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Sequence Stratigraphy

PCCE-02

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GeoIndia – PCCE-02

BeicipFranlab

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Development of sequence stratigraphy

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A brief history of stratigraphy

Concept of stratotype and stage

The **stratotype** or reference section is the term that designates a type locality or the most accessible or representative outcrop of a stratigraphic series.

The time interval that corresponds to the stratotype is called the stratigraphic **stage**.

The notion of stratotype is a **1D vision** now **outdated**. In the early 19th century it nevertheless allowed the creation of the **geological timescale** which is one of the pillars of stratigraphy.

The concept of stage has outlived that of stratotype and the age of stages is still being researched and updated each year by the International Commission on Stratigraphy (ICS).

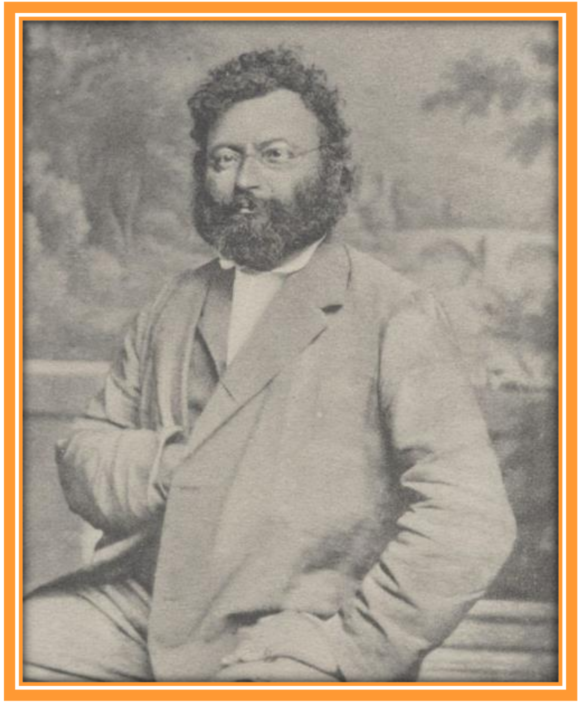
Bajocian stratotype (France)

Concept of facies

Gressly, a Swiss geologist, introduced the concept of facies in geology in his publications (1838-1841) while working on the drilling of railway tunnels.

In its modern definition, the **sedimentary facies** is the set of characteristics (i.e., lithology, mineralogy, fossils, bioturbation, granulometry, classification, bedding, sedimentary structures) that define a sedimentary rock.

Facies allow us to reconstruct the depositional environment from the interpretation of the physical and biological processes that led to the formation of the sedimentary rock.



Source https://en.wikipedia.org/wiki/Amanz_Gressly

Amanz Gressly
(1814-1865)

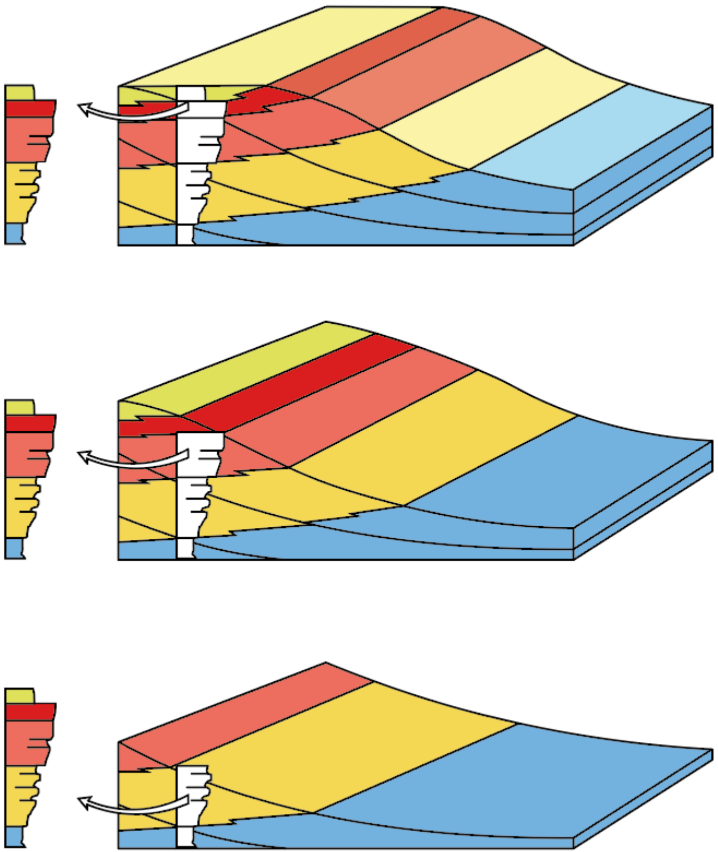
Integration of facies and time – the Walther's law

A considerable step was taken at the end of the 19th century towards the beginnings of modern stratigraphy when Walther linked the notion of geological time to that of facies.

The Walther's Law of Facies was introduced by the German geologist Johannes Walther (1860–1937) as an important geological principle, after the establishment of the concept of "facies," one of the foundations of modern stratigraphy.

Walther's Law states that **any vertical progression of facies is the result of a succession of depositional environments that are laterally juxtaposed to each other**.

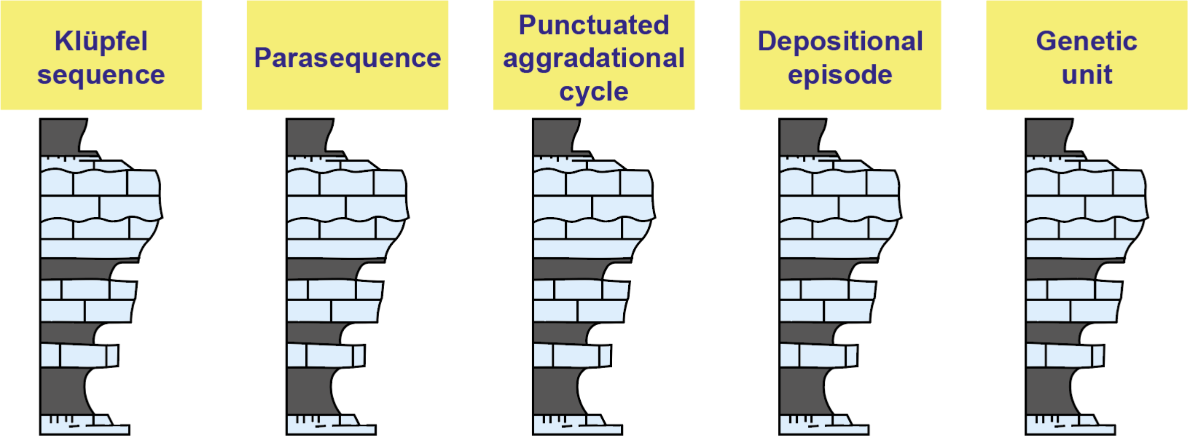
Walther proposes for the first time a dynamic view of stratigraphy that prefigures sequence stratigraphy.



Concept of sequence

At the end of the 19th century Walther formulated for the first time a dynamic vision of stratigraphy that prefigured sequence stratigraphy. The fundamental building brick of stratigraphy: **sequence** makes its appearance.

From then on, **research focused on the definition of the sequence as such** and several concepts of sequences flourished during the 20th century: Klüpfel sequence, Punctuated aggradational cycle, depositional episode, Parasequence, genetic unit…



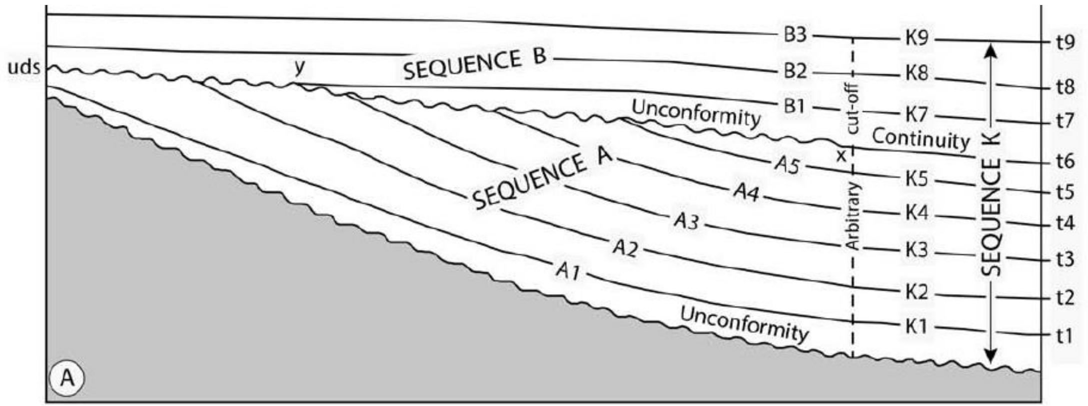
Interpretations evolve depending on concepts… but the object remains the same.

Source Homewood et al. (1998)

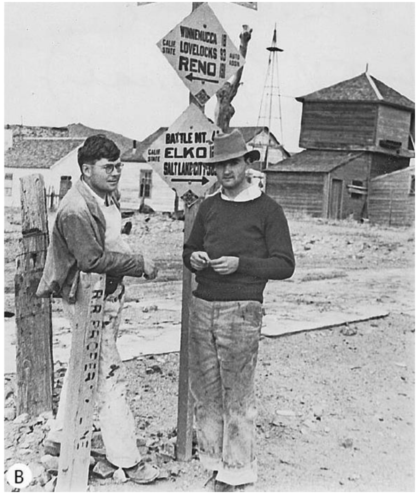
Concept of sequence

Until the 50's, stratigraphy was limited to a vertical 1D vision of the sequence. It is the American geologists (e.g., L. Sloss, H. Wheeler, others) who give a new breath to stratigraphy by **integrating the notion of stratigraphic surface to that of the sequence**: [Time + Facies + Surface] = Sequence.

Sloss 1963 quoted "***Stratigraphic sequences are rock-stratigraphic units*** *of higher rank than group, megagroup or supergroup,* ***traceable over major areas*** *of a continent and* ***bounded by unconformities of interregional scope***."



Section showing physical relationships of successive unconformity-bounded sequences (Wheeler, 1964)



Source: Pemberton et al. (2016)

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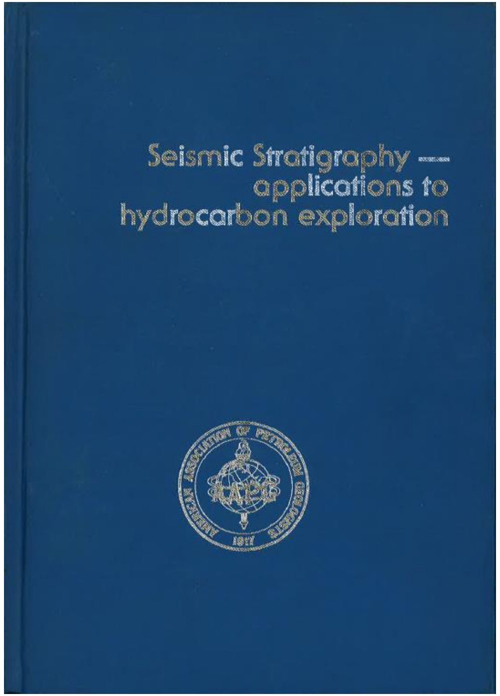
Seismic stratigraphy and the new paradigm

In the 1970s, the development of modern electronic technology allowed routine processing of reflection seismic data and paved the way for a new discipline: **seismic stratigraphy**. Major acquisition of offshore seismic has revealed the geometry of deposits on passive continental margins.

Through the stratigraphic interpretation of seismic data, the Exxon R&D team led by Peter Vail formalized the principles established in the 1950s and 1960s (Sloss, Wheeler, etc.) and (re)defined a set of concepts and terms that together gave birth to **sequence stratigraphy**.

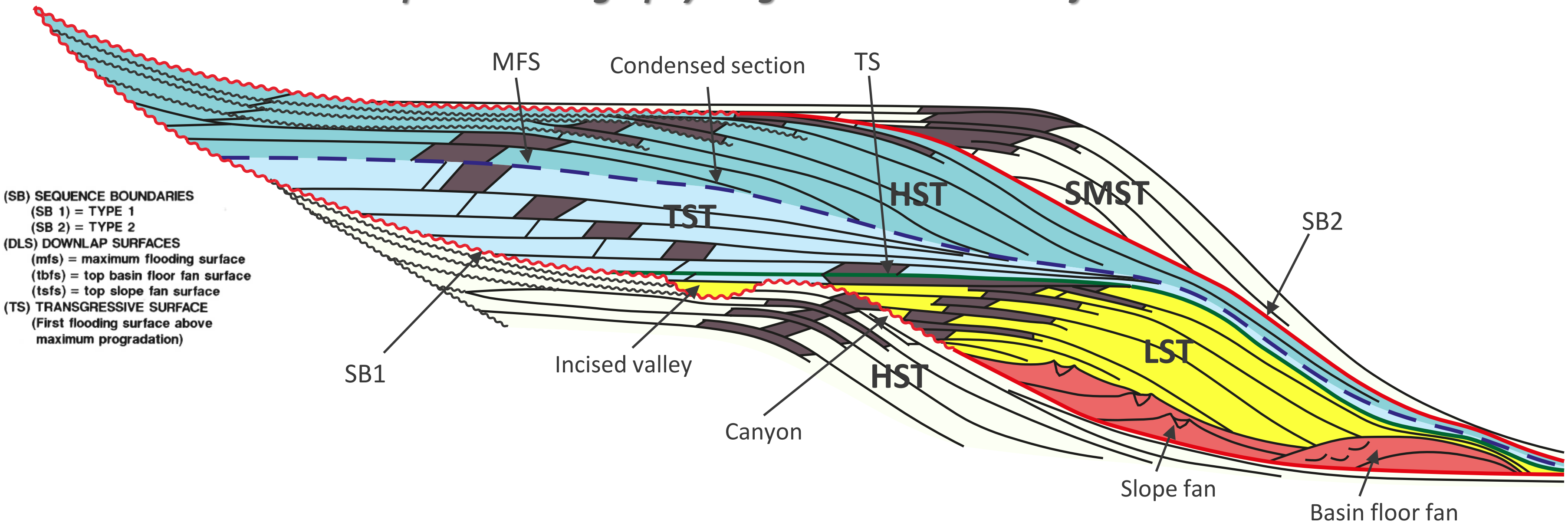
Seismic Stratigraphy – applications to hydrocarbon exploration. AAPG Memoir 26, C.E. Payton (ed.), 1977.



The iconic Vail's "slug" model

The famous Vail's "slug" model became the symbol of sequence stratigraphy. It was published by Vail et al. in 1984.

The sequence stratigraphy diagrammatic section of the EXXON school



Source: P. Vail (1987), AAPG Studies in Geology #27, volume 1 – Atlas of seismic stratigraphy (A.W. Bally editor)

Driving forces behind sequences

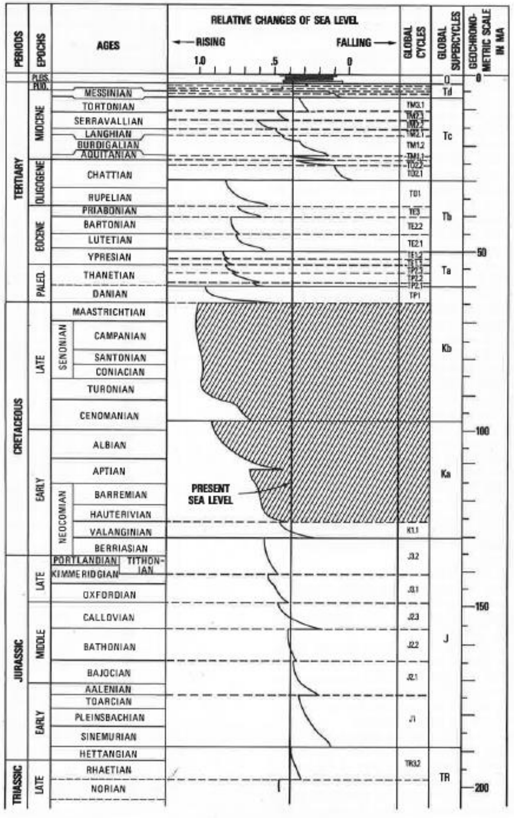
Catuneanu (2006) quoted that *“The concepts of seismic stratigraphy were published together with a global sea-level cycle chart (Vail et al., 1977) based on the underlying assumption that eustacy is the main driving force behind sequence formation at all levels of stratigraphic cyclicity”.*

The Exxon’s model stated that:

1. There are ontrolling factor behind the stratigraphic sequences.
2. A unique controlling factor is invoked: global sea level (eustacy).

These two ideas will fuel research on sequence stratigraphy over the next two decades.

Sample of the first attempt of Global Sea-Level chart Published by Vail et al. (1977) in the AAPG Memoir 26



Jurassic-Cretaceous time scale after Van Hinte 1976 a, b

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Eustasy, tectonics or both?

After the emergence of the concept, the debates focus on the allogenic mechanisms responsible for accommodation. Eustasy or Tectonics.

In the early 90s, the **eustasy-driven model** initially proposed by Exxon was then abandoned in favor of the **Accommodation** or **Relative Sea Level** concept in which subsidence and eustasy are taken into account (e.g., Hunt and Tucker, 1992).

With the introduction of increasing geological investigations into the sequence stratigraphic concepts, the sequence model itself evolves. **Several types of sequences** (Parasequence, Genetic units or R-T cycles, Transgressive-Regressive cycles etc..) and **stratigraphic surfaces** are proposed.

The concepts, models, analogues flourished along the 80s and 90s have **two antagonistic outcomes**: It reinforces and strengthen the concept and at the same time it results in competing approaches and confusing or even conflicting terminology jeopardized the daily use of sequence stratigraphy principles for practitioners.

Towards standardization of sequence stratigraphy

After two decades of research in seismic and sequence stratigraphy, the need for a standardization of sequence stratigraphy was largely agreed upon.

A group of stratigraphers led by Catuneanu published in 2009 a reference article.

In the abstract, authors quoted: *"Standardization of sequence stratigraphy requires the definition of the* ***fundamental model-independent concepts****,* ***units****,* ***bounding surfaces*** *and* ***workflow*** *that outline the foundation of the method. A standardized scheme needs to be* ***sufficiently broad to encompass all possible choices of approach****, rather than being limited to a single approach or model."*

In practice, the 2009 article put an end to the contradictory debates that have marked the rise of sequence stratigraphy

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Towards the Standardization of Sequence Stratigraphy

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Abstract

Sequence stratigraphy emphasizes facies relationships and stratal architecture within a chronological framework. Despite its wide use, sequence stratigraphy has yet to be included in any stratigraphic code or guide. This lack of standardization reflects the existence of competing approaches (or models) and confusing or even conflicting terminology. Standardization of sequence stratigraphy requires the definition of the fundamental model-independent concepts, units, bounding surfaces and workflow that outline the foundation of the method. A standardized scheme needs to be sufficiently broad to encompass all possible choices of approach, rather than being limited to a single approach or model.

A sequence stratigraphic framework includes genetic units that result from the interplay of accommodation and sedimentation (i.e., forced regressive, lowstand and highstand normal regressive, and transgressive), which are bounded by "sequence stratigraphic" surfaces. Each genetic unit is defined by specific stratal stacking patterns and bounding surfaces, and consists of a tract of correlatable depositional systems (i.e., a "systems tract"). The mappability of systems tracts and sequence stratigraphic surfaces depends on depositional setting and the types of data available for analysis. It is this high degree of variability in the precise expression of sequence stratigraphic units and bounding surfaces that requires the adoption of a methodology that is sufficiently flexible that it can accommodate the range of likely expressions. The integration of outcrop, core, well-log and seismic data affords the optimal approach to the application of sequence stratigraphy. Missing insights from one set of data or another may limit the "resolution" of the sequence stratigraphic interpretation.

1

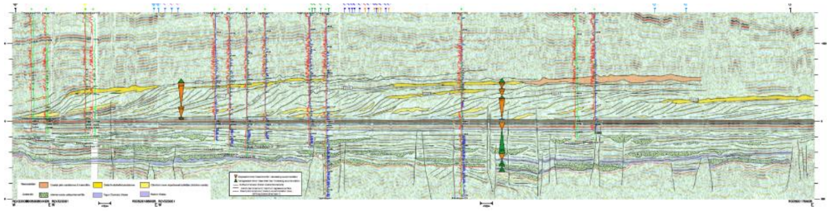
Stratigraphic forward modelling – from 90s onwards

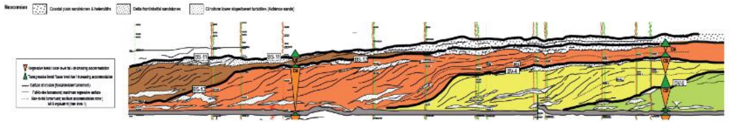
Stratigraphic modeling began in the late 1980s and developed over the following decade.

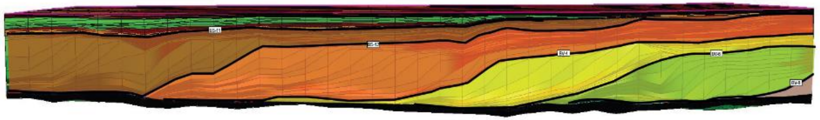
The main challenge of the stratigraphic modelling was to quantify the stratigraphic parameters (sediment supply, erosion rate, subsidence, eustasy) and to understand their interactions in terms of resulting depositional geometries.

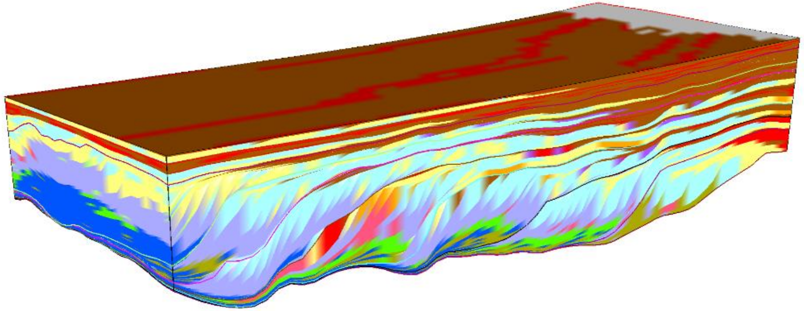
Another aspect of stratigraphic modeling had been the search for equations and physical laws able to capture stratigraphic phenomena on time and spatial macroscopic scales (hundreds of thousands to tens of millions of years, and tens to hundreds of kilometres).

In the late 90s, IFP developed DIONISOS, a 3D stratigraphic froward modeling software based on a generalized diffusion equation. With 20 years of research and industrial application, DIONISOSFLOW is the most advanced stratigraphic forward model now.









