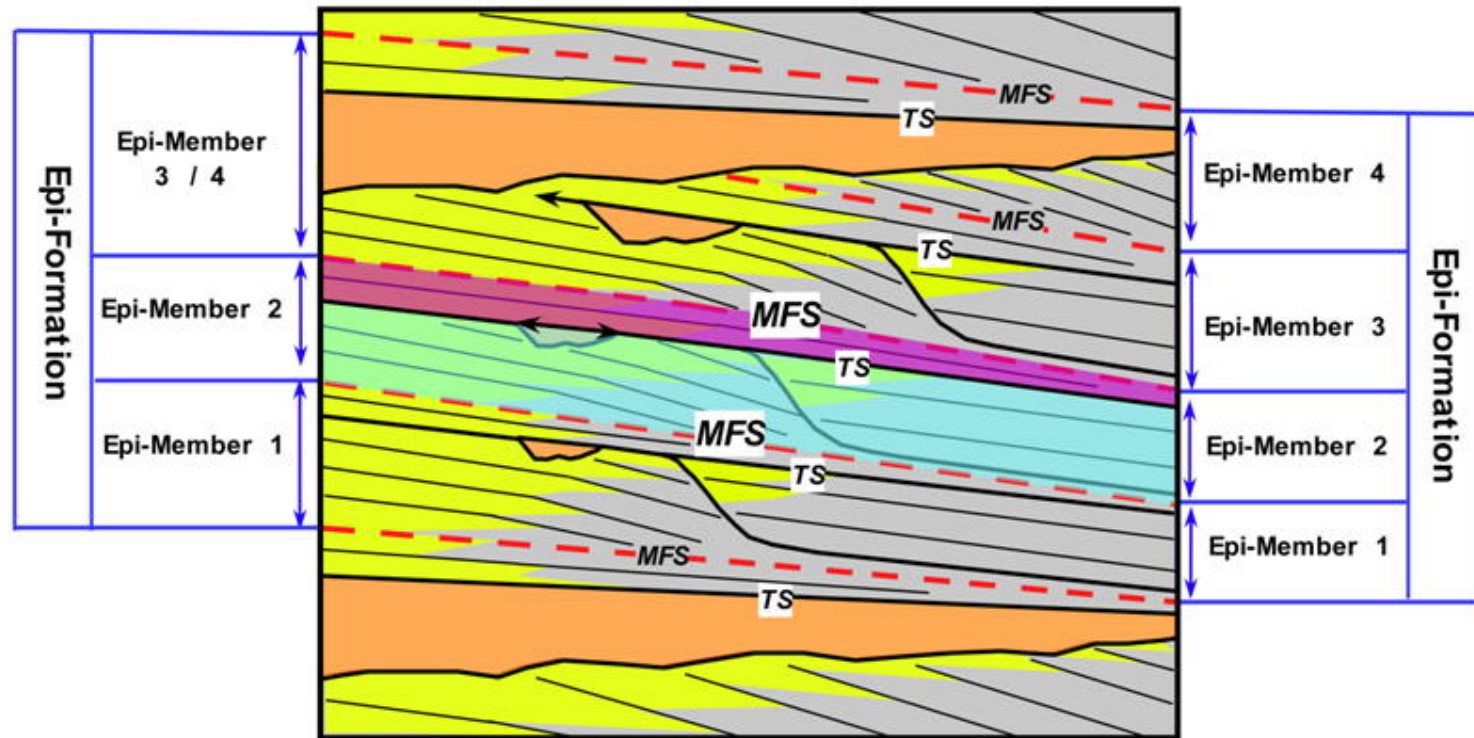
*However, there is a need for formal stratigraphic units
between bed and member !*

Epi-Compartments: Depositional Sequence Paradigm



- Epimembers can be divided into epi-compartments
- Bounded by key stratal surfaces within an epi-member