Principles of sequence stratigraphy

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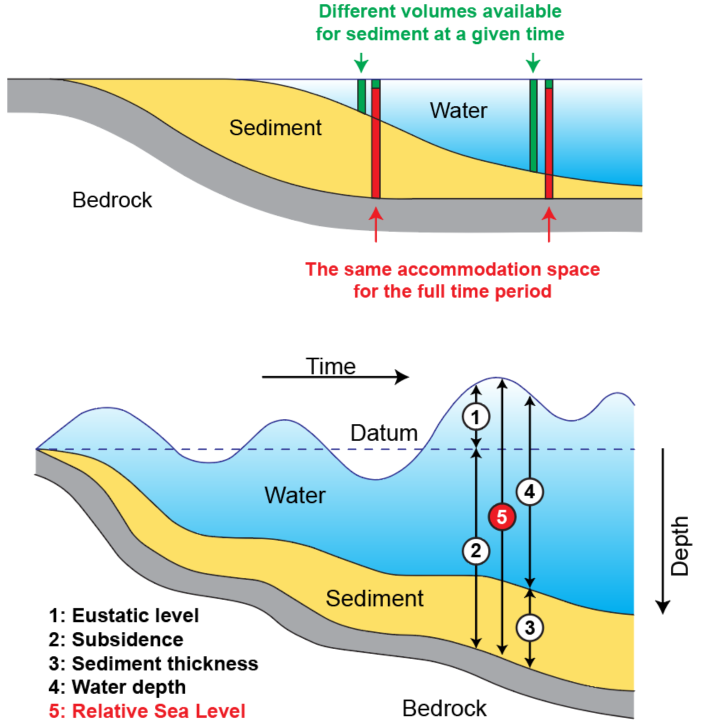
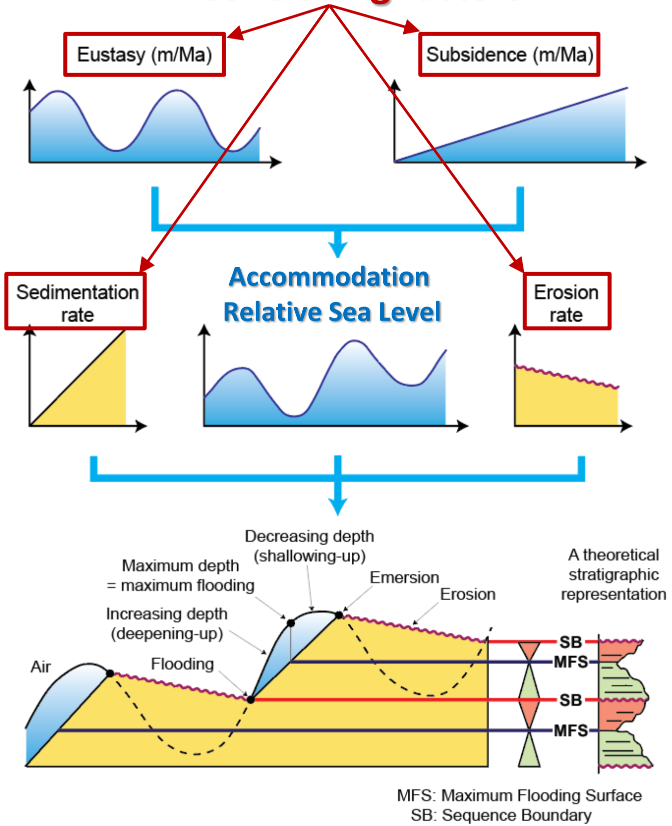
Controlling factors and their consequences

Controlling factors

Accommodation Space, Supply, Water depth



Controlling factors

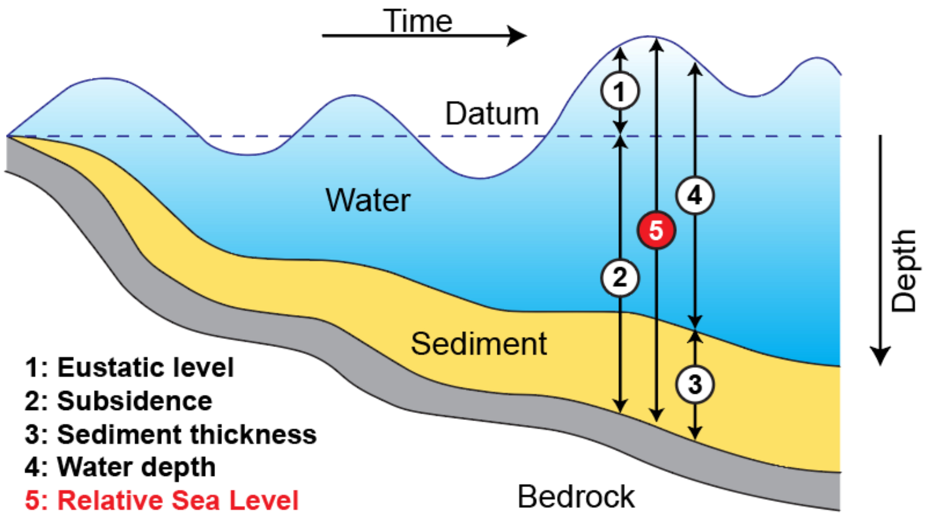


Source: Homewood et al. (1998)

Accommodation or Relative Sea Level (RSL)

Accommodation is the total space (i.e., volume) available for sediment accumulation. In the literature, accommodation is generally referred to as the **Relative Sea Level** (RSL). There are two ways to calculate or estimate accommodation from geological data:

RSL = [Eustacy + Subsidence] = [Water Depth + Sediment Thickness]



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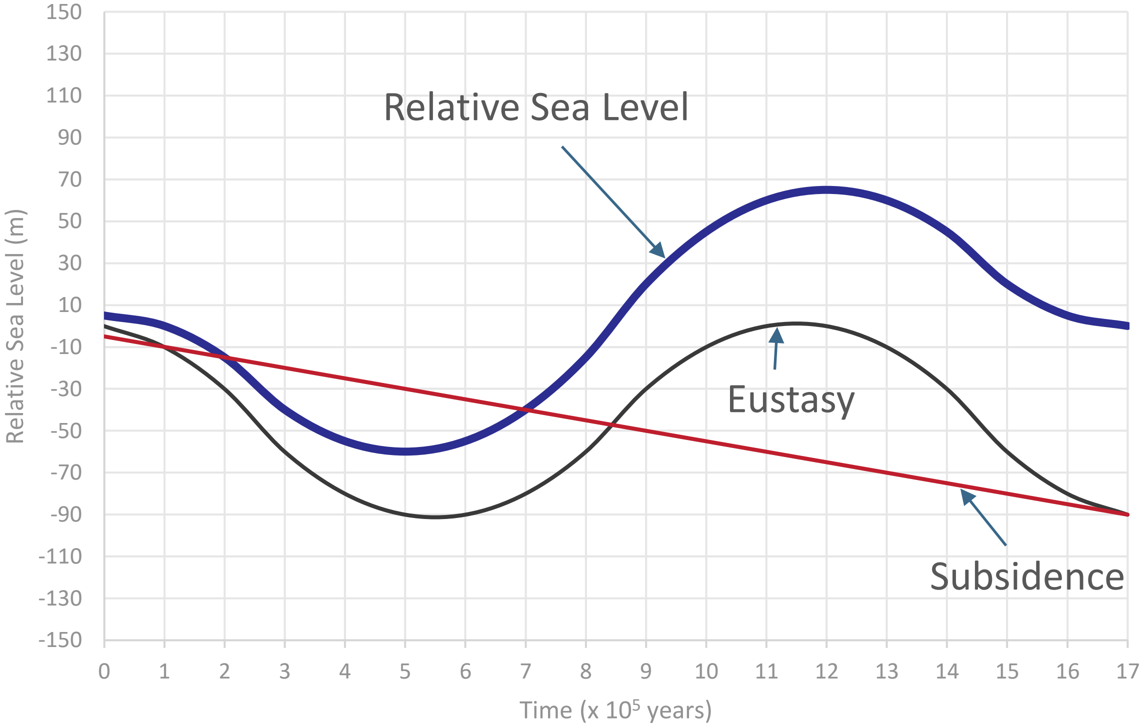
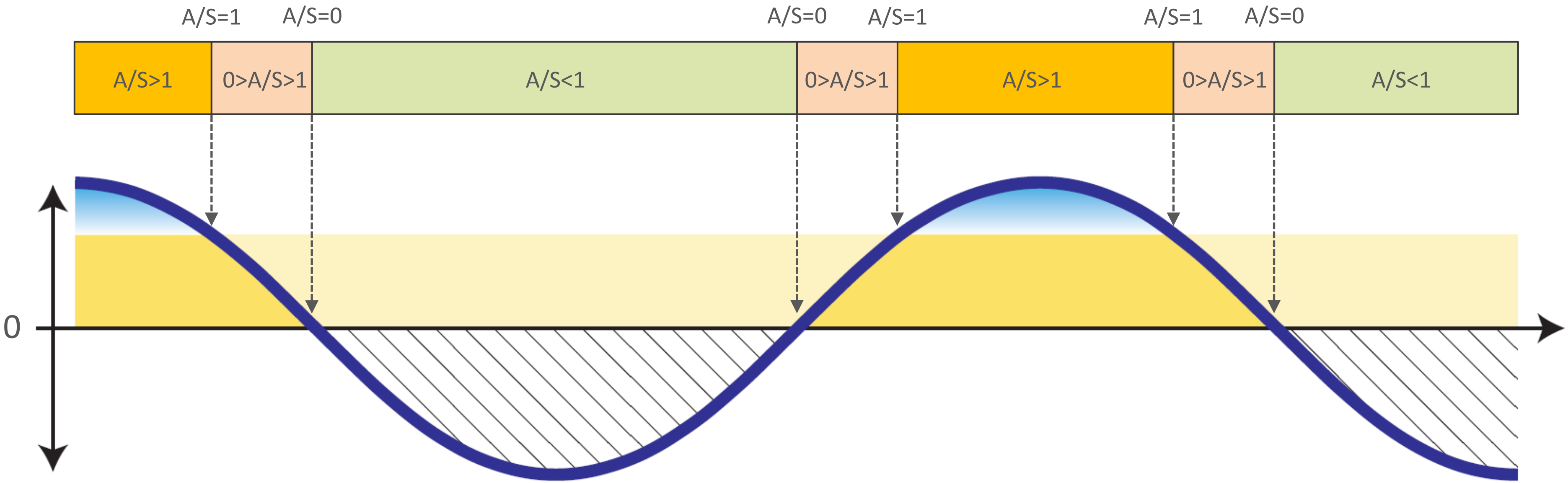
Accommodation or Relative Sea Level (RSL)

Time	Δ Eustasy	Δ subsidence	Δ RSL	Σ RSL
0 to 1	0	-5	5	5
1 to 2	-10	-5	-5	0
2 to 3	-20	-5	-15	-15
3 to 4	-30	-5	-25	-40
4 to 5	-20	-5	-15	-55
5 to 6	-10	-5	-5	-60
6 to 7	0	-5	5	-55
7 to 8	10	-5	15	-40
8 to 9	20	-5	25	-15
9 to 10	30	-5	35	20
10 to 11	20	-5	25	45
11 to 12	10	-5	15	60
12 to 13	0	-5	5	65
13 to 14	-10	-5	-5	60
14 to 15	-20	-5	-15	45
15 to 16	-30	-5	-25	20
16 to 17	-20	-5	-15	5
17 to 18	-10	-5	-5	0



The Accommodation/Sedimentation ratio



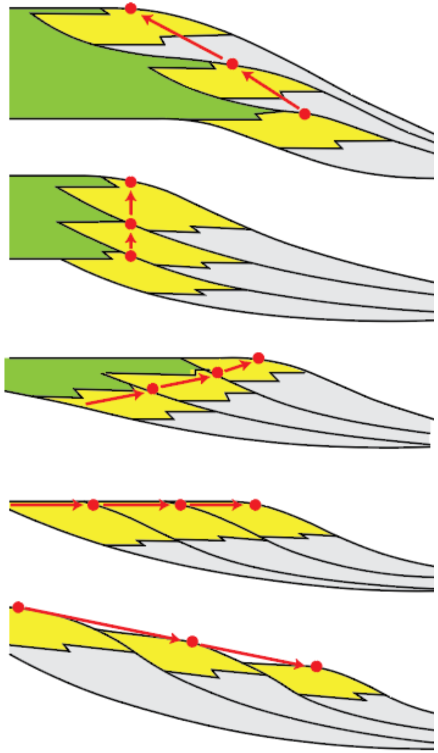
A/S ratio translates into depositional geometries

Stratal geometries are connected to the balance between Accommodation and Supply.

The stratigraphic architecture is controlled and reflects the A/S ratio (Accommodation Potential versus Sediment Supply).

5 main stratigraphic architectures can be defined according to the geometry of the staked sequences.

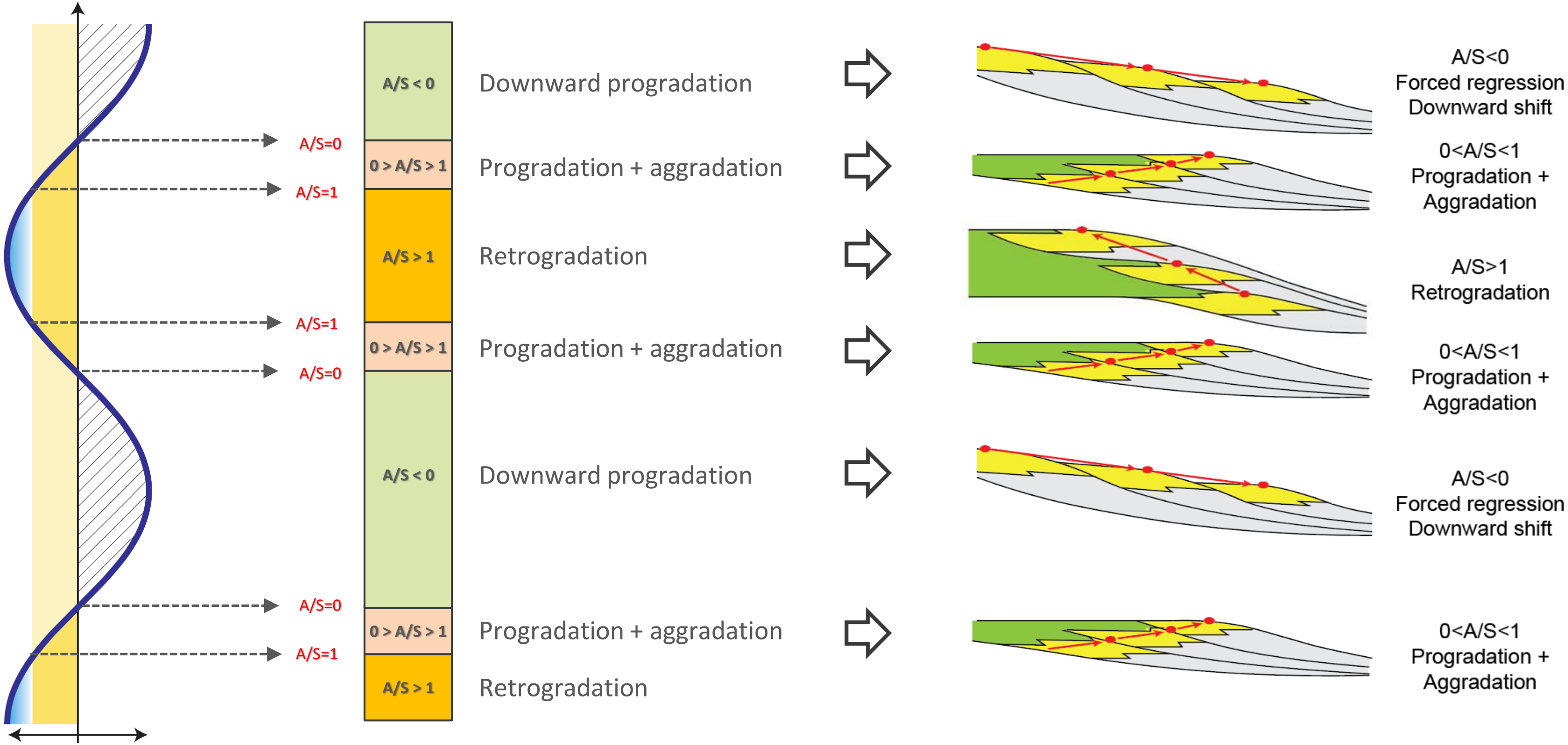
Stratigraphic architecture



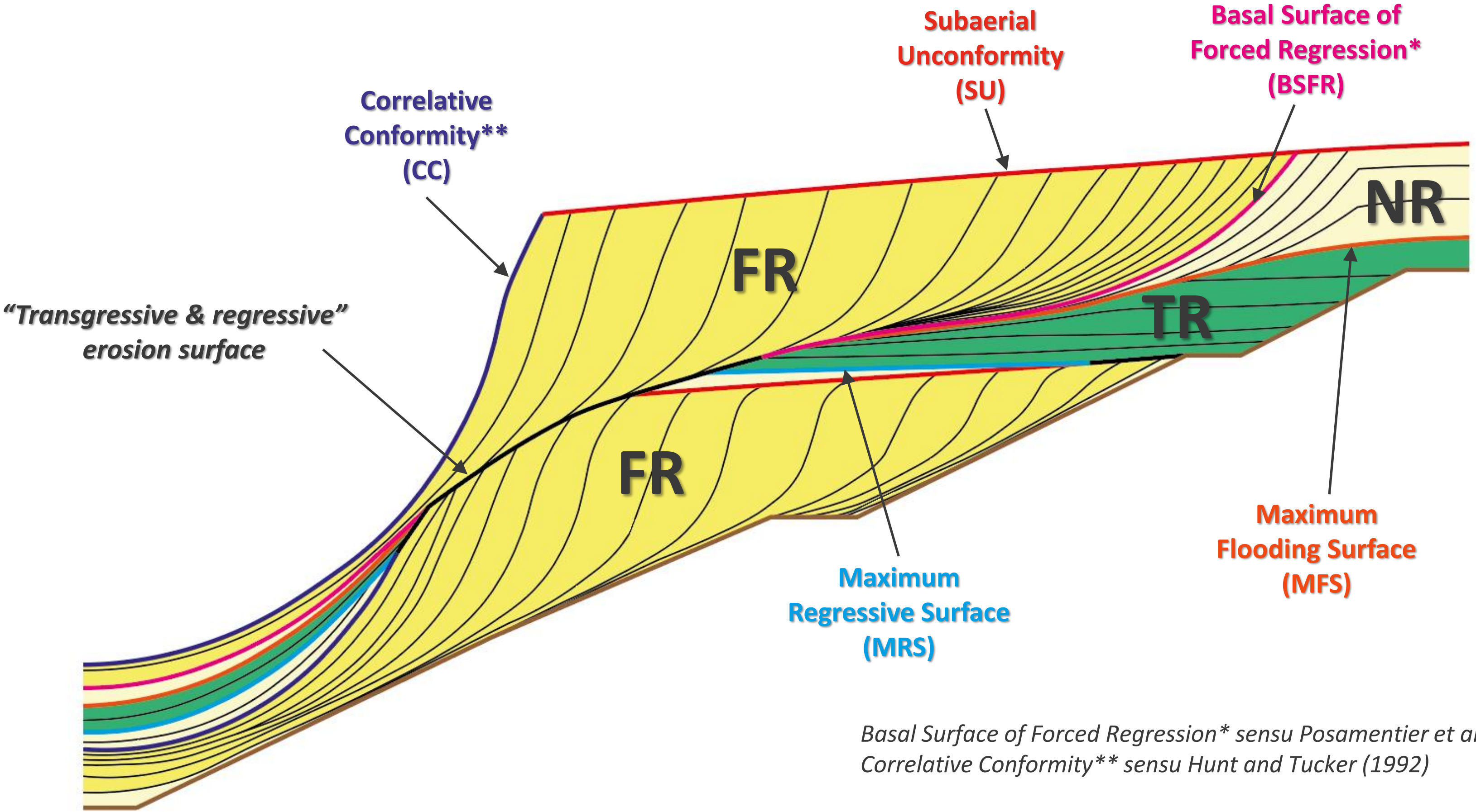
Accommodation / Sediment supply
A/S>1 Retrogradation
A/S=1 Aggradation only
0<A/S<1 Progradation + Aggradation
A/S=0 Progradation only
A/S<0 Forced regression Downward shift

A/S ratio translates into depositional geometries

Relative Sea Level | A/S patterns | Depositional geometries



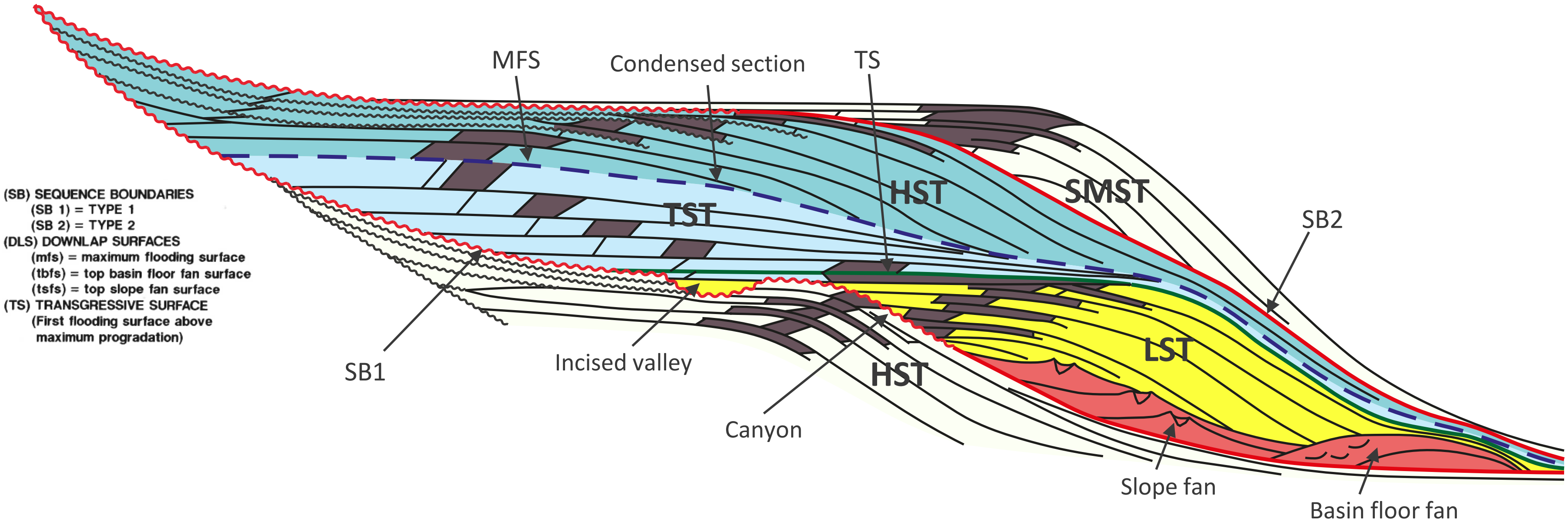
Stratigraphic surfaces and stratigraphic packages



Basal Surface of Forced Regression sensu Posamentier et al. (1988)*
*Correlative Conformity** sensu Hunt and Tucker (1992)*

Back to the Exxon's model – how does it fit?

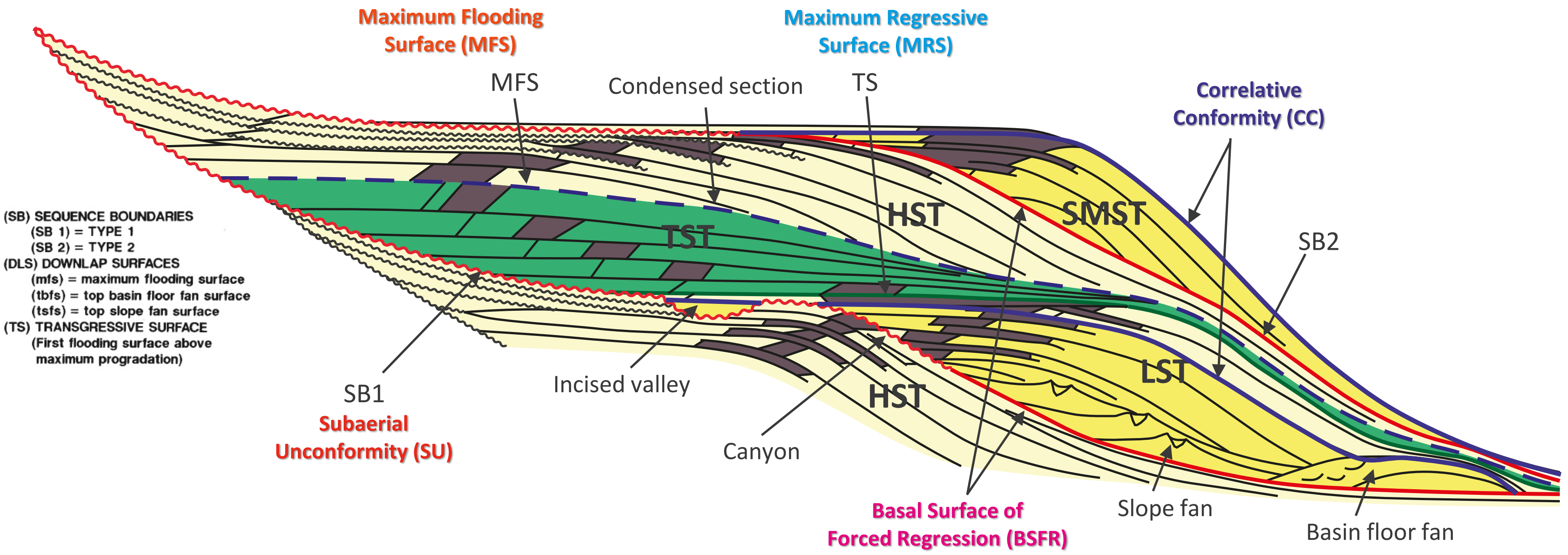
The sequence model of Exxon (Vail et al., 1984): System Tracts and bounding surfaces. Are they consistent with modern sequence stratigraphic concepts and terminology?



Source: Adapted from P. Vail (1987), AAPG Studies in Geology #27, volume 1 – Atlas of seismic stratigraphy (A.W. Bally editor)

Back to the Exxon's model – Stratigraphic surfaces

As it can be seen on this scheme, **terminology used for naming surfaces is model (school) –dependent**. It's up to you!



Source: Adapted from P. Vail (1987), AAPG Studies in Geology #27, volume 1 – Atlas of seismic stratigraphy (A.W. Bally editor)

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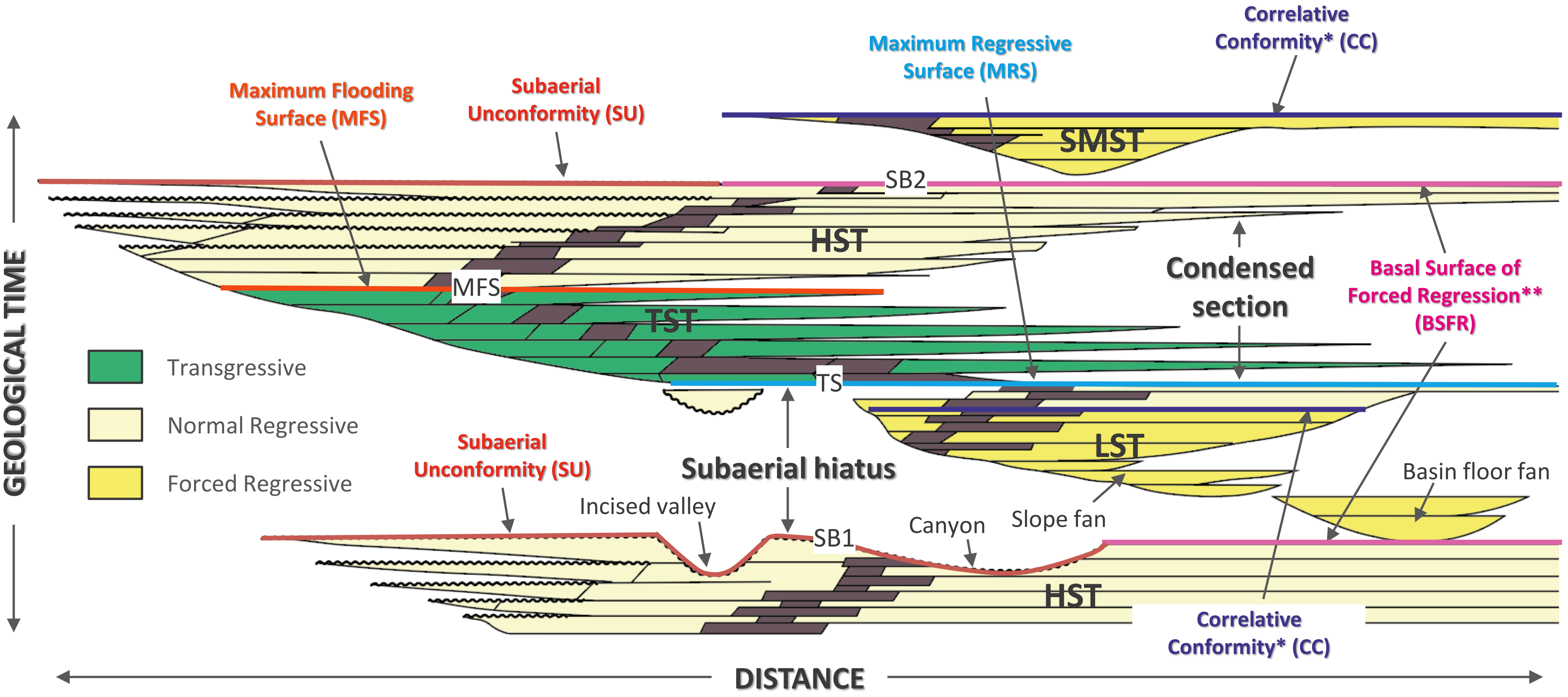
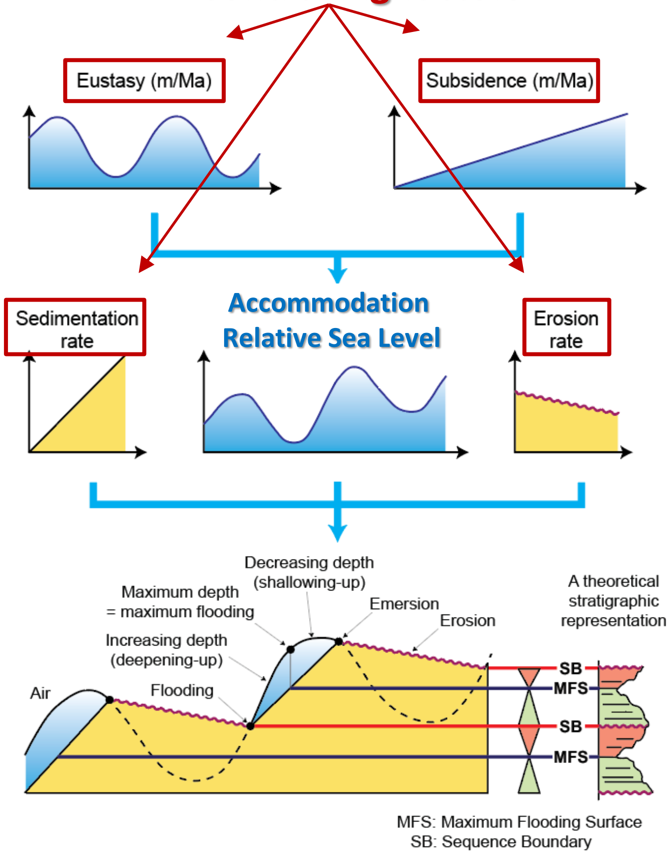
A chronostratigraphic view – the Wheeler diagram

The Wheeler diagram shows the distribution of time gaps (subaerial hiatus) and condensed section.

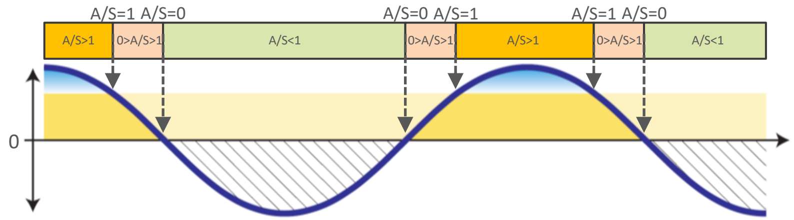


Overview of the principles

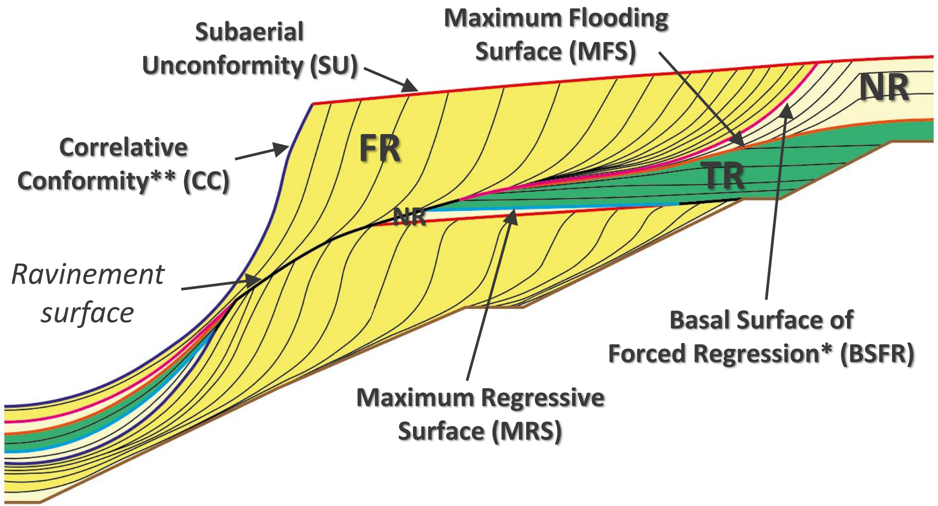
Controlling factors



Relative Sea Level & Accommodation/Sediment ratio



Depositional geometries, packages & surfaces



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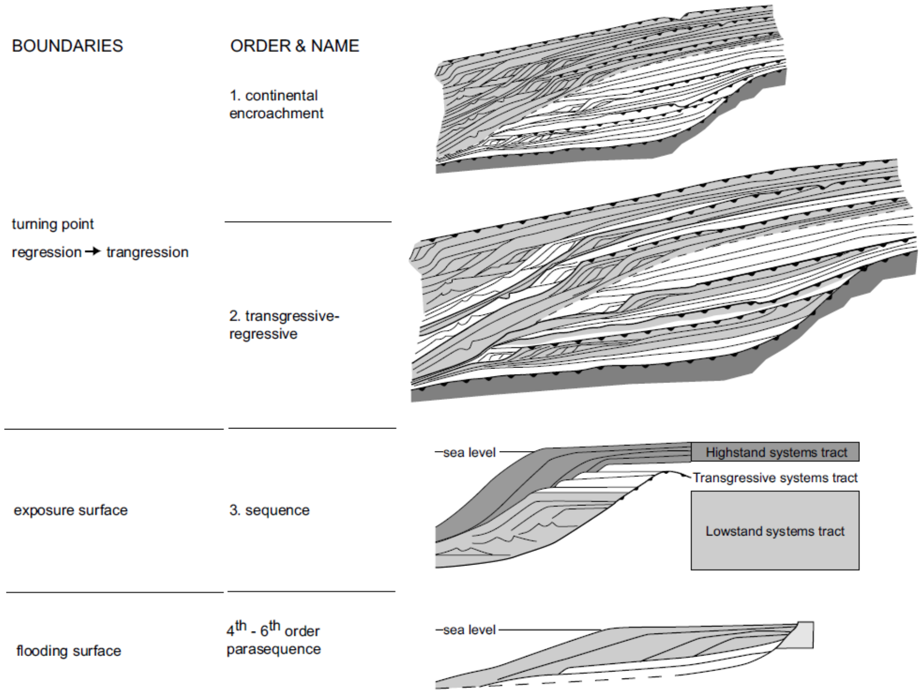
A note about the concept of orders in sequence stratigraphy



Source: Duval et al. (1998), Schlager (2004, 2005)

Orders are subdivisions of convenience rather than an indication of natural structure (Schlager, 2004).

Sediment architecture is largely scale invariant over a wide range of scales in time and space.

Duration of orders of stratigraphic sequences, as defined by various authors, show differences, especially in the 5th and 6th order.

The link between sequence order and dominant controlling factor (eustasy, tectonics, orbital forcing etc. is highly debated).

Usually sequence stratigraphic studies deal with "3rd" and "2nd order" cycles.

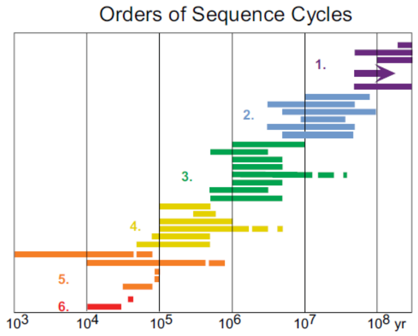


Fig. 6.15.— Orders of stratigraphic sequences as defined by various authors since 1977. In each category, the oldest publication is on top. Differences are about 1/2 order at each boundary, in the 4^{th} - 6^{th} orders even larger; opinions do not seem to converge with time. After Schlager (2004), modified.

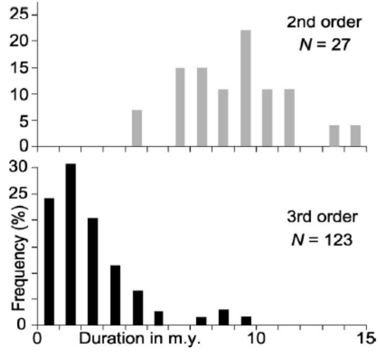
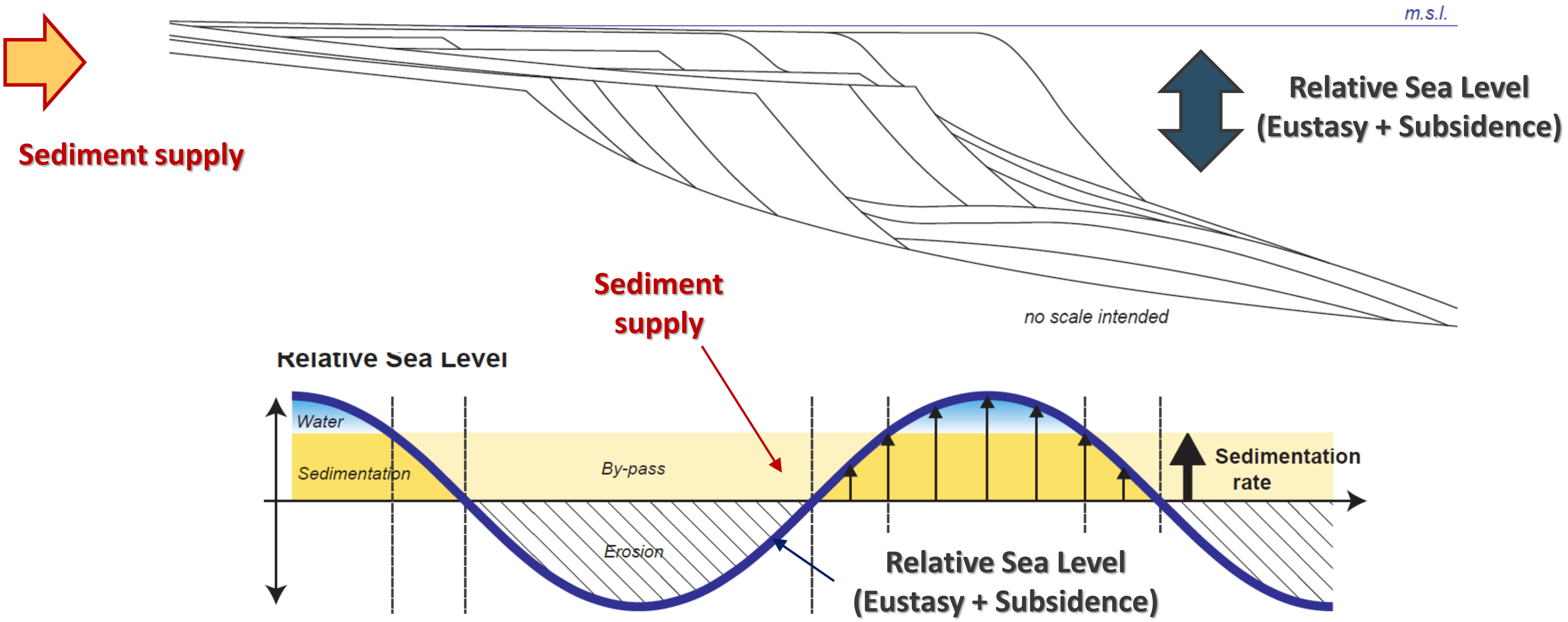


Figure 2. Durations of sea-level cycles of 3rd and 2nd order of eustatic curve of Haq et al. (1987). Two orders broadly overlap.

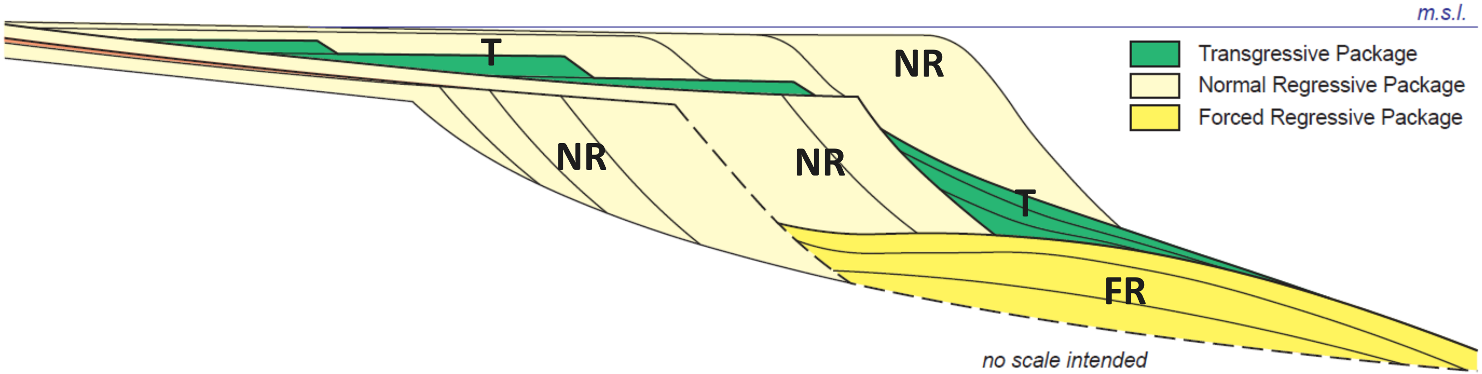
Summary – Accommodation vs Sediment supply

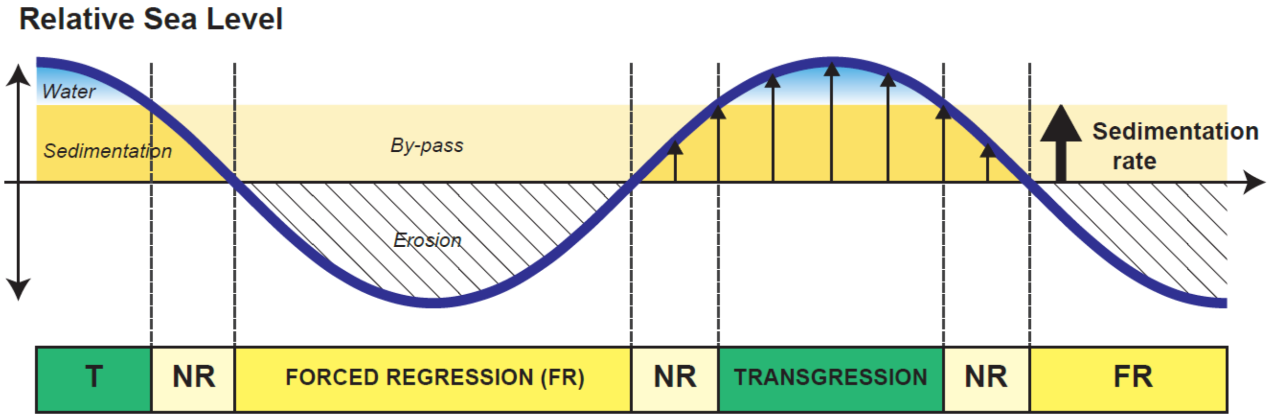
Sequence stratigraphic breakdown is based on the analysis of A/S ratio (RSL vs Supply)



Subdivision into stratigraphic packages

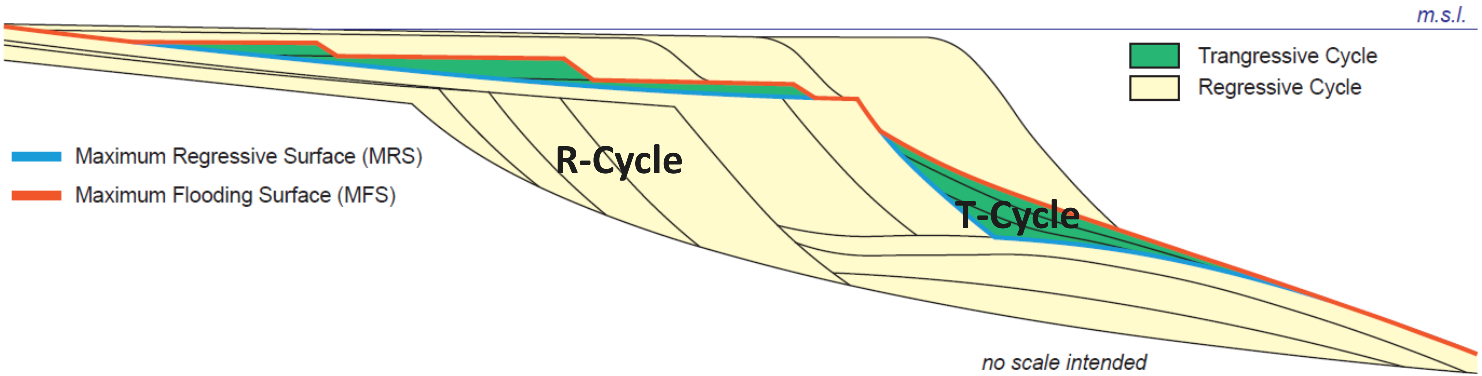
Model-independent **key step** of the sequence stratigraphic breakdown.

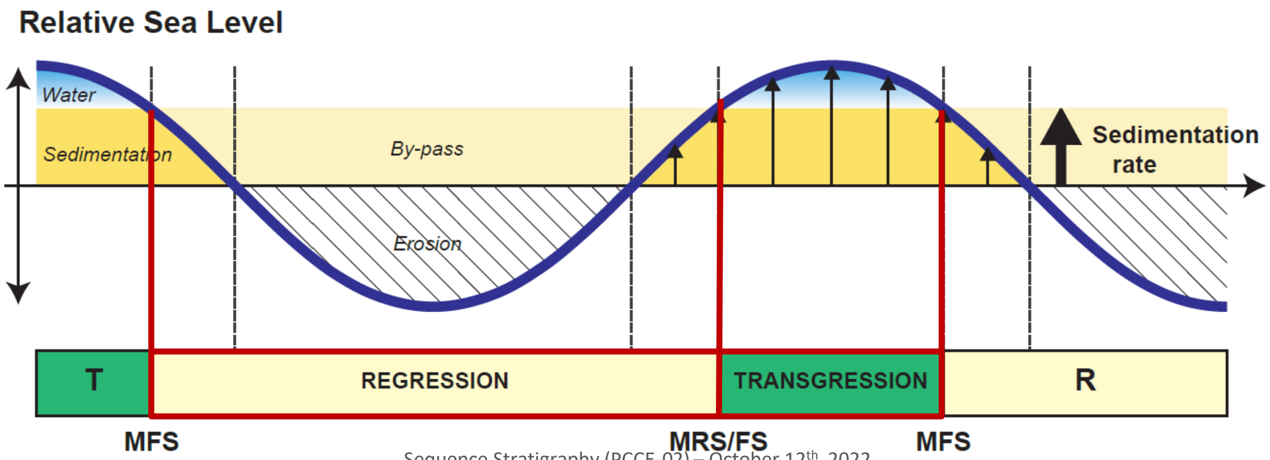




Option 1 – Breakdown into T-R Cycles

Packages can be assembled into Regressive Cycles (NR + FR) and Transgressive Cycles (TR)

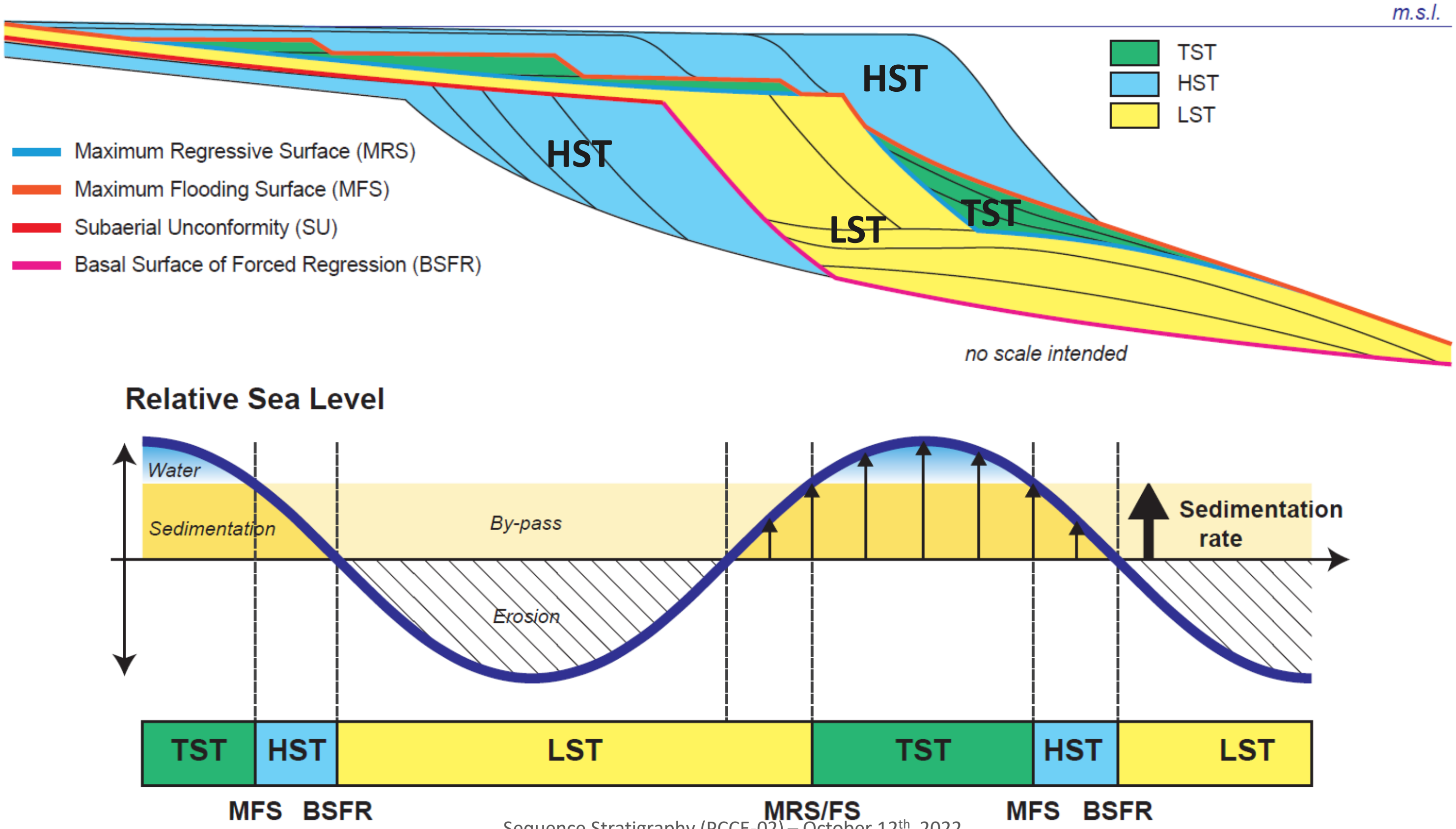




** T-R Cycles were defined by Embry and Johannessen (1992). Here their sense is after Catuneanu (2006).*

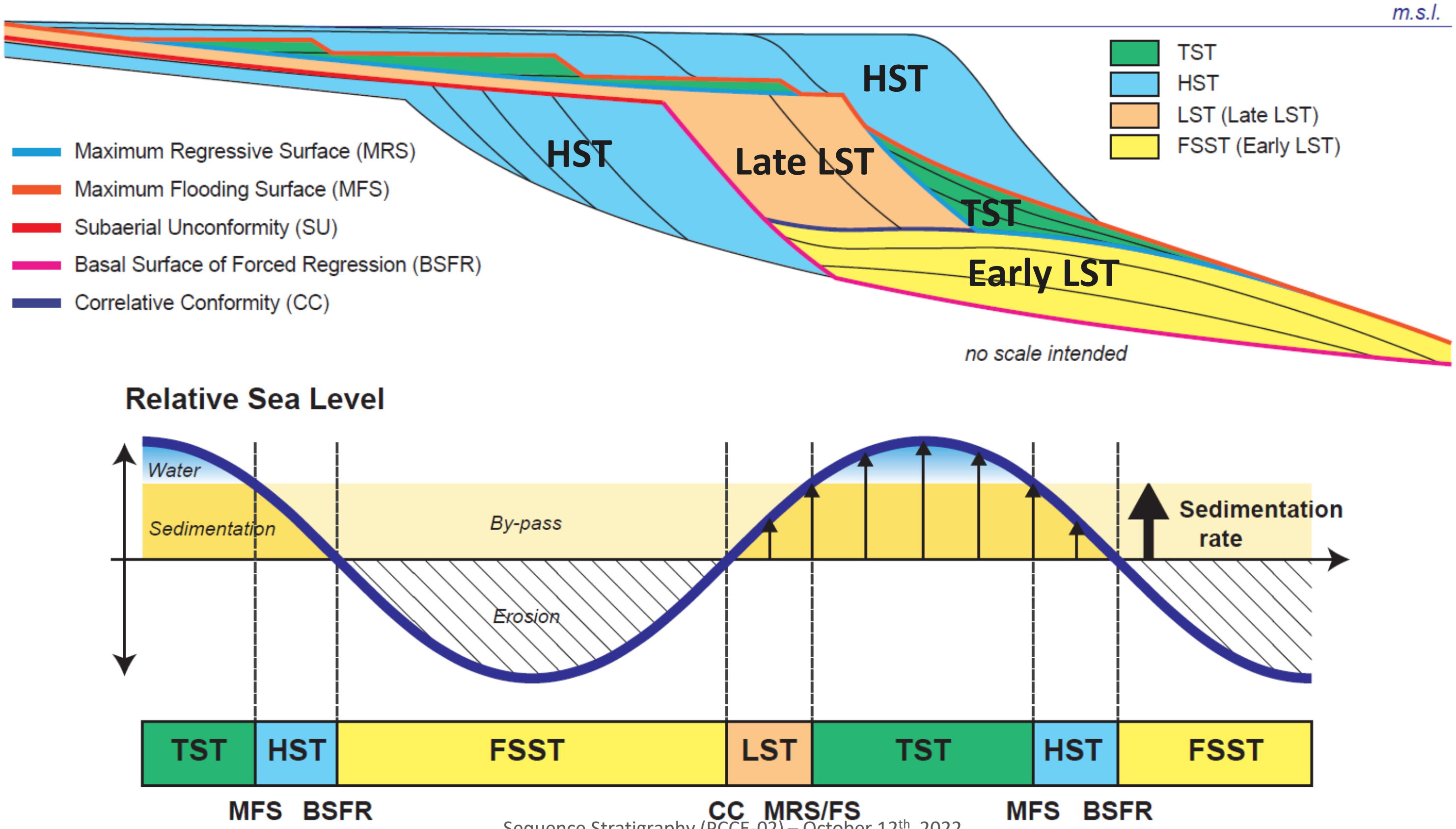
Option 2 – 3 System Tracts (TST, HST and LST)