Epi-Compartments: Genetic Sequence Paradigm



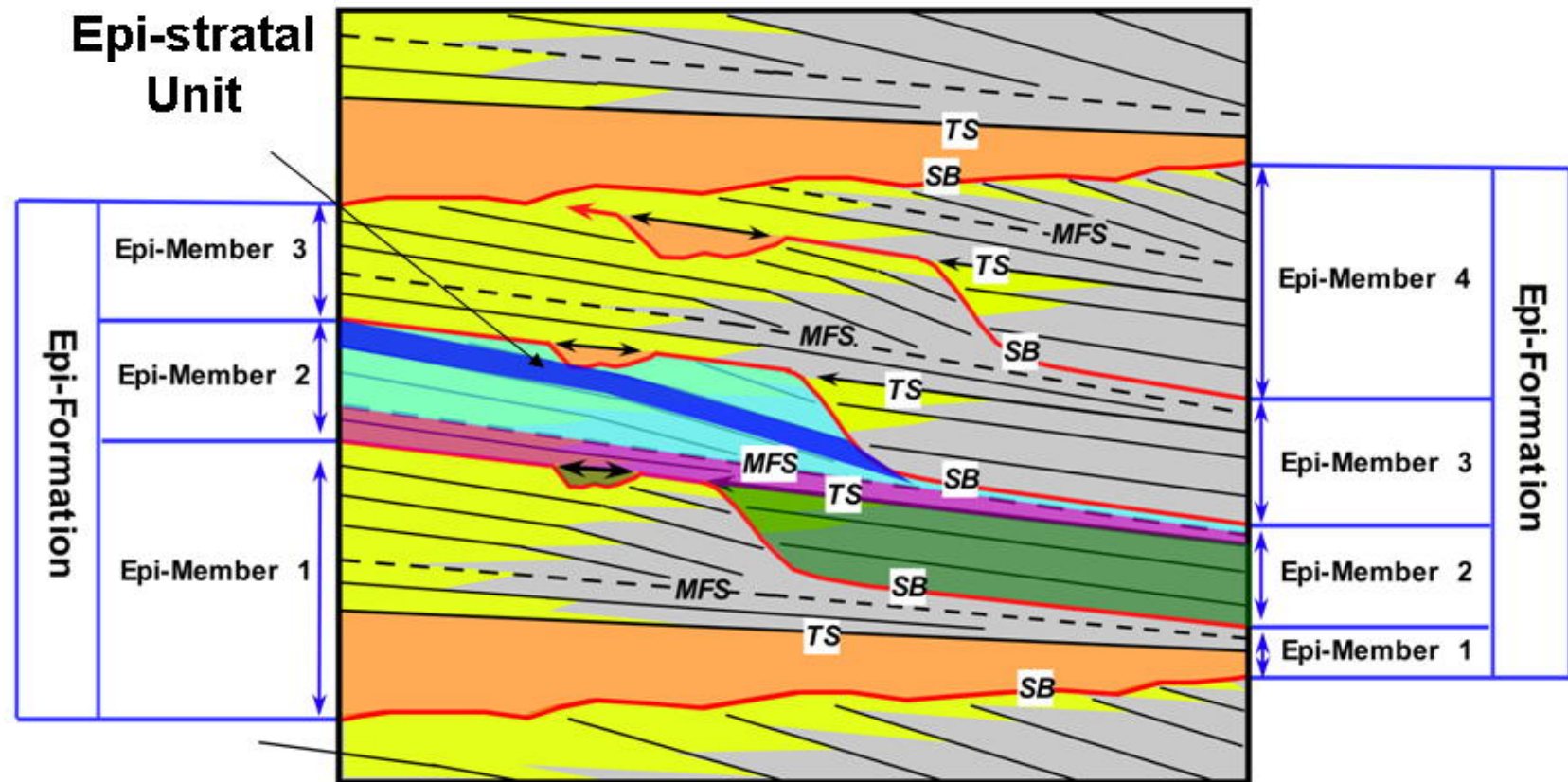
 Regressive Compartment

 Transgressive Compartment

- Epimembers can be divided into epi-compartments
- Bounded by key stratal surfaces within an epi-member

Epi-Stratal Unit

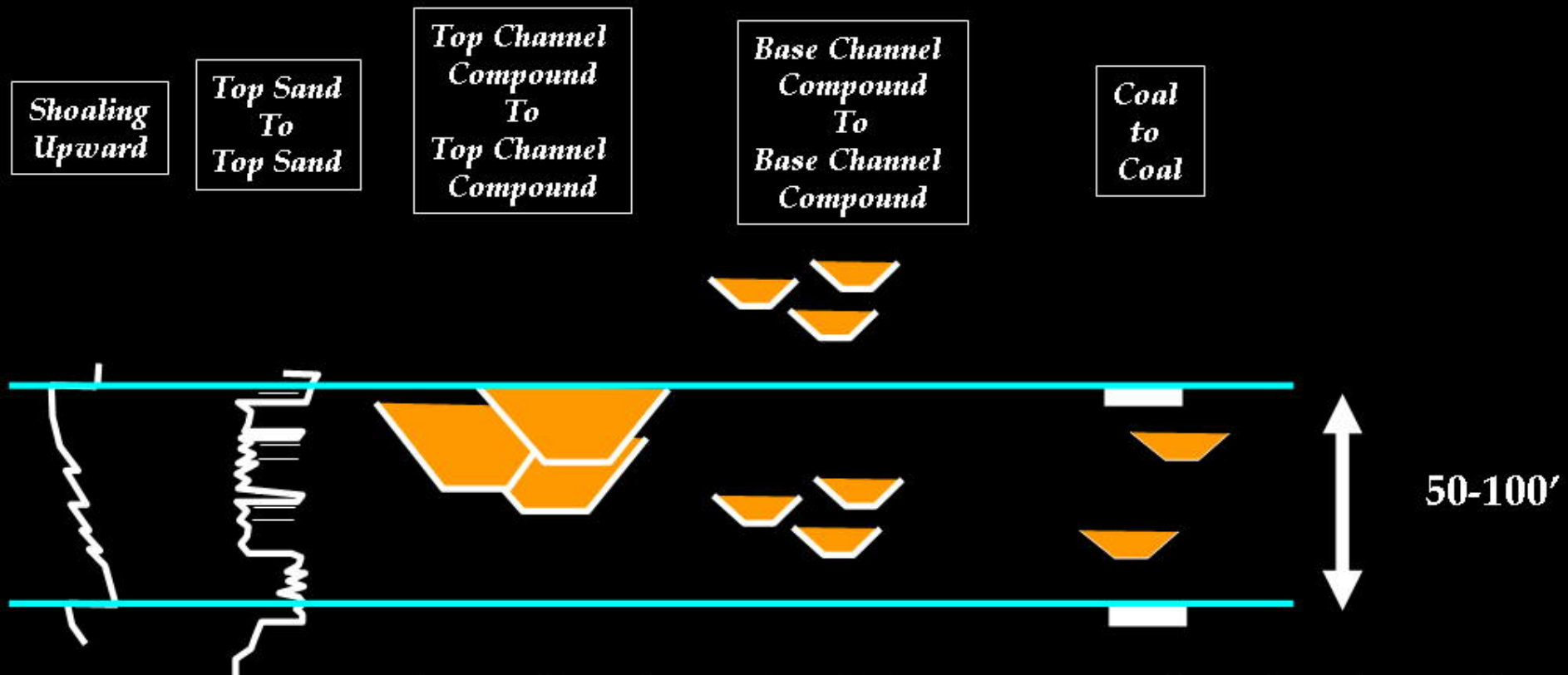
An surface bounded unit within a compartment bounded by distinct mapable stratal surfaces