Packages can be assembled into Highstand (NR), Lowstand (NR+FR) and Transgressive system tracts (T)



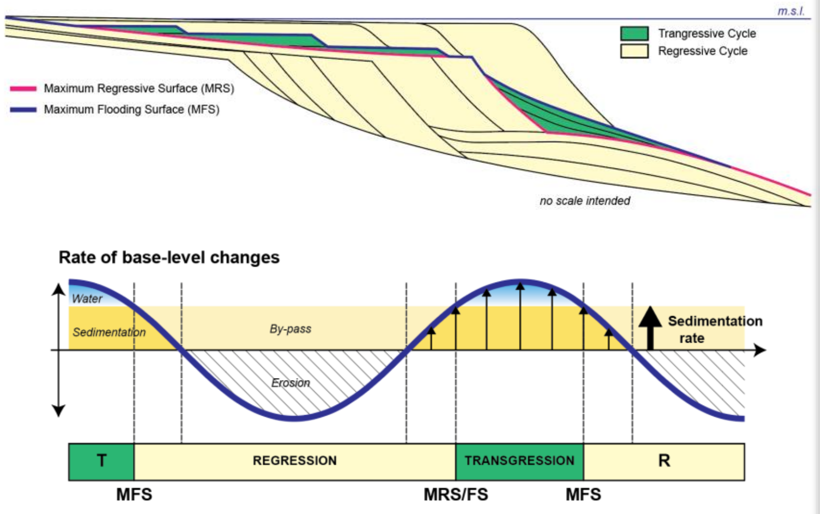
Option 3 – 4 System Tracts (TST, HST, early LST and late LST)

Lowstand package can be further divided into early LST (FR) and late LST (NR)



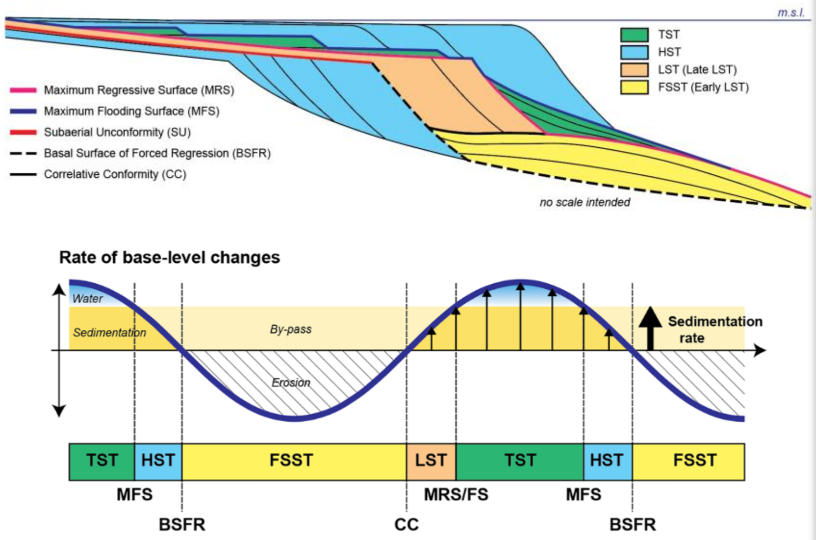
T-R Cycles vs System Tracts

TR Cycles



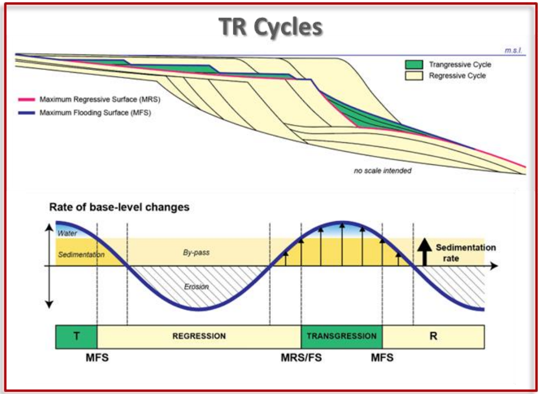
- Broad or Quick Look approach (2nd order).
- Used in exploration studies or incomplete/sparse datasets.
- Provide the gross envelop of potential reservoir stacks (R cycles) and correlation rails (T Cycles).

System Tracts

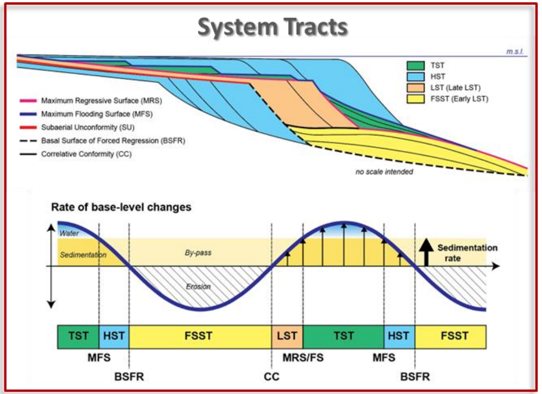


- Refined approach (3rd to 4th order).
- Used in reservoir studies, involving good-quality datasets.
- Provide a precise correlation scheme, allowing individual reservoir units to be deciphered within stacks.

What option to take, under what circumstance?

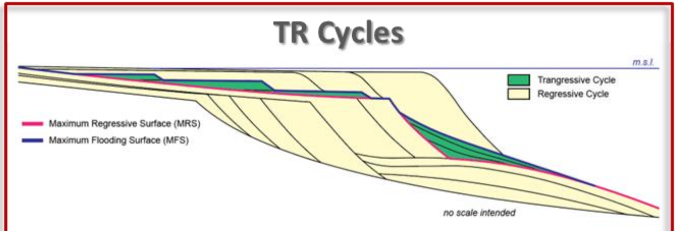
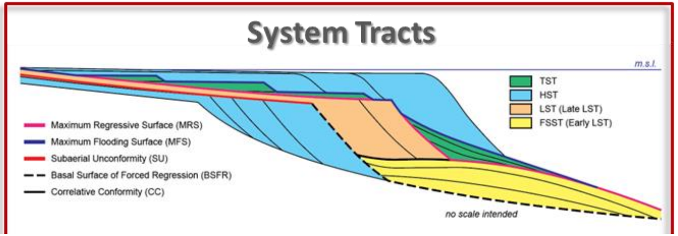
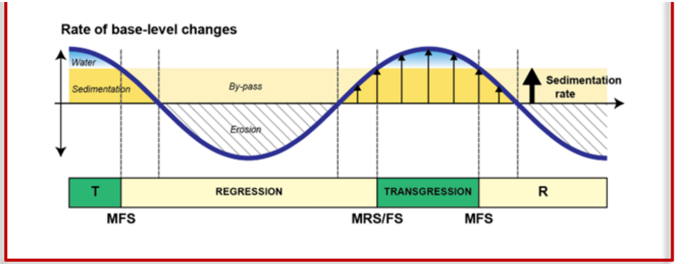
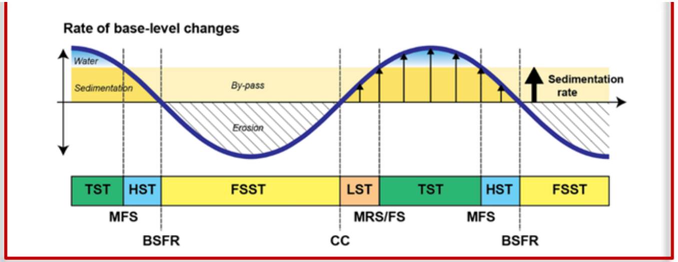


- **Data**: regional 2D lines, large area with 2D and/or 3D seismic cover
- **Timeframe**: 4 to 12 weeks to cover 1000s km² (play to basin scale)
- **Technical objective**: regional stratigraphic frame, play to basin scale
- **Technical context**: Exploration project of frontier to immature basin

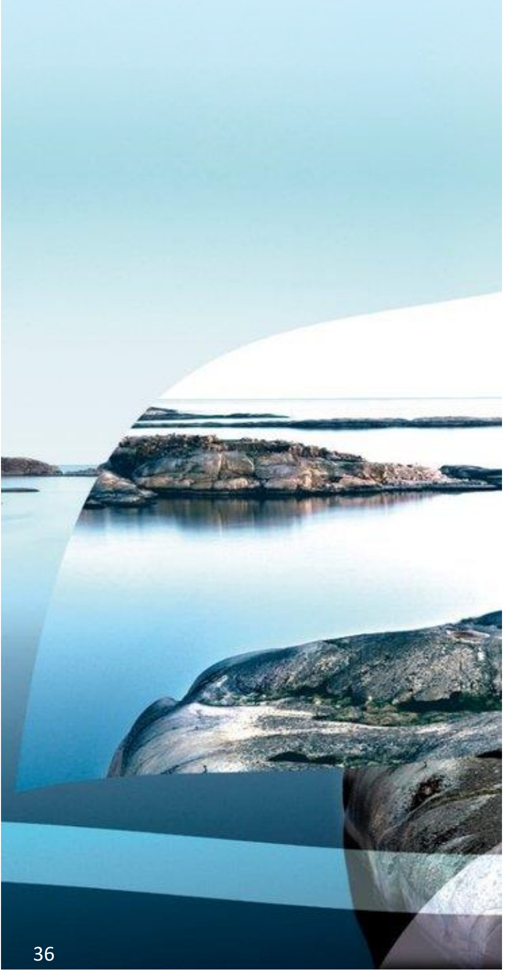


- **Data**: high-resolution 3D seismic survey, seismic attributes
- **Timeframe**: 4 to 20 weeks to cover 100s km²
- **Technical objective**: specific target, down to field to prospect scale
- **Technical context**: Near field exploration to field development scale

Two alternative workflows / disciplines

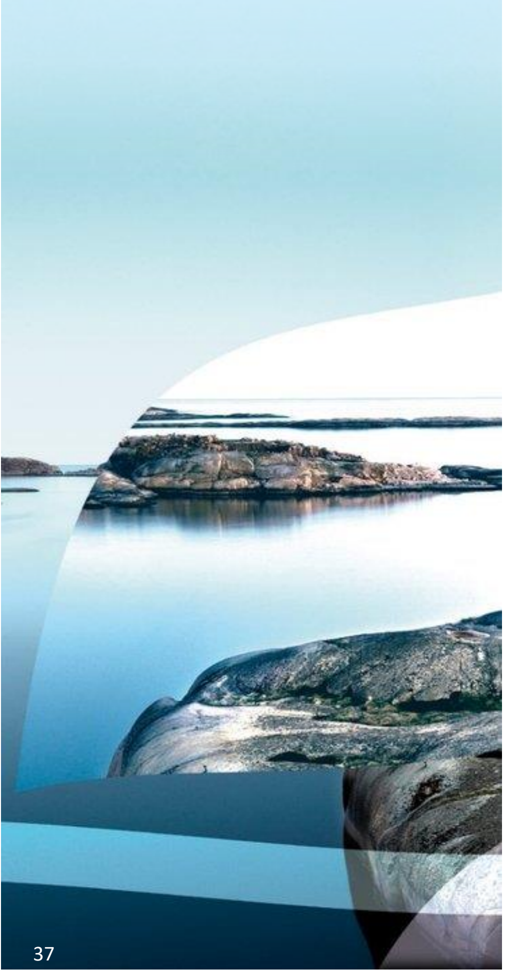
	Play to basin-scale Exploration of frontier to immature basins	Field to play scale Near-field to field development
Seismic-based approach Depositional geometries		
Well-based approach A/S patterns		

Principles of sequence stratigraphy – Summary



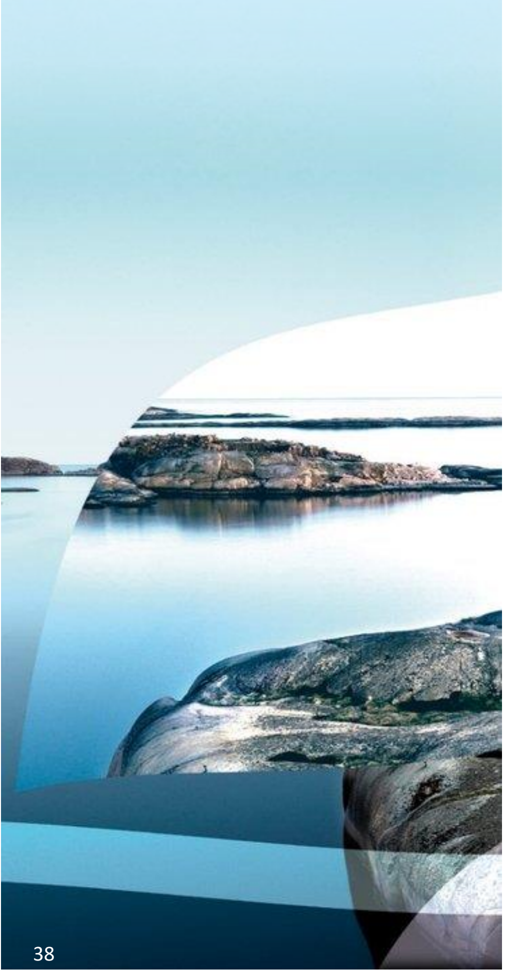
- 3 controlling factors (allogenic): **eustasy**, **subsidence**, **sediment supply**
- Eustasy + Subsidence = **Accommodation** also referred as to **Relative Sea Level** in most articles and textbooks
- **Interplay** between **RSL** and **Sediment supply** define the **stratal architecture** of sequences
- The architecture of sequences can be deciphered from the analysis of **A/S ratio** and **depositional geometries** (progradation, aggradation, retrogradation)
- Stratigraphic sequences can be subdivided into 3 types of stratigraphic packages: **Normal Regressive** (P+A), **Forced Regressive** (downward P) and **Transgressive** (R)

Principles of sequence stratigraphy – Summary



- The stratigraphic **packages** are **bounded** by stratigraphic **surfaces**
- The definition of stratigraphic **packages** and bounding **surfaces** are **model-independent**
- The **naming** of stratigraphic **surfaces** is **model-dependent** (EXXON school or others)
- The **grouping** and **naming** of stratigraphic **packages** is also **model-dependent**
- Two sequence models are conventionally used nowadays:
  - **System tracts** (modernized EXXON model)
  - **Transgressive-Regressive Cycles**

Principles of sequence stratigraphy – Summary



- In practice, it is suggested to choose the sequence model according to scope:
  - **T-R Cycles**: Regional scale interpretation or fast-track analysis of frontier to immature basins, with limited dataset and low to moderate data resolution
  - **System Tracts**: Near field-to-field development scale, prospect maturation with significant dataset and good data resolution
- Two approaches can also be envisaged:
  - **Seismic-driven** approach based on the analysis of **depositional geometries** imaged on seismic
  - **Well-driven** approach based on the analysis of the **vertical stacking of sedimentary facies**

Seismic stratigraphy

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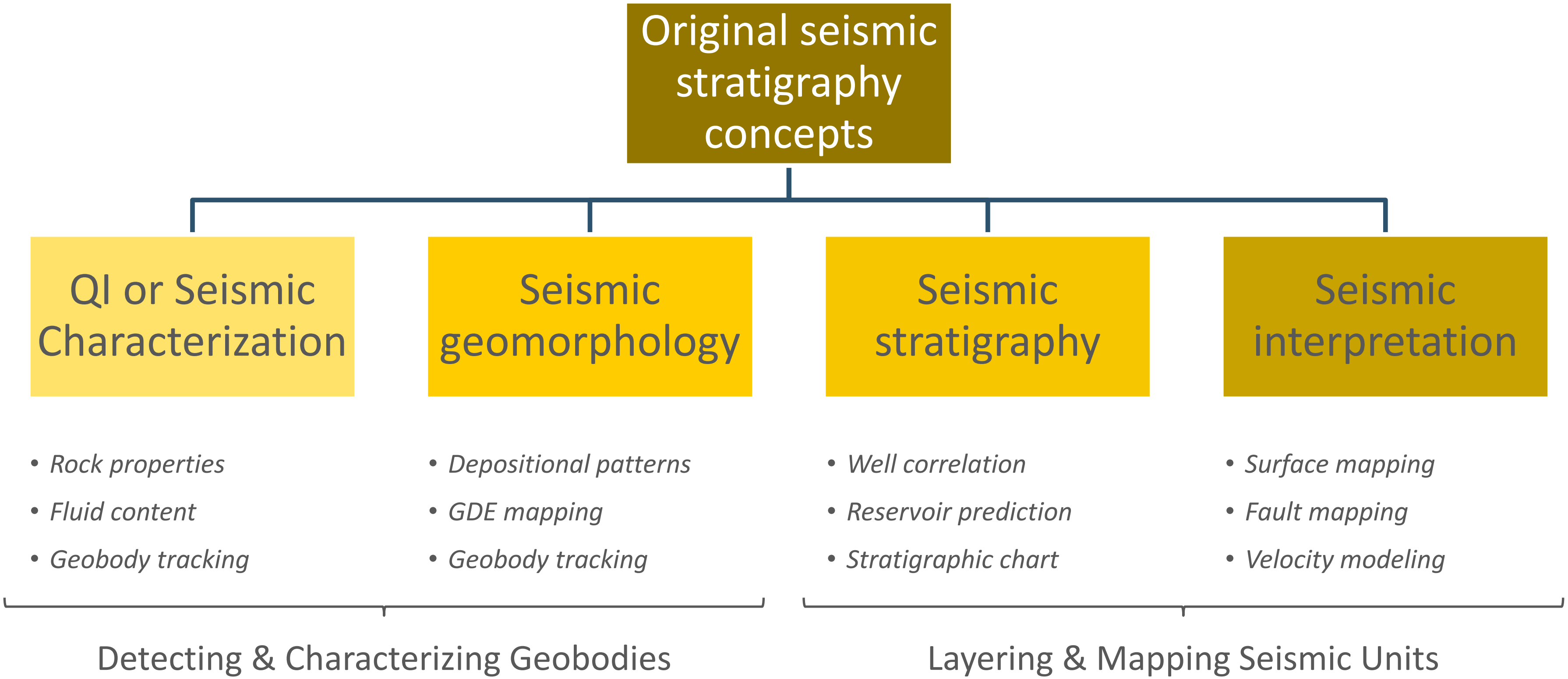
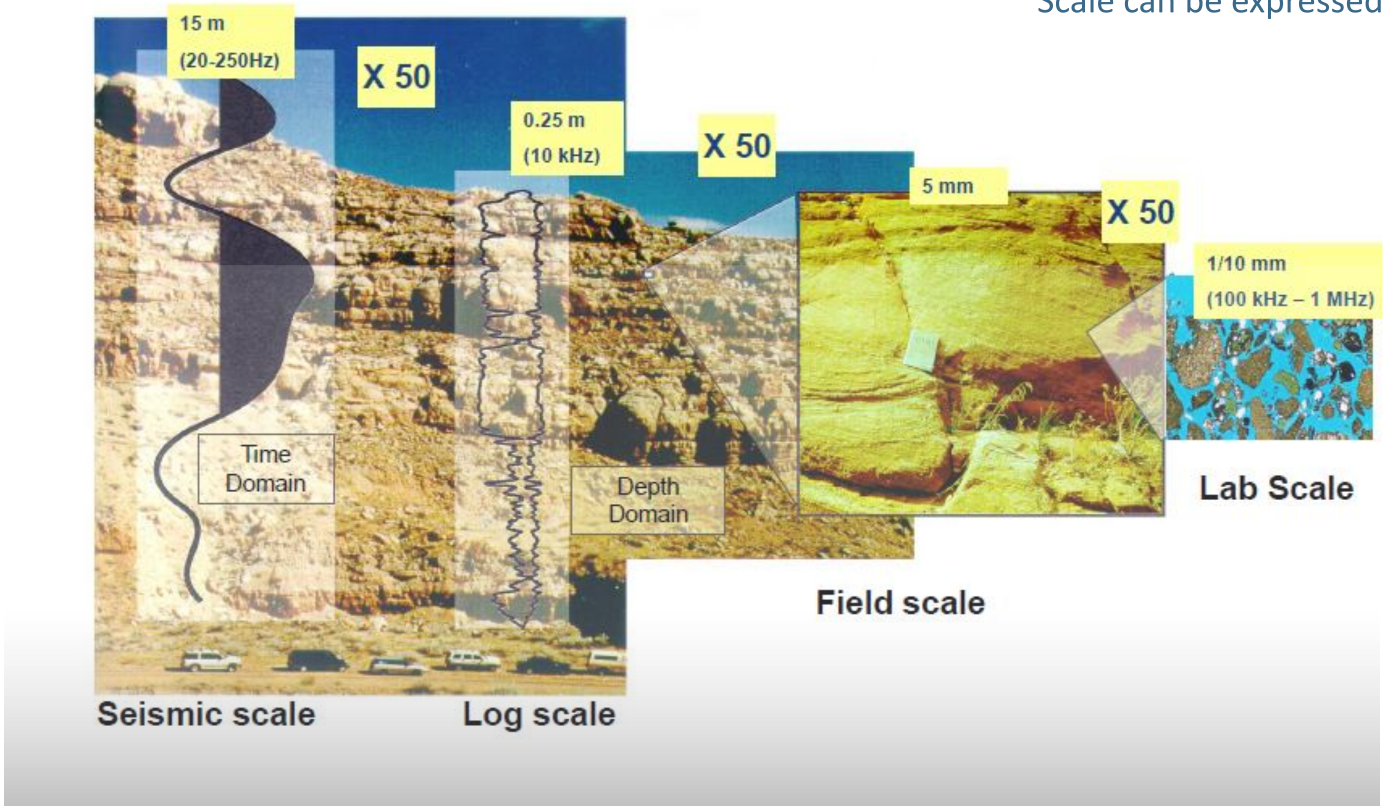
Basic principles

The descendants of seismic stratigraphy



The seismic scale



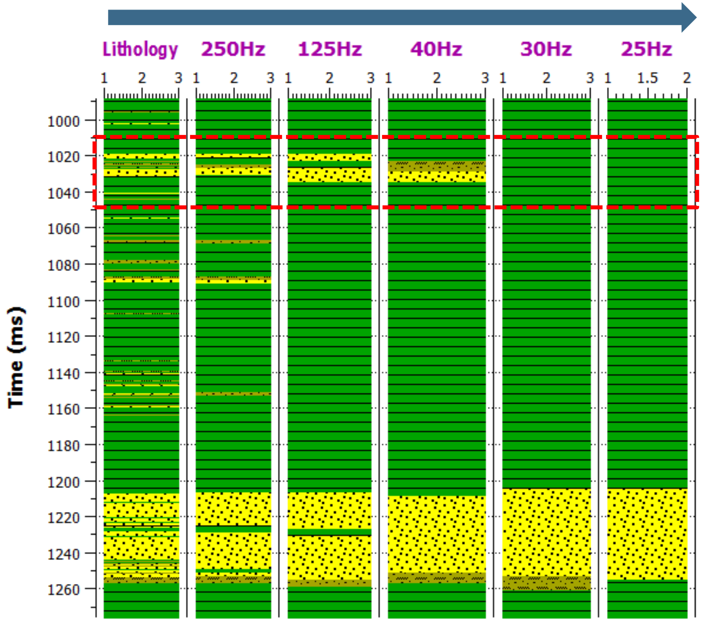
Scale can be expressed in terms of frequency ranges

- The range of seismic frequencies is usually 40 to 80 Hz
- Logging frequencies are around 10 kHz
- Laboratory frequencies traditionally range from 100 kHz – 1 MHz

Seismic waves and resolution

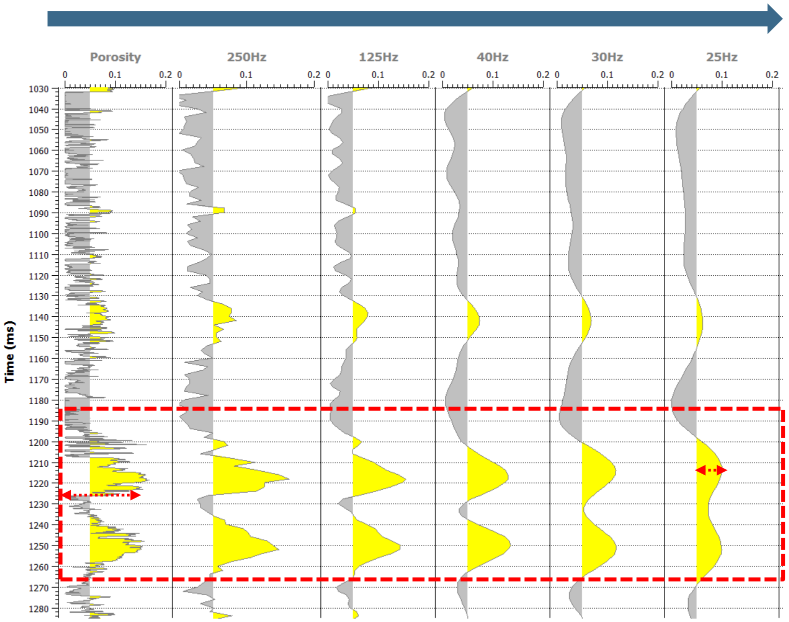
Facies/lithology data is upscaled using "most of" algorithm. The facies is assigned according to the most represented in a time window, **mimicking the seismic resolution**.

Decreasing resolution



Continuous petrophysical properties are **upscaled** using a low-pass filtering, with corner **frequencies consistent with the seismic bandwidth.**

Decreasing resolution



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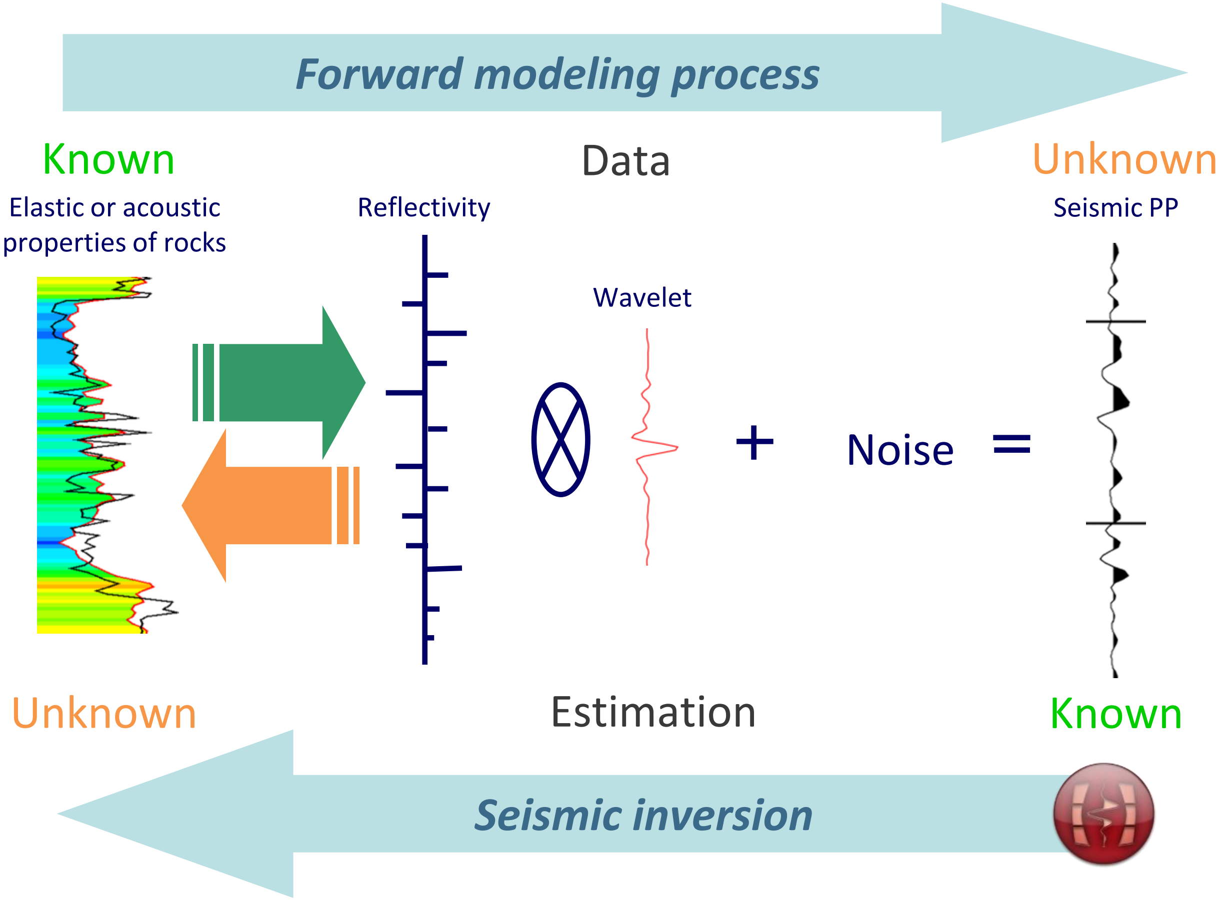
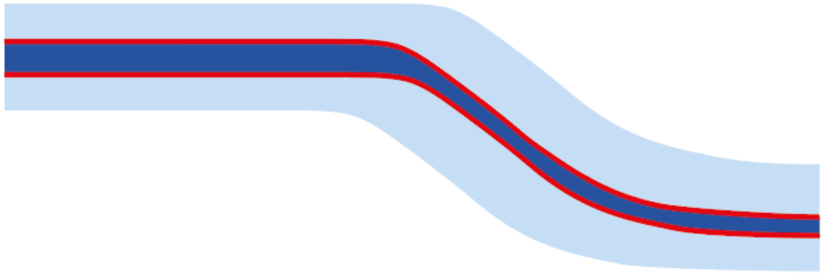
Relationships between rocks, impedance and seismic amplitude



The chronostratigraphic significance of seismic reflections

Chronostratigraphic significance of seismic reflectors



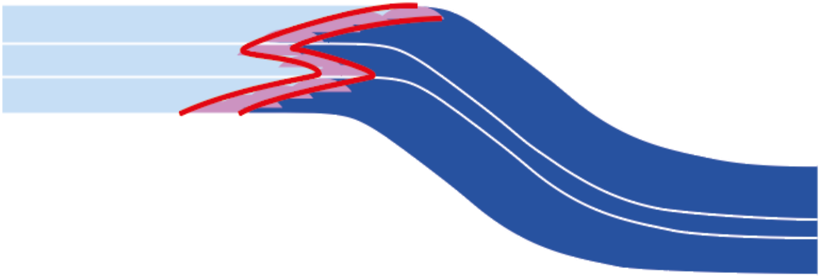
Distribution of petrophysical properties follow the depositional surfaces.

Applies to almost all clastic and some carbonate depositional systems.

Seismic reflector can be approximated to time-lines

Reality is in between

No chronostratigraphic significance of seismic reflectors

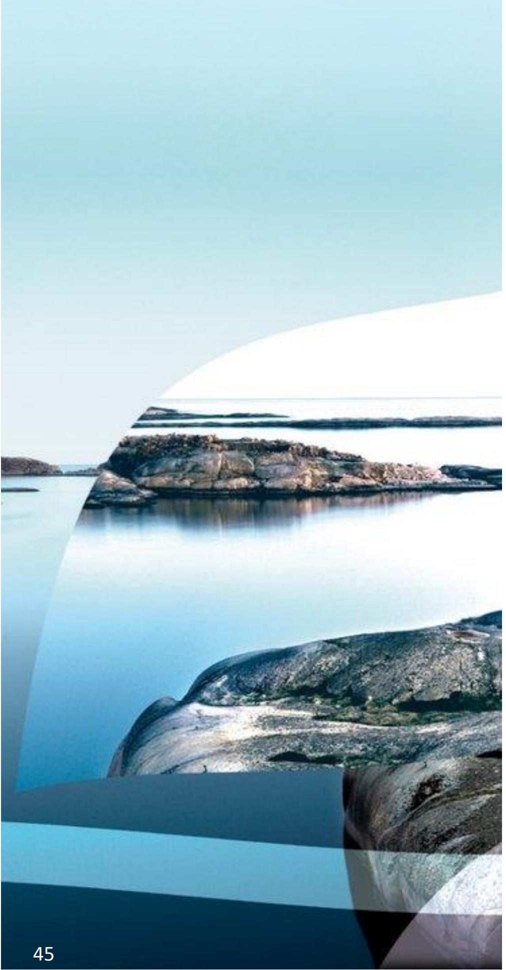


Distribution of petrophysical properties cross-cut the depositional surfaces.

Applies to some carbonate depositional systems.

Seismic reflector cannot be used as time-lines with confidence

Summary



- **Seismic scale** is larger than geological scale. Resolving or detecting geological bodies documented at well can be challenging
- **Seismic frequency** has a primary impact on seismic imaging of depositional surfaces and geometries, making it sometimes difficult to resolve properly
- **Seismic reflector** responds to contrasts in petrophysical properties of rock bodies. These properties may either follow or cross-cut depositional surfaces
- **Seismic reflector** have not necessarily a chronostratigraphic significance. Diagenetic alteration of carbonate rock may impact rock properties across depositional surfaces
- **Seismic data** may contain artifacts due to acquisition or (re)processing. These artifacts may mimic depositional features

Seismic stratigraphy

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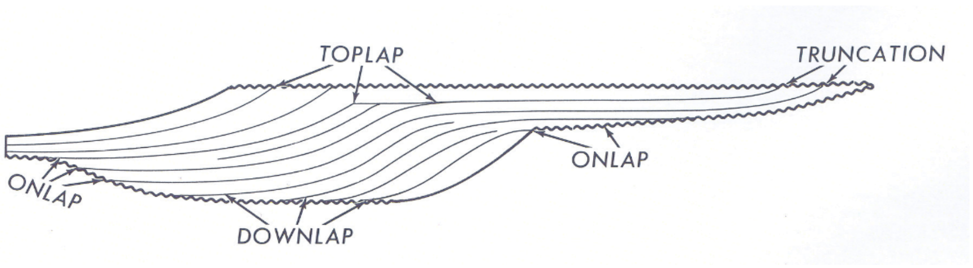
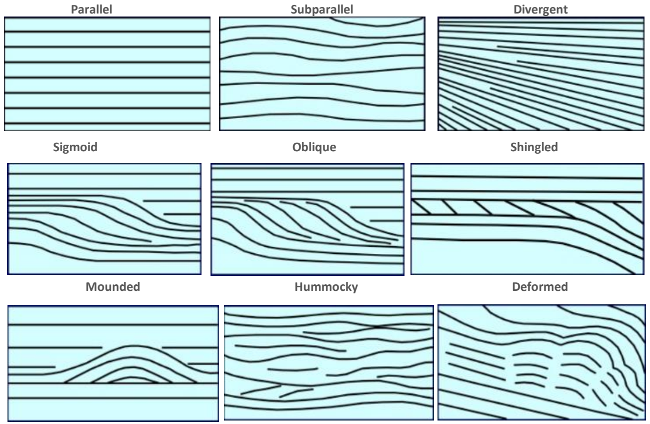
Components

Seismic Reflection Terminations, Configurations and External Forms

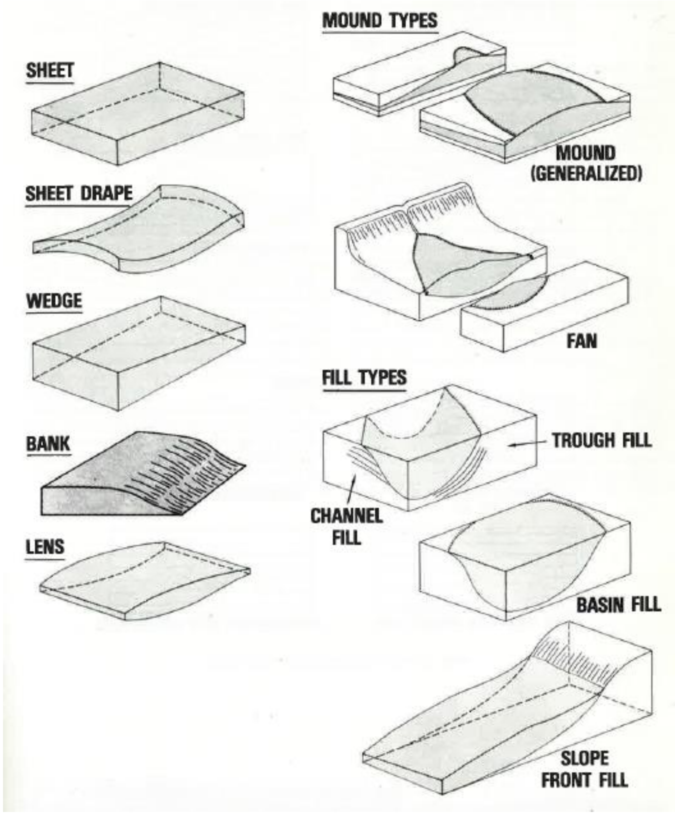
Seismic Reflection Terminations



Seismic Reflection Configurations



External forms of some seismic units



Source: Mitchum et al. (1977)

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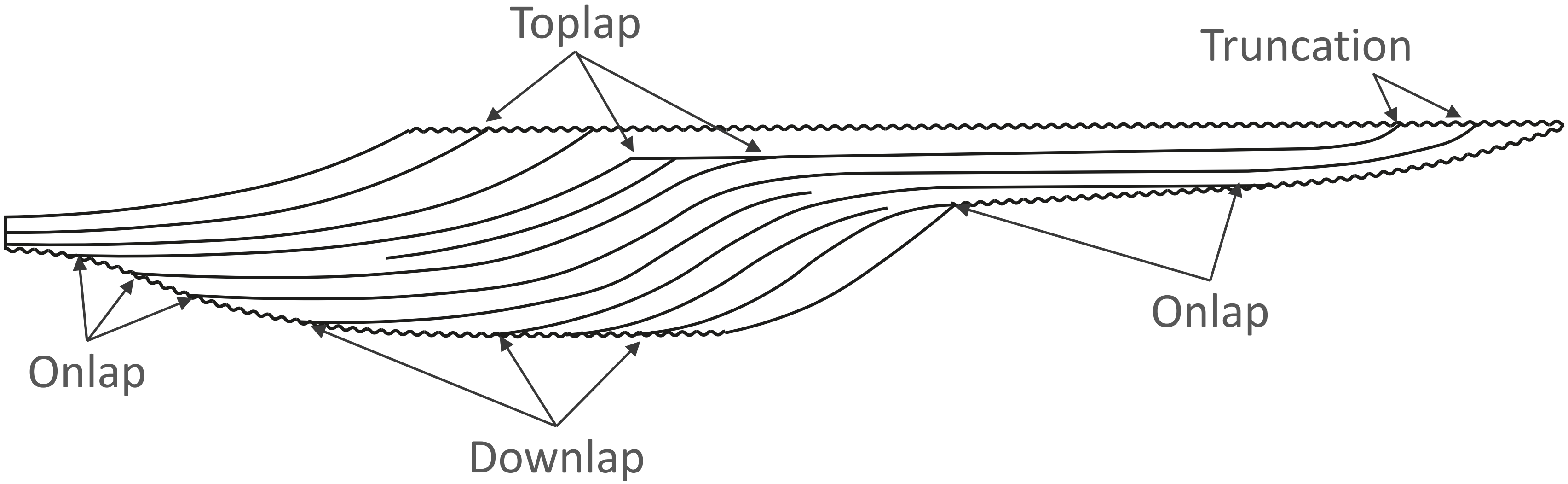
Seismic Reflection (strata) Terminations

A seismic sequence is a relatively conformable succession of reflections on a seismic section, interpreted as genetically related strata; this succession is bounded at top and base by […] unconformities or their correlative conformities.

Reflection (stratal) terminations are **the principal criteria for recognition of seismic sequence boundaries**.



Source: Mitchum et al. (1977)

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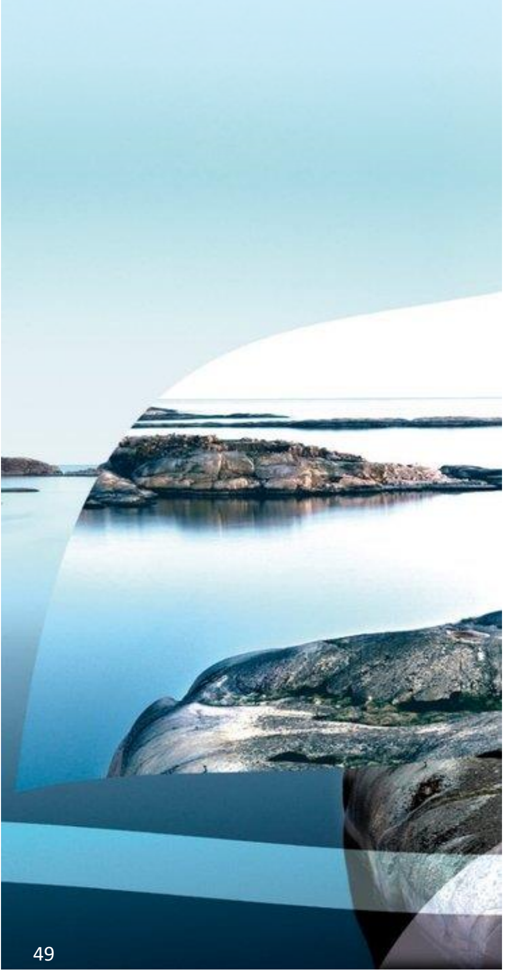
Stratal terminations in short

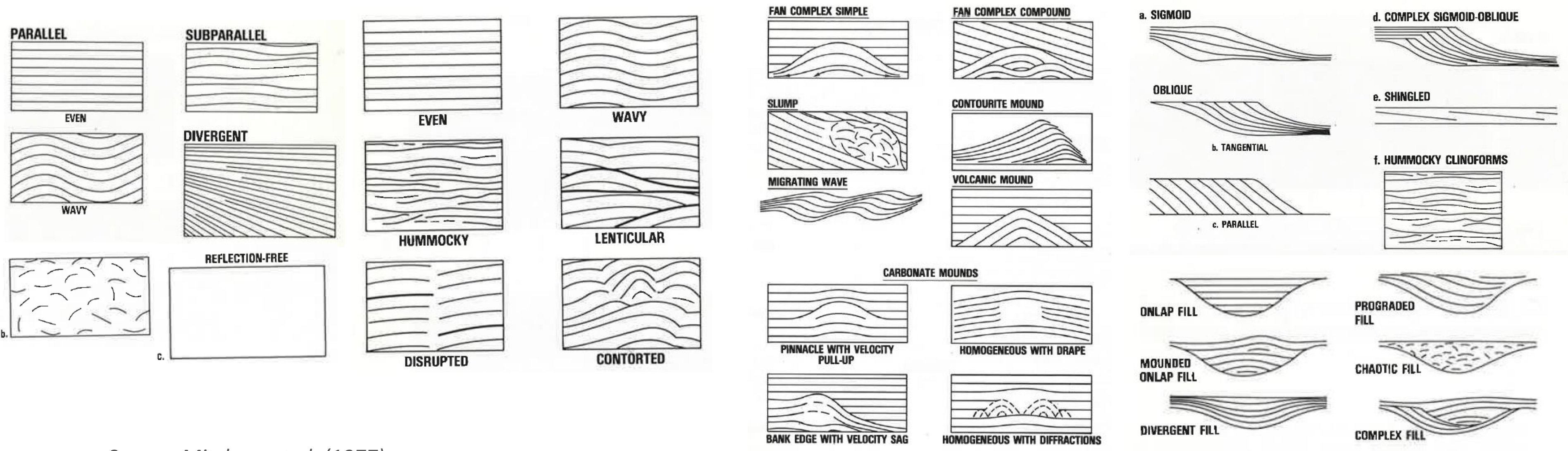


- Although stratal terminations were introduced in the early days of seismic stratigraphy:
  - They are still very popular: easy to recognize on seismic images
  - No need for sophisticated tool to interpret them (seismic software, drawing software etc.)
- Avoid overinterpret stratal terminations:
  - A single stratal termination is not enough to conclude
  - Observation is dependent upon seismic data (smoothing etc.)
  - Some system lack of stratal terminations (layered cake seismic data)
- Seismic Characterization (QI) offer now a wide spectrum of robust seismic attributes compared to seismic facies identified in the 70's on seismic amplitude display.

Seismic Reflection Configurations

Seismic facies analysis is the description and the geologic interpretation of seismic reflection parameters, including **configuration**, continuity, amplitude, frequency, and interval velocity.

Reflection configuration reveals the gross stratification patterns from which depositional processes, erosion, and paleotopography can be interpreted. In addition, fluid contact reflections (flat spots) commonly are identifiable.