Aggradational Compartment Retrogradational Compartment Progradational Compartment

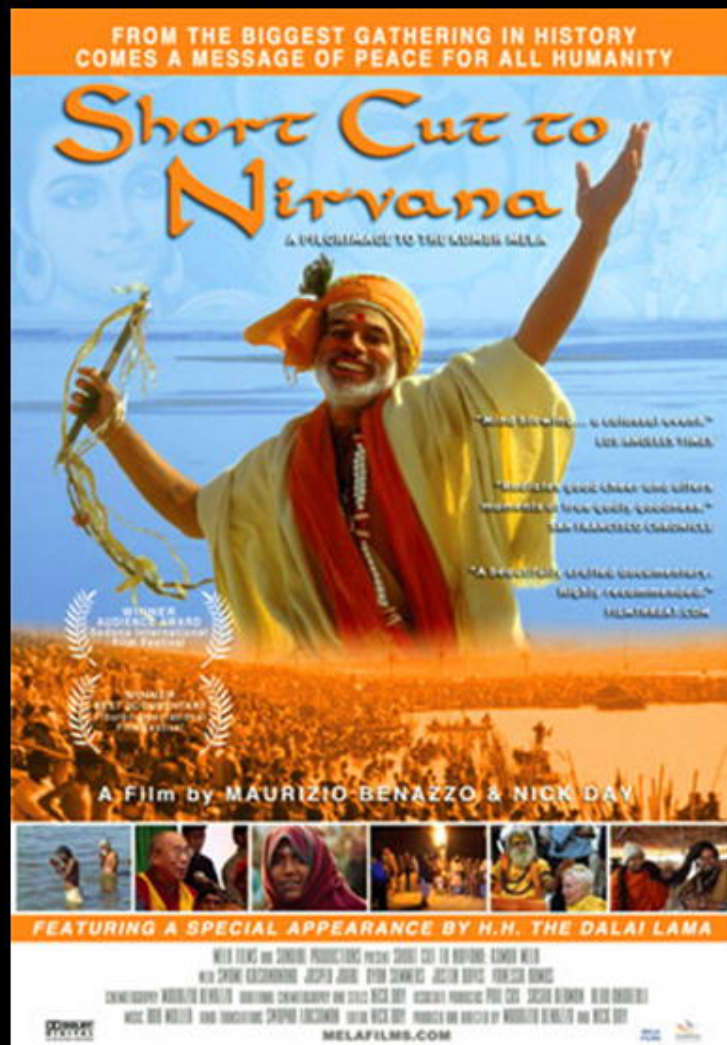
Epi-Stratal Unit

A heterolithic & cyclic succession of strata, typically 50-100' thick, bounded by stratal surfaces



- A Parasequence is a Basic Epi-Stratal Unit, however, not all Basic Epi-Stratal Units are Shoaling Upward Successions!
- Therefore the Basic Building Block of the Epi-members should be considered the Stratal Unit not the Parasequence

Short Cut to Nirvana



- Forget about Unconformity-related Units
- Don't worry about what is a Sequence
- Don't Fret about a given surface being a discontinuity or not
- Think Surface-bounded Epi-Stratigraphic Units

THE END



My Assistants