Source: Mitchum et al. (1977)

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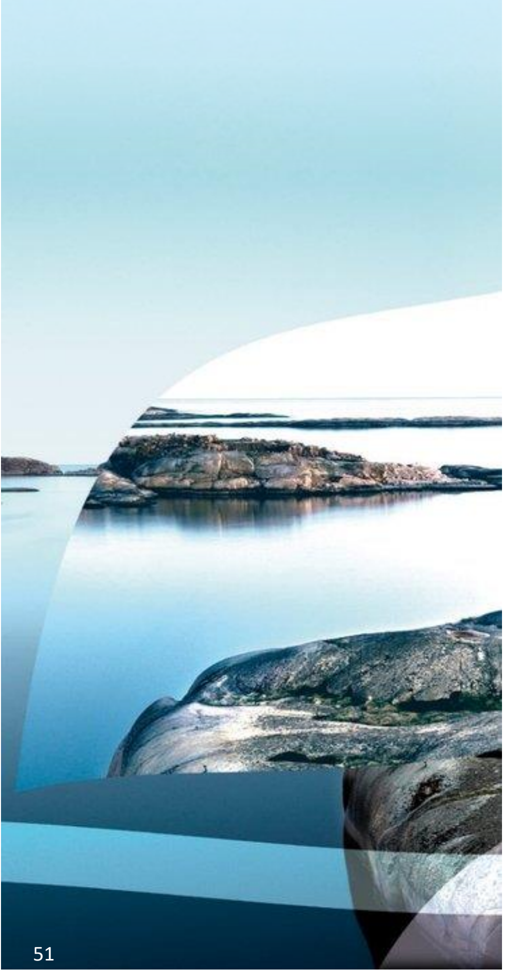
Seismic configurations in short



- Seismic configurations have many applications:
  - Identification of bedding patterns
  - Interpretation of depositional processes
  - Identification of erosion and paleotopography
  - Fluid contacts (DHI)
- Nowadays more sophisticated tools such as seismic inversion and characterization provide an effective way to quantitative assess lithologies and fluids.
- Yet seismic configurations prove to be useful to identify geological features or fluid contacts on the fly
- Seismic configurations are mostly used in seismic geomorphology, less in seismic stratigraphy (unlike stratal terminations)

Seismic stratigraphy

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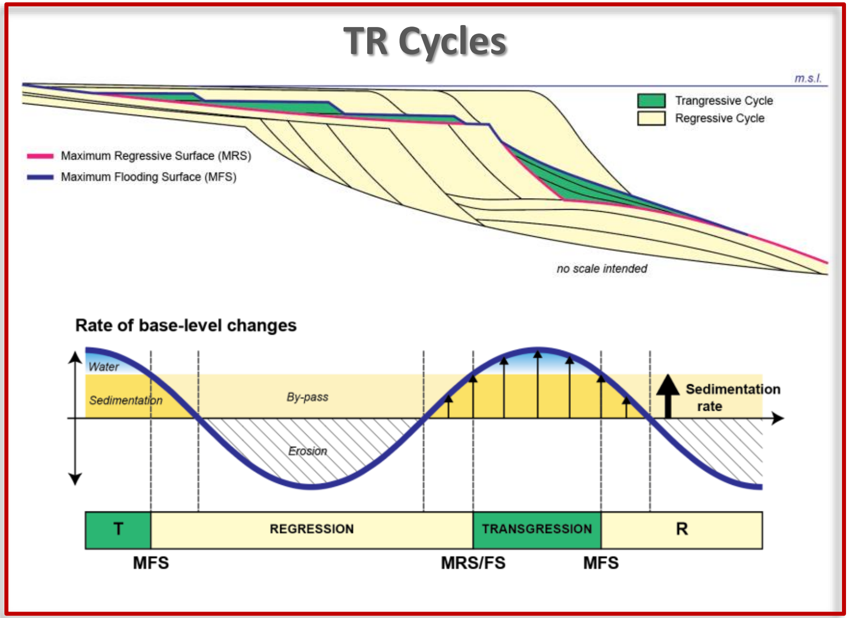
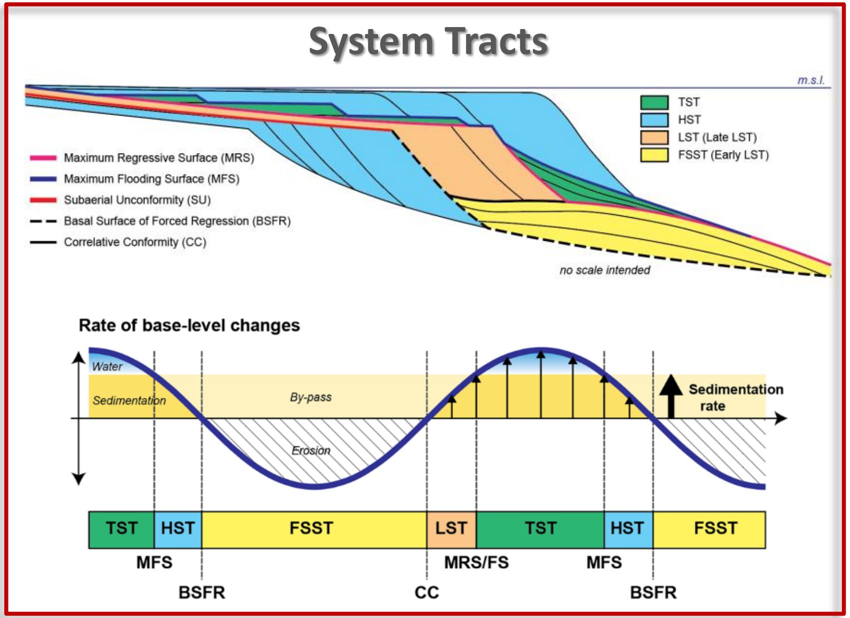
Workflow

Reminder

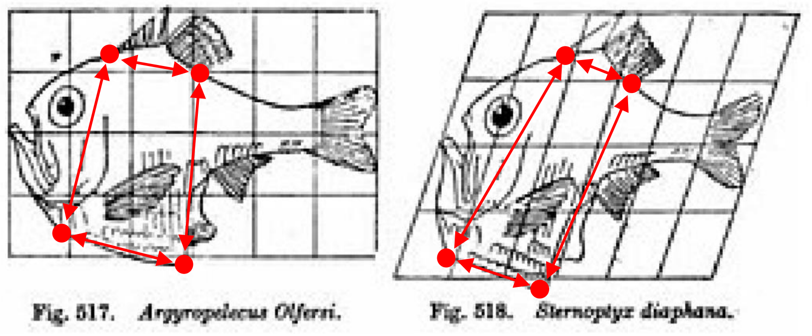
Variations in accommodation and sediment flux over time directly affect the geometry of sedimentary deposits. By analyzing the geometry of the sedimentary deposits, it is usually possible to trace the stratigraphic parameters and determine the sedimentary surfaces that delineate the sequences. There are procedures that allow this work to be done in a systematic and reproducible way, whatever the resolution of the desired cut (e.g., T-R cycles or System Tracts)



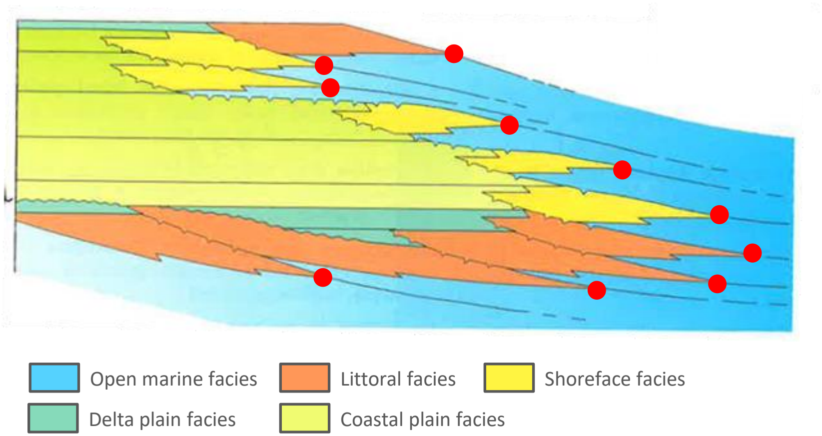


How to quantify change in shape or geometry?

Landmark based morphometrics



Source: D'Arcy W. Thompson (1917)



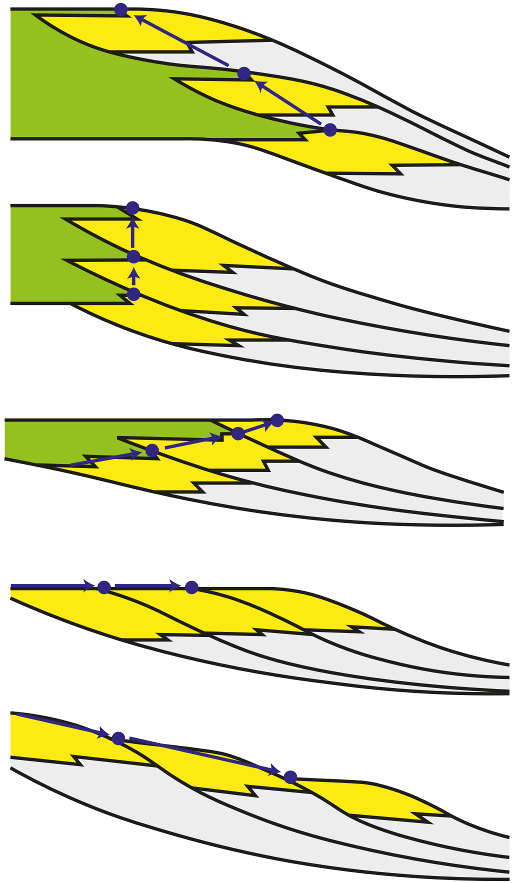
Defining sequences from the geometry of sedimentary deposits involves following the movement of one or more landmarks through time.

This method is very well known to paleontologists who study the evolution of the shape of biological organisms using this method.

The same method can be applied to the analysis of the geometry of depositional sequences: Follow the displacement of a landmark over time to analyze the evolution of the A/S ratio

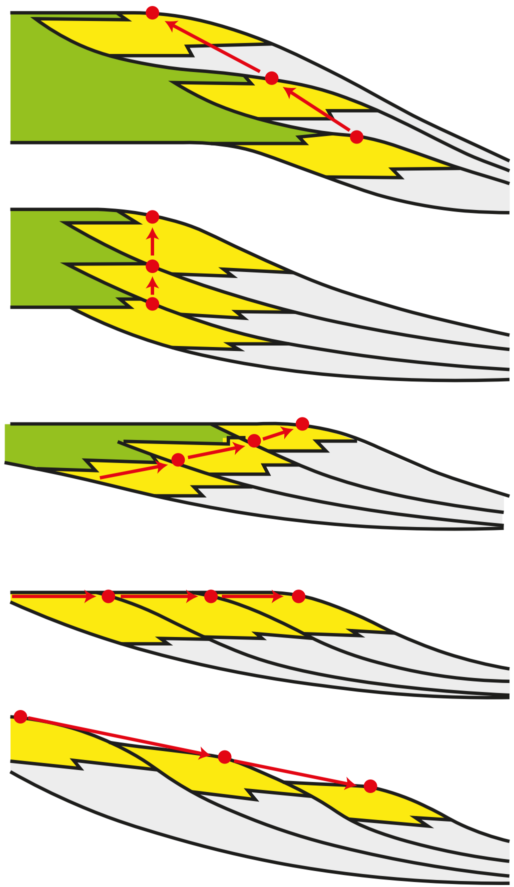
But which landmark to choose?

The shoreline shifts



- Ideally, it is recommended to follow the lateral displacements of the shoreline over time to analyze the stacking patterns of depositional packages (e.g., Catuneanu, 2006).
- However, tracking the shoreline is not easy in practice for several reasons:
- The shoreline is practically invisible on seismic images because no geomorphic features materialize it.
- The shoreline is not always present in the seismic zone studied, either on land or offshore seismic data.
- Therefore, it is necessary to find another landmark to track the lateral displacements of the depositional tracts.

The offlap break trajectory



- The offlap break is a geomorphic feature that marks a break in slope on the continental shelf.
- The nature of this break in slope varies from case to case:
- It can be related to inner shelf sedimentation processes (small-scaled, often short-lived delta or nearshore clinoforms)
- It can mark the shelf edge (large scale, long-lived continental slope break).
- The offlap break is a convenient landmark that can be easily tracked on passive continental margins. Assumptions about water-depth or lithology associated to the offlap break are not a primary necessity for tracking the offlap break trajectory.

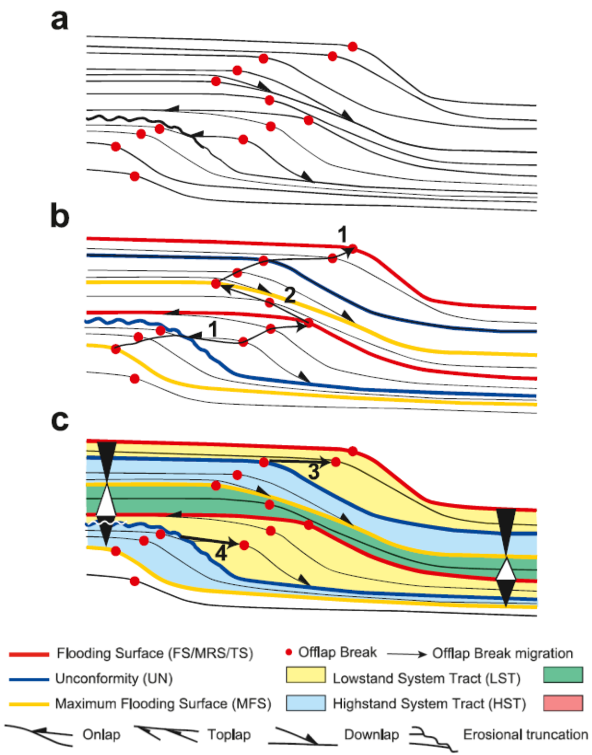
Seismic Stratigraphy – The workflow

Key article:

- P. Jermannaud, D. Rouby, C. Robin, T. Nalpas, F. Guillocheau, S. Raillard (2010). Plio-Pleistocene sequence stratigraphic architecture of the eastern Niger Delta: A record of eustasy and aridification of Africa. Volume 27, Issue 4, Pages 810-821.

Workflow:

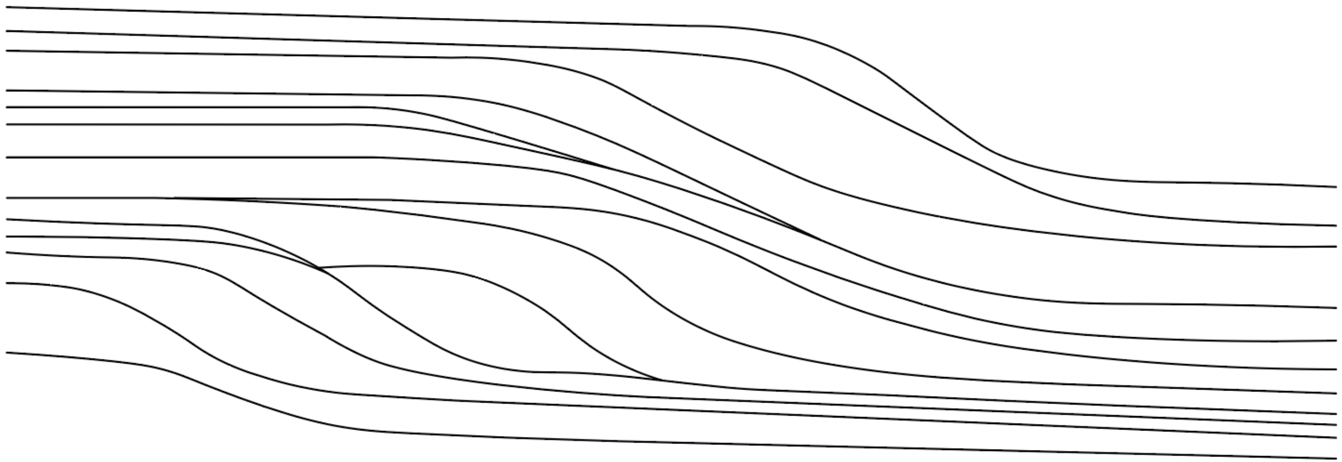
- Step 1: ***Line drawing*** (to capture the overall geometry of seismic reflectors)
- Step 2: Identification of ***Terminations***, ***Offlap Breaks***, and ***Offlap Break Migration***
- Step 3: Definition of ***Stratigraphic surfaces***
- Step 4: Interpretation of ***Depositional Packages*** and ***System Tracts***
- Step 5: Interpretation of ***GDE*** and ***Lithofacies***



Seismic Stratigraphy – The workflow

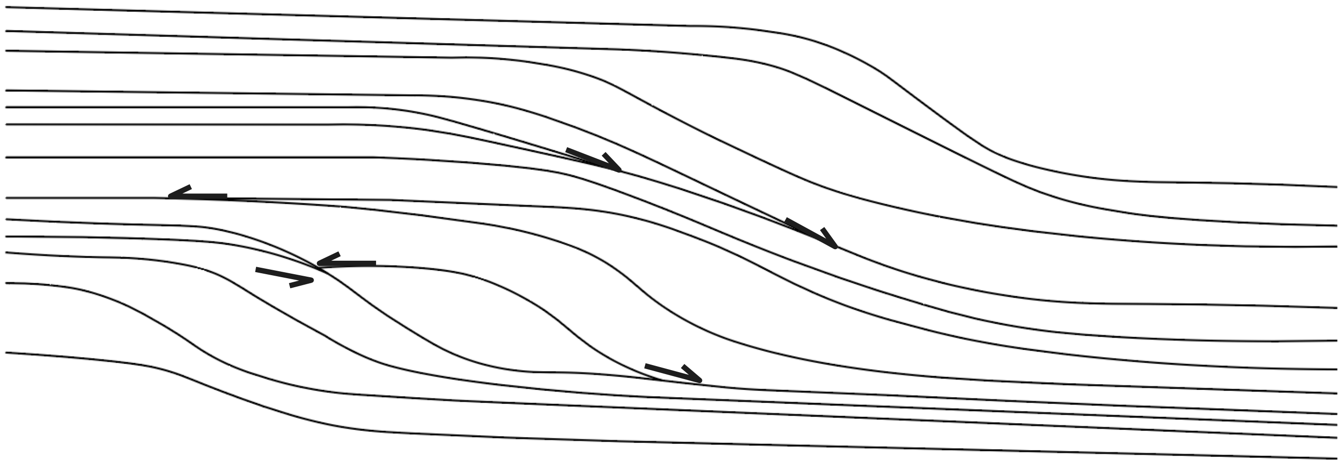
Step 1: Line Drawing / Seismic picking

- Draw (interpret) relevant seismic reflections to filter the stratigraphic packages from seismic noise and irrelevant reflectors (sort of geological filtering of seismic reflectors)



Step 2: Stratal Terminations and Offlap Breaks

- The **offlap Break** is a **landmark** that allow the relative position of various identical depositional features to be compared across the seismic section.
- Usually, the Shelf Break is a good landmark candidate because its geomorphological signature is well defined on marine shelves.



Seismic Stratigraphy – The workflow

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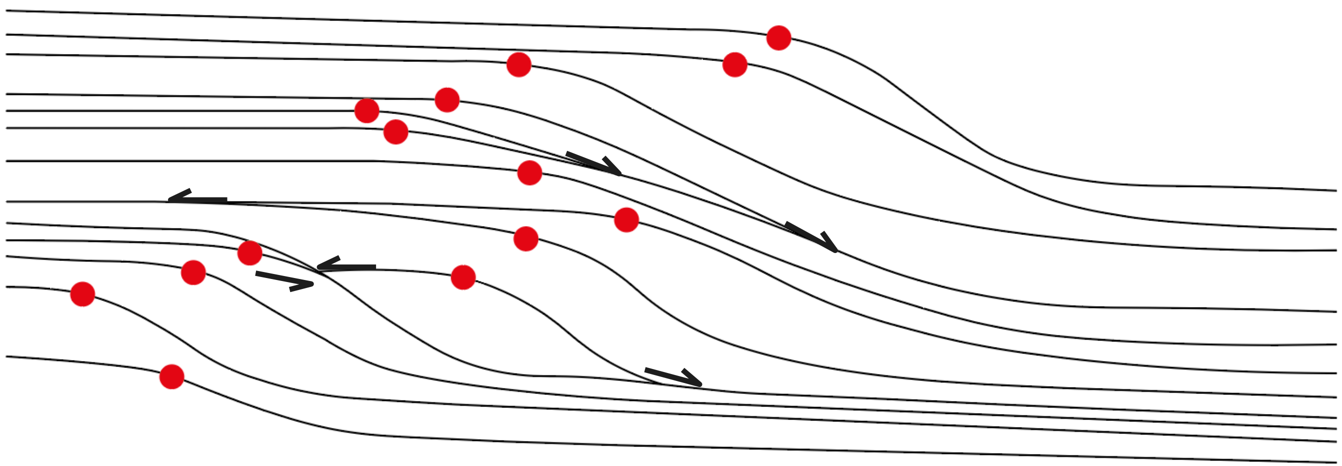

Seismic Stratigraphy – The workflow

Step 2: Stratal Terminations and Offlap Breaks

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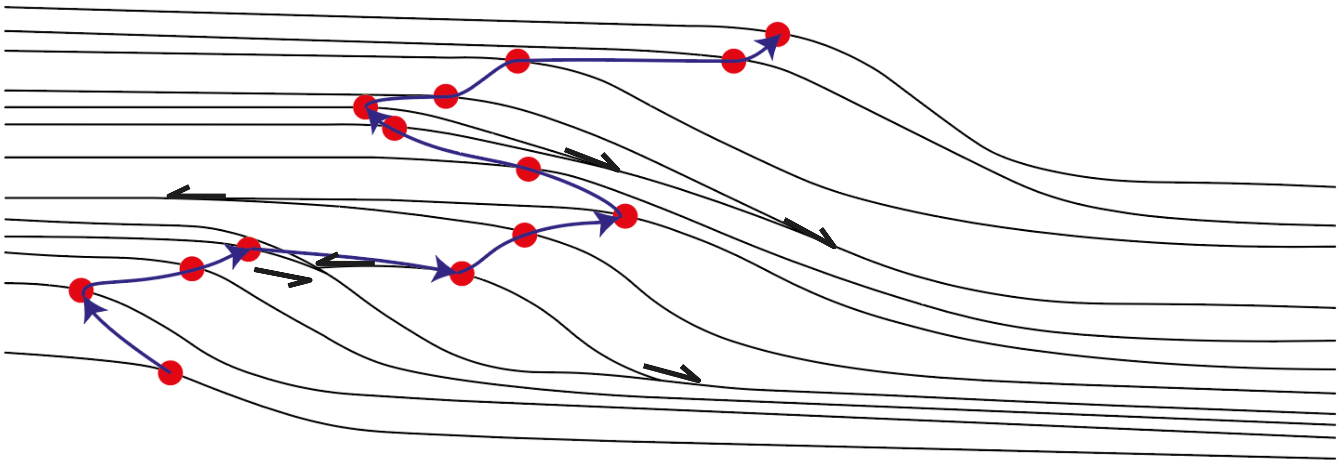
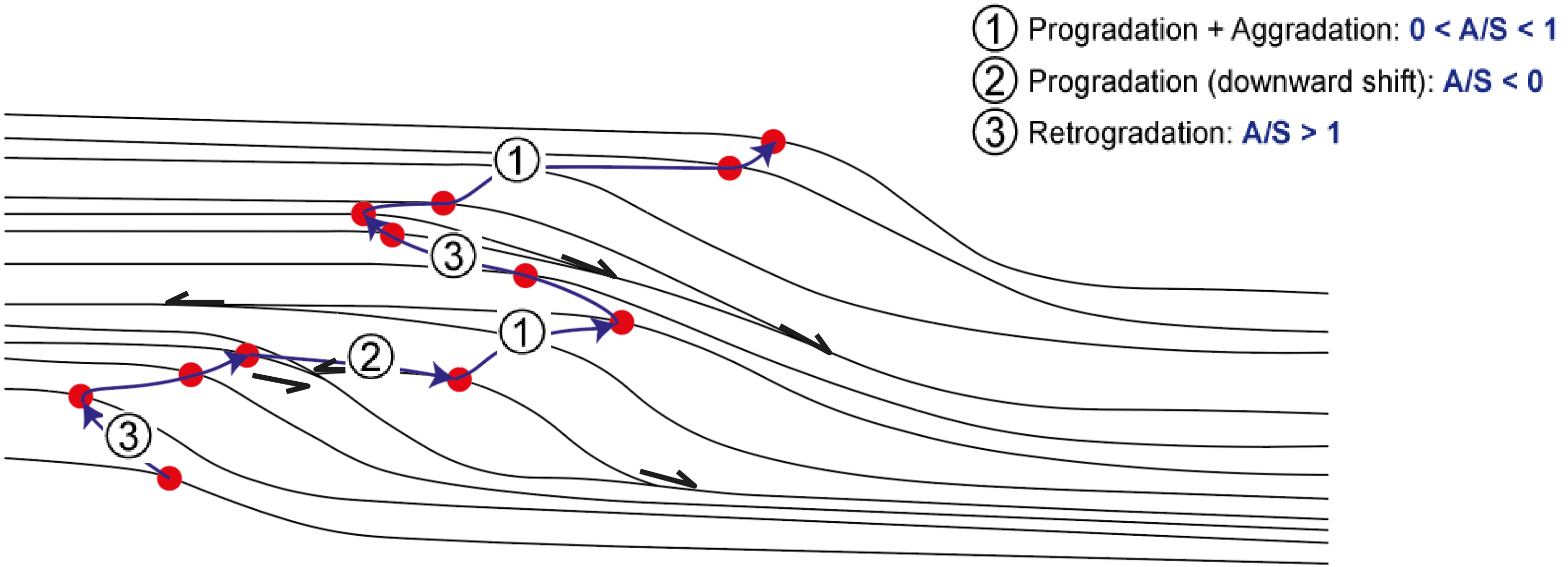


Seismic Stratigraphy – The workflow

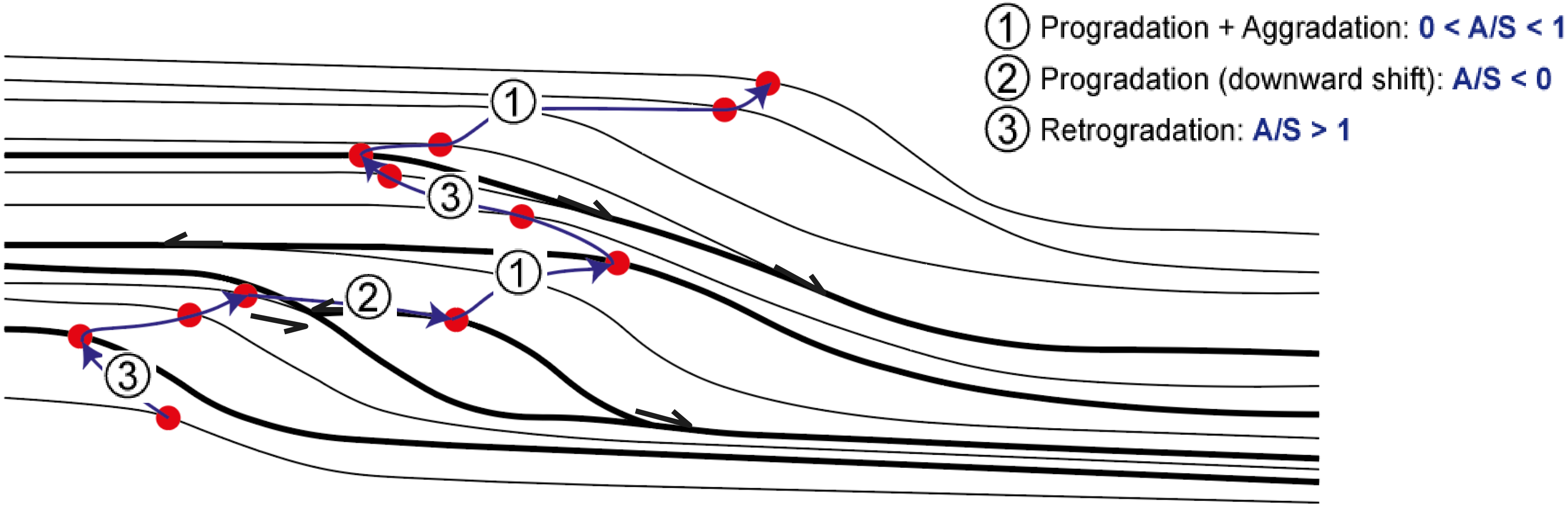
Step 3: Offlap Break Migration

- Definition: Lateral displacement of the "Shelf Edge" as a result of variations of the Accommodation Space (A) and the Sediment Supply (S)
- The trajectory of the Offlap Break can be (1) Prograding and Aggrading, (2) Downward Prograding, (3) Retrograding



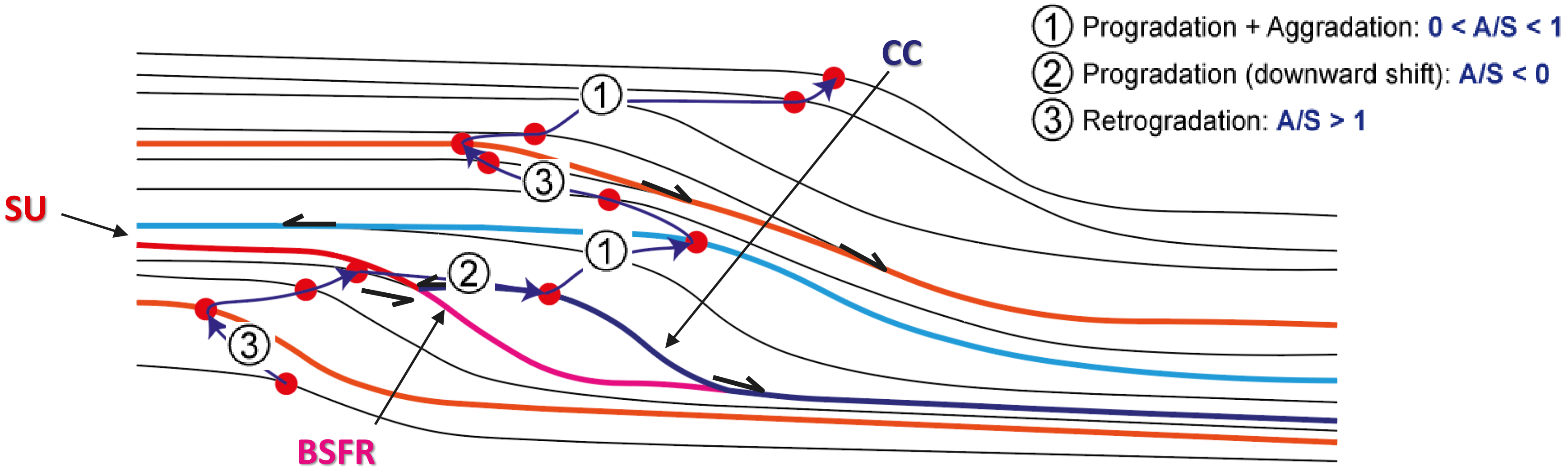
Step 3: Picking stratigraphic Surfaces

- Stratigraphic surfaces are picked at the turnovers of trajectories.



Step 4: Interpreting stratigraphic Surfaces

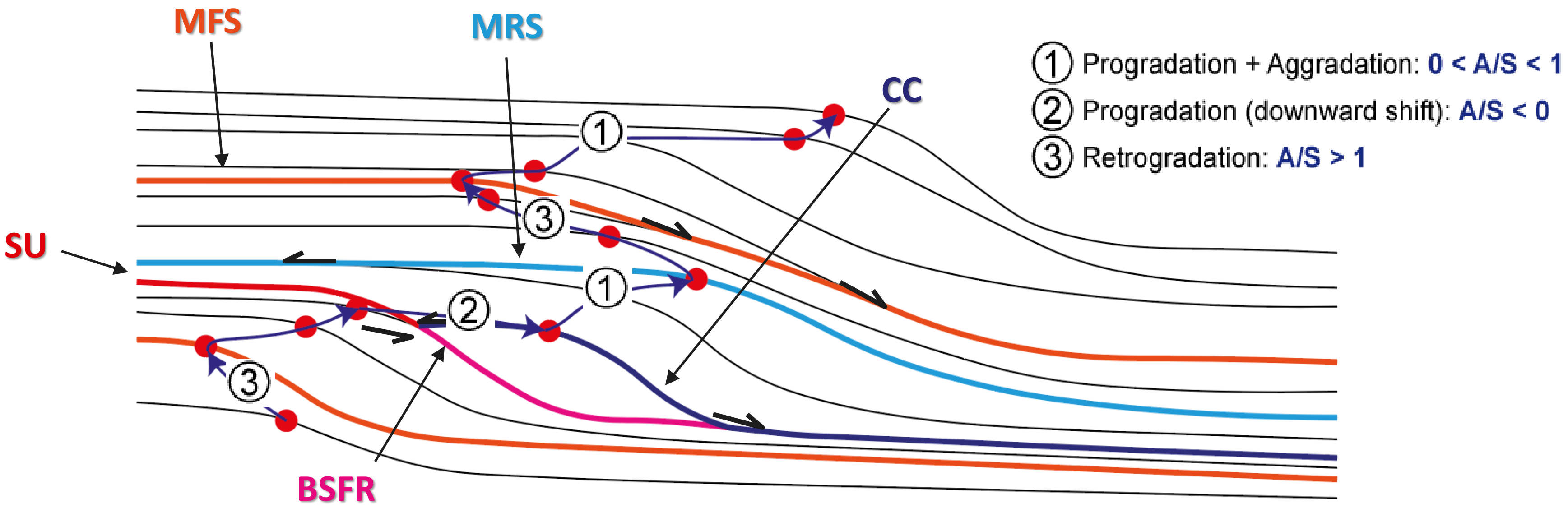
- **Subaerial Unconformity (SU)**: surface of erosion or non-deposition, associated with offlap terminations (truncations) and onlapped by a topset of normal regressive (prograding) strata;
- **Basal Surface of Forced Regression (BSFR)**: surface associated with top of the oldest clinoform with offlaps;
- **Correlative Conformity (CC)** *sensu* Hunt and Tucker, 1992: surface which correlates with the basinward termination of the Subaerial Unconformity. It separates the forced regressive strata below from the normal regressive strata above;



Seismic Stratigraphy – The workflow

Step 4: Interpreting stratigraphic Surfaces

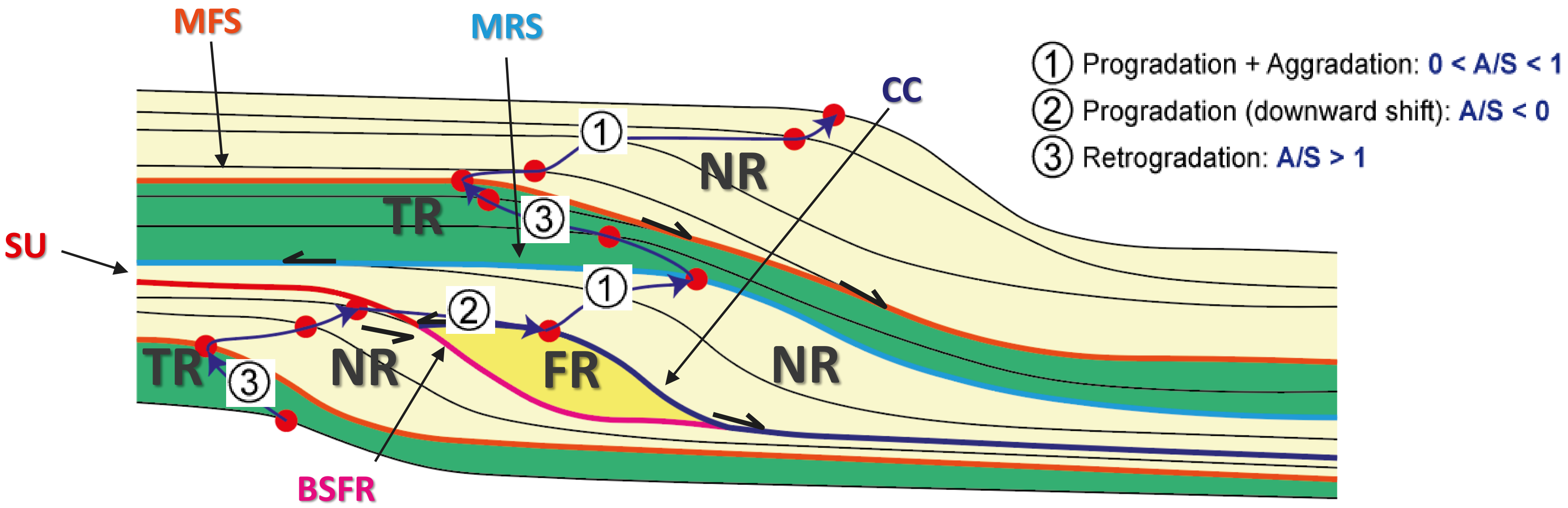
- **Maximum Regressive Surface (MRS)**: surface capping the youngest clinoform associated with the shoreline/offlap break regression (progradation);
- **Maximum Flooding Surface (MFS)**: surface separating retrograding strata below from prograding strata above;



Seismic Stratigraphy – The workflow

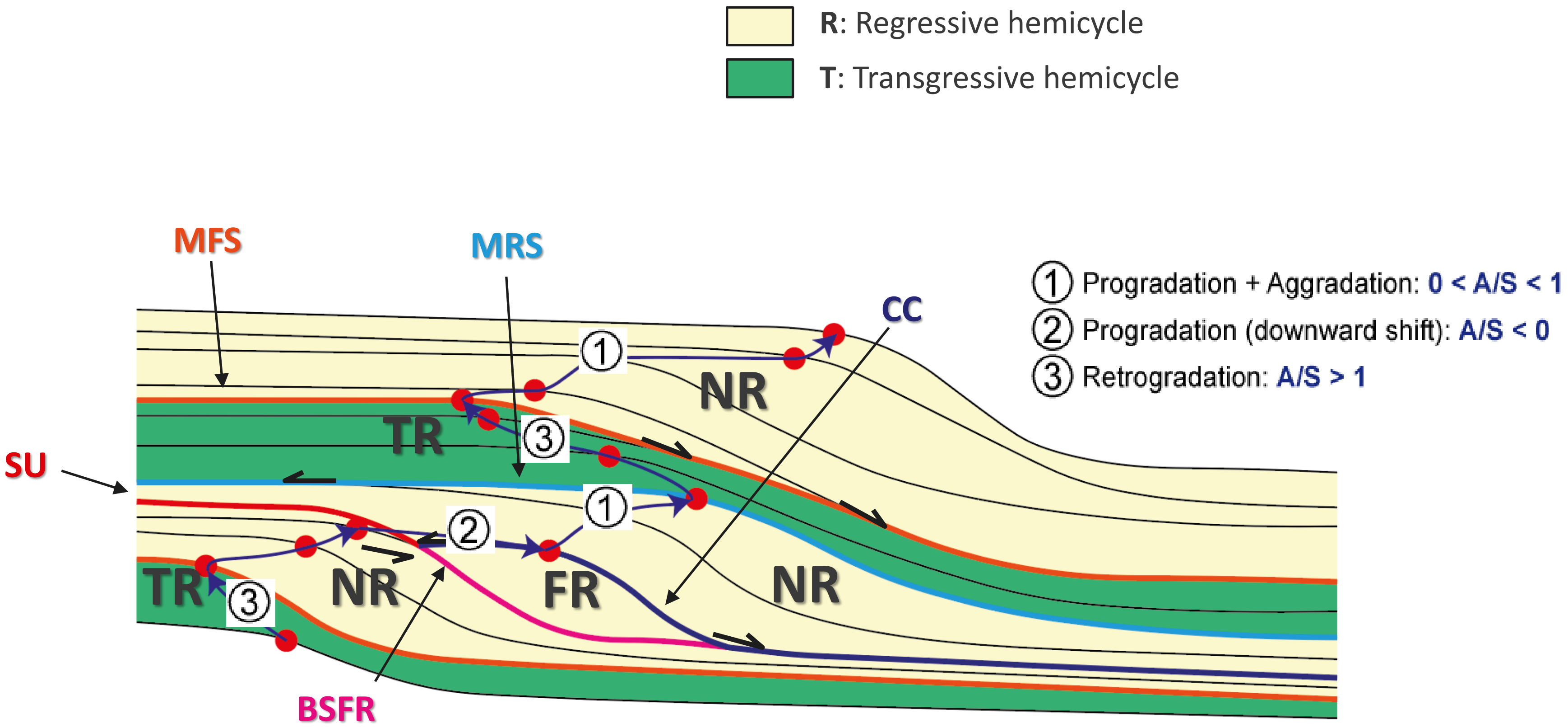
Step 5: Interpretation of depositional packages

- Depositional Packages are subdivided into 3 main types:
  - Normal Regressive: Progradation + aggradation and Coastal Onlap (1 > A/S > 0)
  - Forced Regressive: Downward Progradation (A/S > 0)
  - Transgressive: Retrogradation (A/S >1)



Seismic Stratigraphy – The workflow

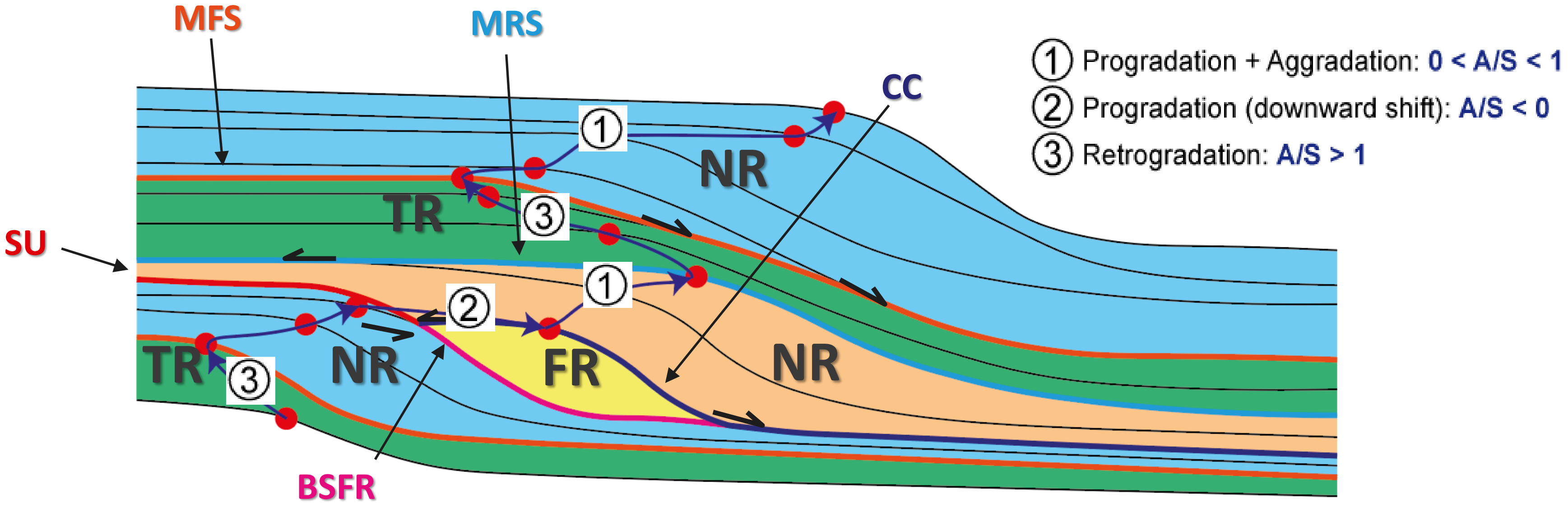
Step 6: Interpretation of T-R Cycles



Seismic Stratigraphy – The workflow

Step 6: Interpretation of System Tracts

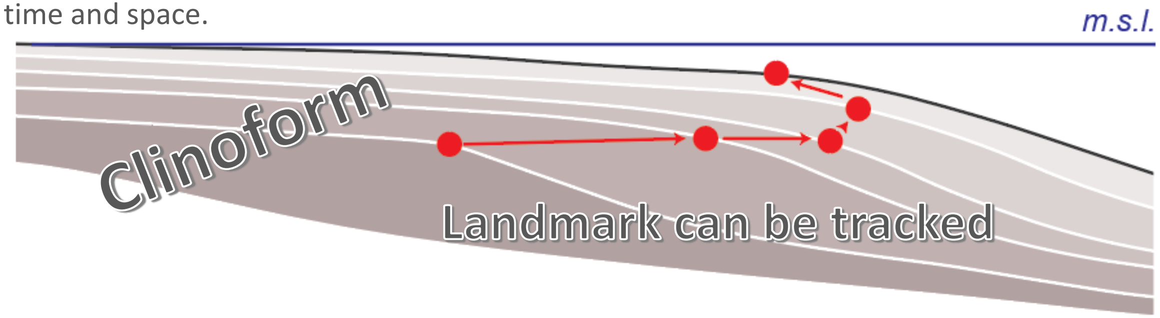
- **HST**: Highstand System Tract
- **FSST** (early LST): Falling Stage System Tract
- **LST** (late LST): Lowstand System Tract
- **TST**: Transgressive System Tract



Limitation – Ramp systems

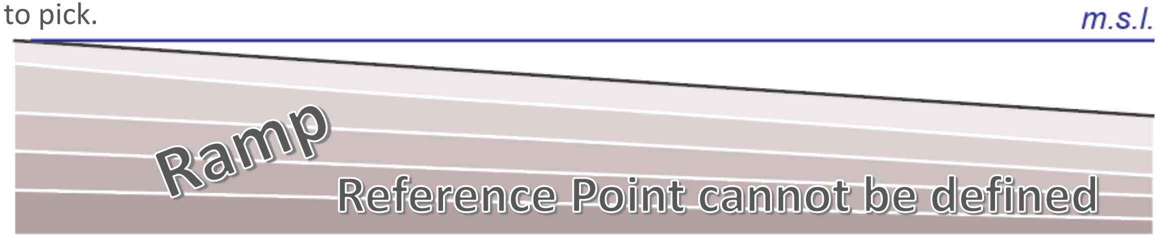
Ideal case: geomorphological footprint of the landmark

The landmark is tied to a geomorphological feature, it can be tracked through time and space.



Worst case: no geomorphological footprint associated with the landmark

No observed geomorphological feature exists making the landmark impossible to pick.

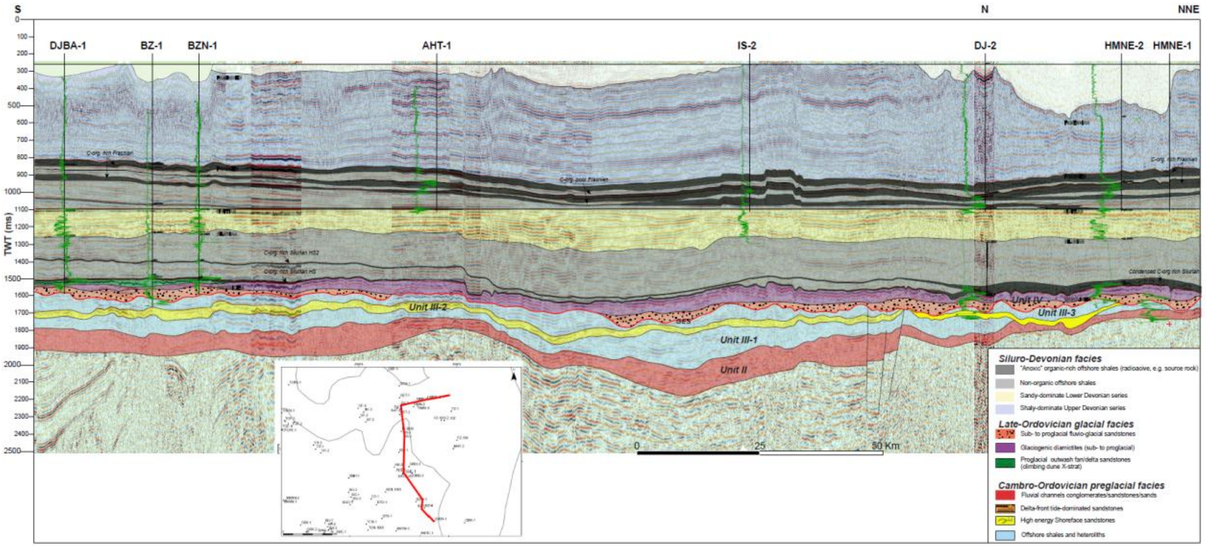


- ❑ Stratal geometry-dependent: hardly usable in flat depositional systems (ramp or nonmarine) and structurally-disturbed systems (salt, faulted or folded deposits).
- ❑ The landmark is not easy to pick (erosion, uncertainties).
- ❑ Characteristics of the landmark may change through space and time.

Limitation – Ramp systems

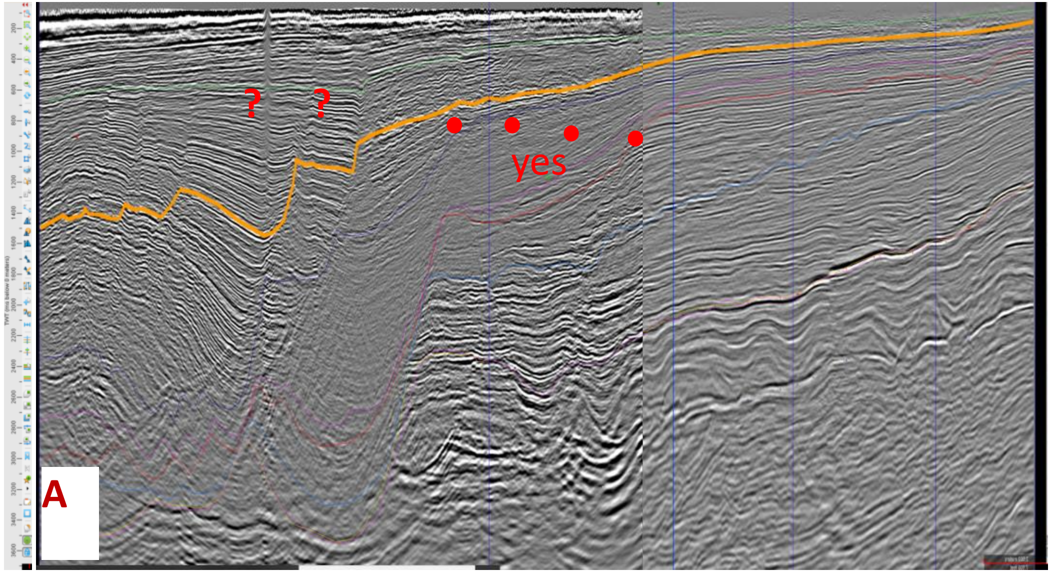
Ramp systems are common features of continental shelves and intracratonic basins.

No landmark can be picked with confidence and the only thing one can do without well control is to pretend doing seismic stratigraphic breakdown.



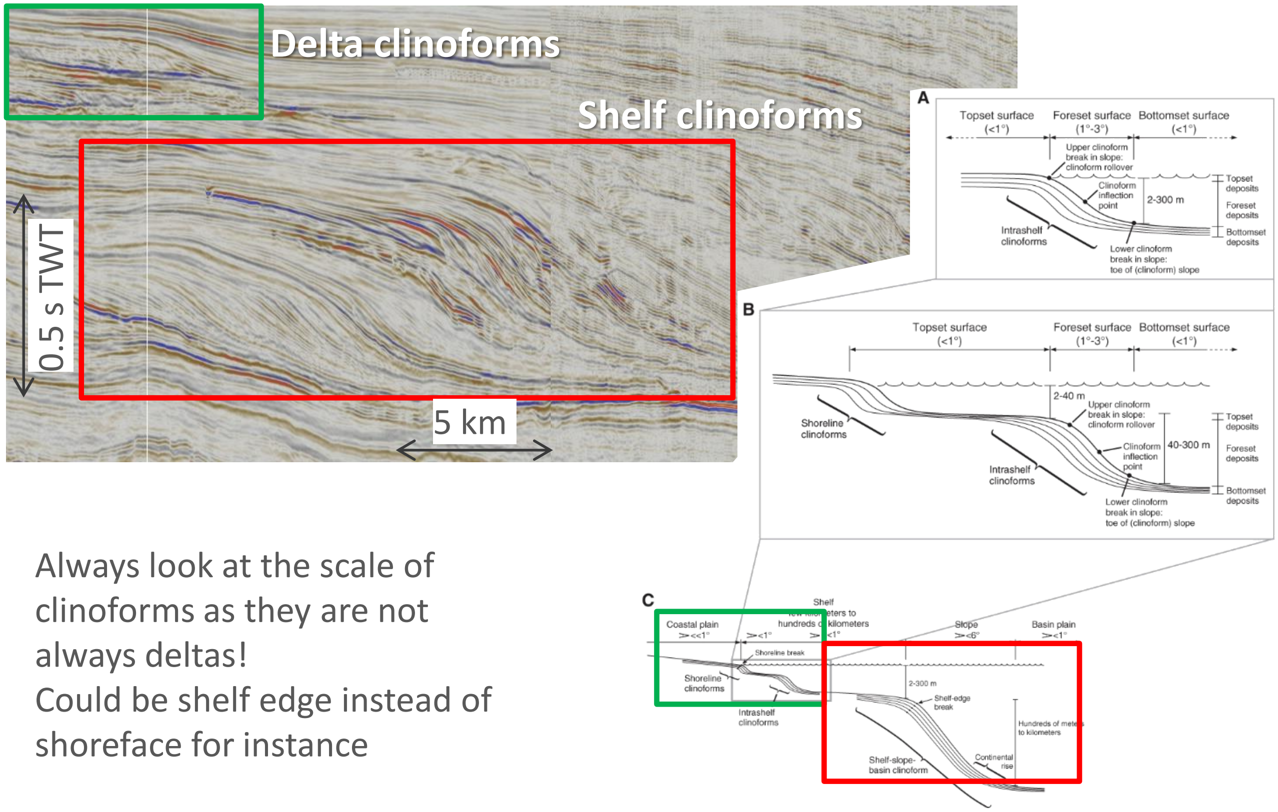
- Stratal geometry-dependent: hardly usable in flat depositional systems (ramp or nonmarine) and structurally-disturbed systems (salt, faulted or folded deposits).
- The landmark is not easy to pick (erosion, uncertainties).
- Characteristics of the landmark may change through space and time.

Limitation – Faults and especially growth faults



- Stratal geometry-dependent: hardly usable in flat depositional systems (ramp or nonmarine) and structurally-disturbed systems (salt, faulted or folded deposits).
- The landmark is not easy to pick (erosion, uncertainties).
- Characteristics of the landmark may change through space and time.

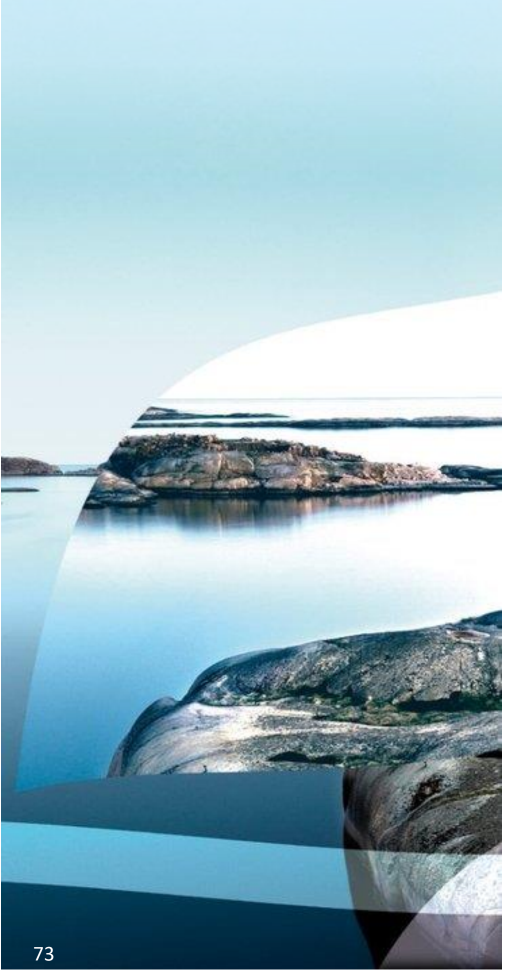
Limitation – Keep the landmark in mind



Always look at the scale of clinoforms as they are not always deltas!
Could be shelf edge instead of shoreface for instance

- Stratal geometry-dependent: hardly usable in flat depositional systems (ramp or nonmarine) and structurally-disturbed systems (salt, faulted or folded deposits).
- The landmark is not easy to pick (erosion, uncertainties).
- Characteristics of the landmark may change through space and time.

Offlap break trajectory workflow in short



- It is the most convenient method for interpreting depositional geometries on seismic data
- Based on the tracking of a landmark on seismic data.
- The landmark tied to a geomorphological feature is needed (e.g., offlap break).
- It is assumed that the geomorphological landmark is unique.
- The trajectory of the landmark allows stratigraphic packages (T-R Cycles or System Tracts) to be defined.
- Main limitation: observable depositional geometries are compulsory.

The specificity of carbonate systems

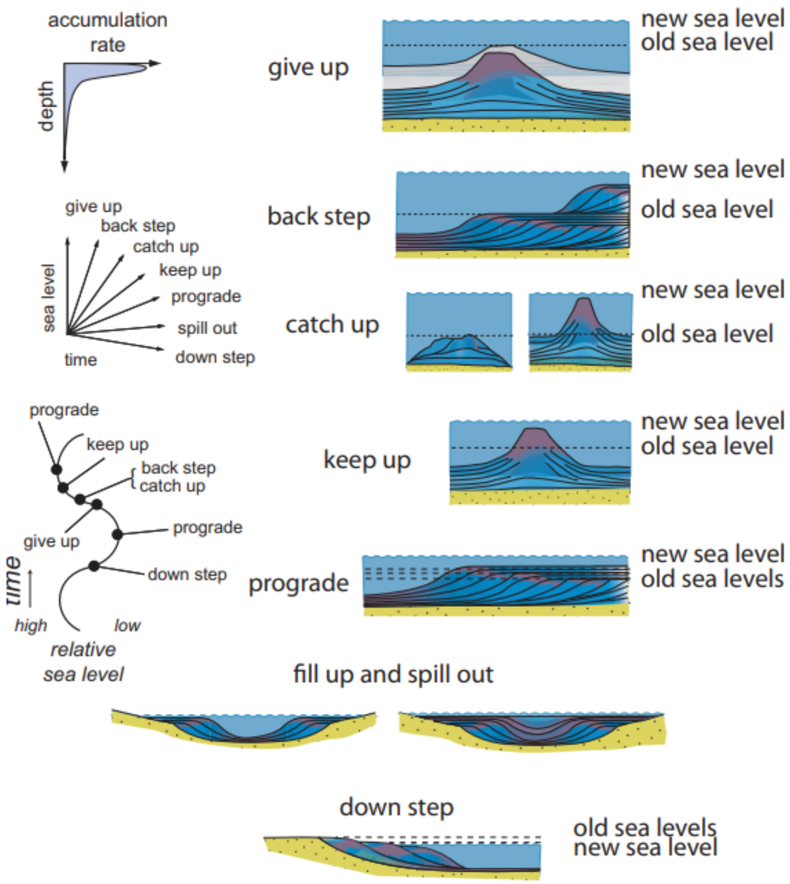
- Unlike clastics which are supplied by fluvial systems flowing from the hinterland to the sedimentary basin, most of carbonate sediments are produced by living marine (lacustrine) organisms

- Carbonate bioproducers are:
  - Sensitive to ecological conditions (water depth, temperature, salinity, turbidity etc.).
  - Reactive to changes in water depth
  - Form areas of production termed **Carbonate Factories**

- There are 3 types of Carbonate Factories:
  - **T Factory**: “Tropical” ; coralgal assemblage (reef), oolitic sands
  - **M Factory**: “Mud-mound” ; microbial, sponge etc. mounds
  - **C Factory**: “Cool-water” ; red algae, mollusks and foraminifers (no shoal-water reefs and oolites)

- Other particularities of carbonate sediments:
  - Sensitive to **dissolution** (karstic dissolution), limiting seaward transport of detrital grains
  - Carbonate sediments can be **mobile** but also **bounded** unlike clastics

Marine carbonate systems

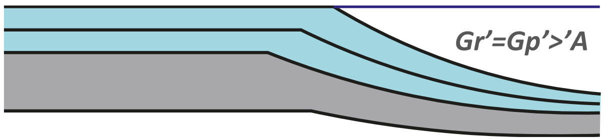


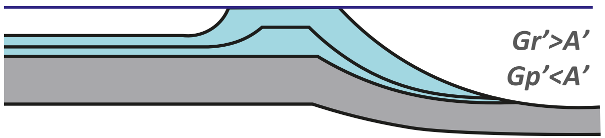
Source: Scaturo et al. (1989), Catuneanu et al. (2011)

- Carbonate factories react to changes of the Relative Sea Level.
- Several geometrical patterns or "behavior" could be identified.
- They resemble the Progradation, Aggradation and Retrogradation patterns of clastics (with more intermediate steps):
  - Downstep: Downward progradation
  - Spill out: Pure progradation
  - Prograde: Progradation and aggradation
  - Keep up: Aggradation
  - Catch up: Aggradation
  - Back step: Retrogradation
  - Give up: Specific to Carbonate Factory

The specificity of carbonate systems

Catch to keep up: Carbonate Factory produces enough sediment everywhere to keep shallow marine setting

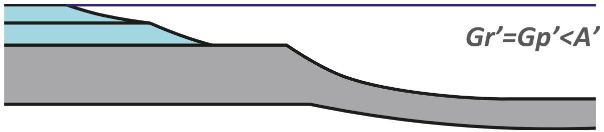


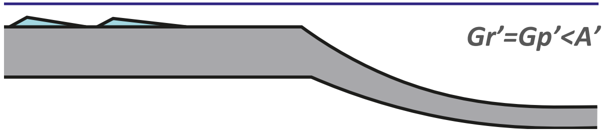


Catch to keep up: Carbonate Factory produces enough sediment along the edged to keep shallow marine setting

Favorable

Back step: Carbonate Factory cannot fully sustain rising sea level. Carbonate platform back steps

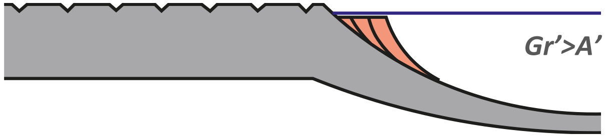


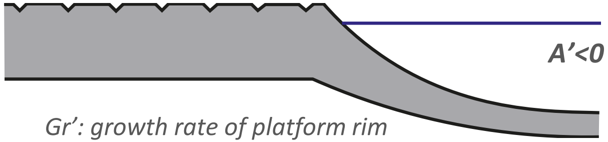


Give up: Carbonate Factory cannot sustain rapid rising sea level. Carbonate platform is drowned and production stops

Moderately favorable

Down step: Narrow carbonate platform is created downwards as sea level falls





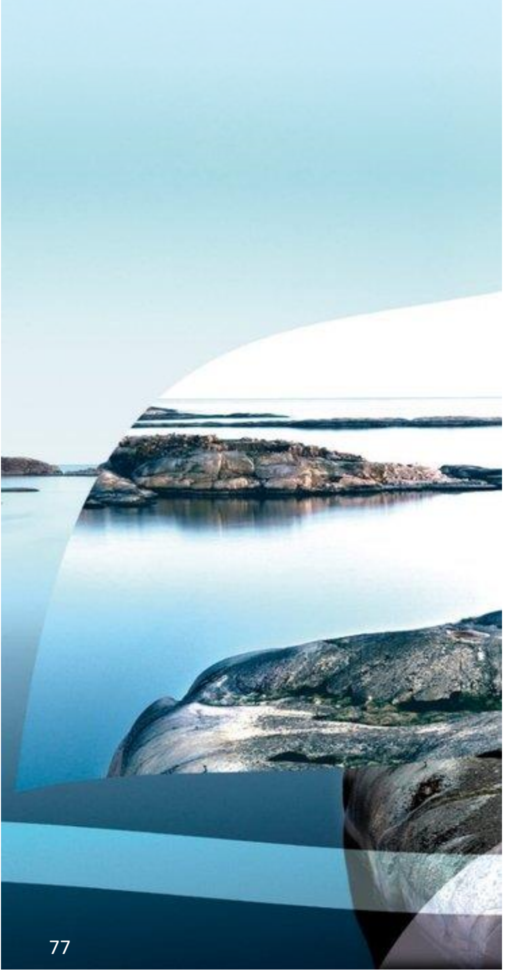
Gr': growth rate of platform rim
Gp': growth rate of platform interior
A': rate of change in accommodation

Give up: Carbonate Factory cannot move seawards and platform is fully exposed

Unfavorable

Source: Schlager (2002, 2005)

Marine carbonate systems in short



- Sediment supply is the major difference compared to clastics
- Depositional geometries are nearly similar than those documented in clastics, yet with specific terminology
- Due to sensitivity of Carbonate Factories to water depth and extension, carbonate platform best develop during slow fall or rise of the Relative Sea Level (HST or TST)
- Due to marine retreat resulting from Forced Regression, Carbonate Factories to be shut down during downward shift events (LST)
- Unlike siliciclastic systems, in which sandstone reservoirs tend to form during Lowstand, carbonate reservoir tend to form during HST or event TST
- Note that exposure causes karstification to occur, potentially enhancing reservoir quality of underlying carbonate.

Log-based stratigraphy

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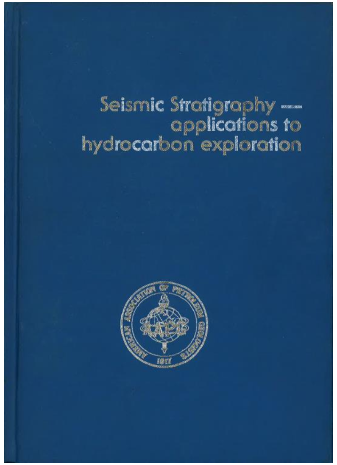
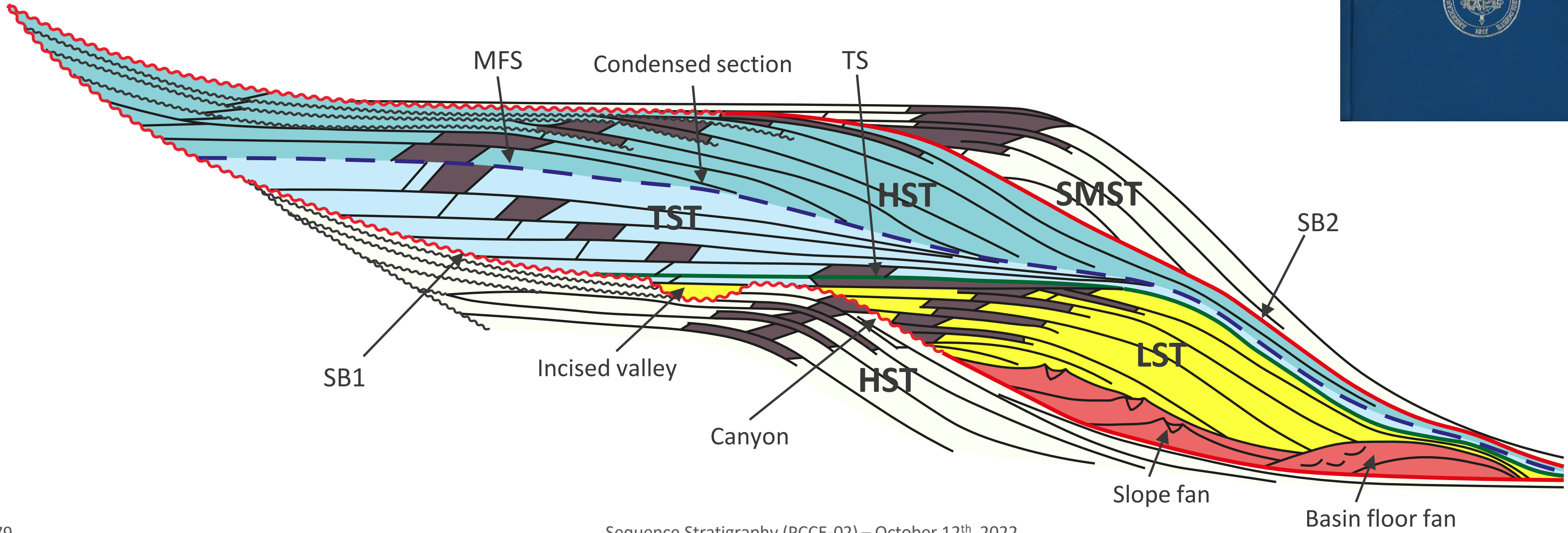
Principles

In the beginning there is seismic stratigraphy...

In the early days, sequence stratigraphy (i.e., seismic stratigraphy) is very much oriented to the analysis of seismic data. No sequence breakdown procedures **involving analysis of sedimentary rocks** are published in AAPG Brief 26.

The integration of the sedimentary record into sequence stratigraphy came gradually during the following decade.





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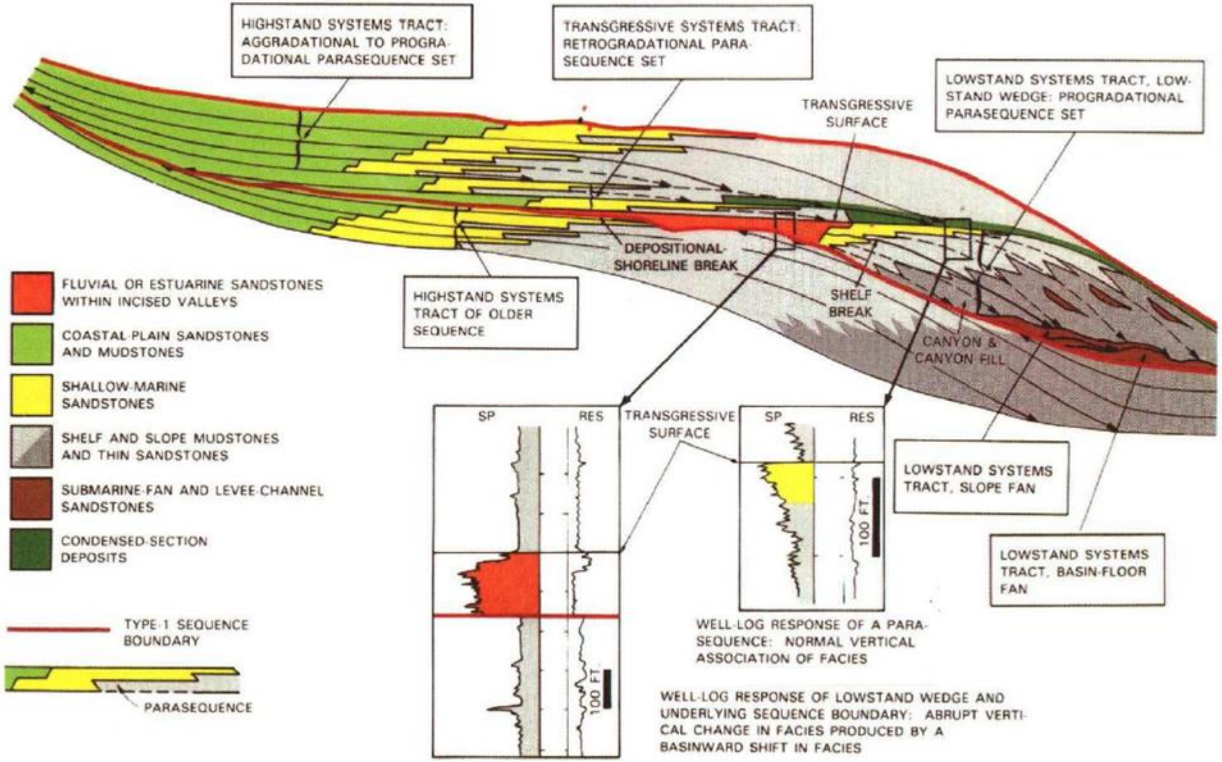
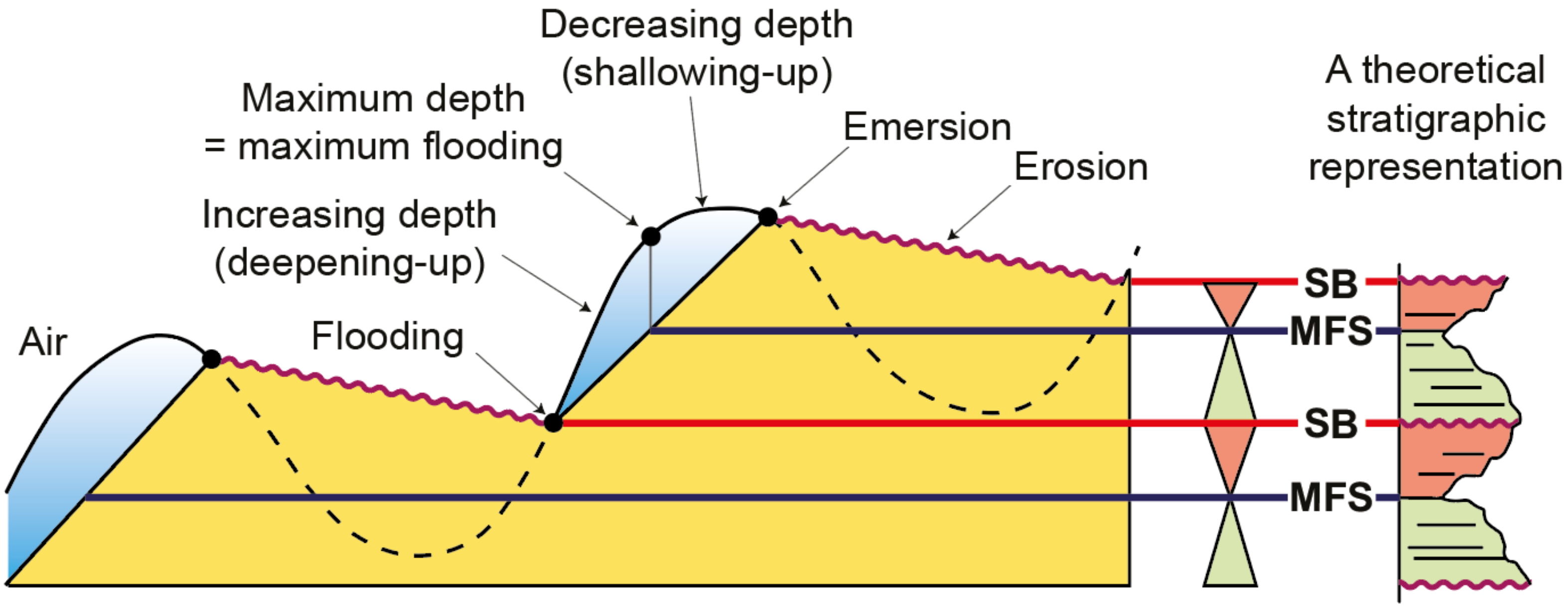
… but what about sedimentary rocks?

As the sequence stratigraphic theory were initially created by petroleum geologists, it made its ways from seismic to field geology through wireline logs.



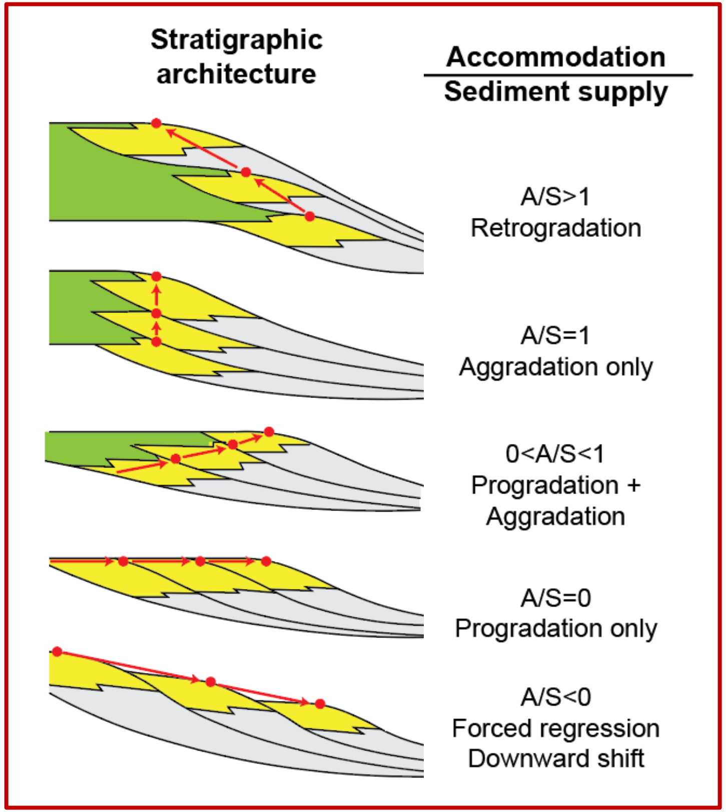
Source Hardenbol et al. (1988)

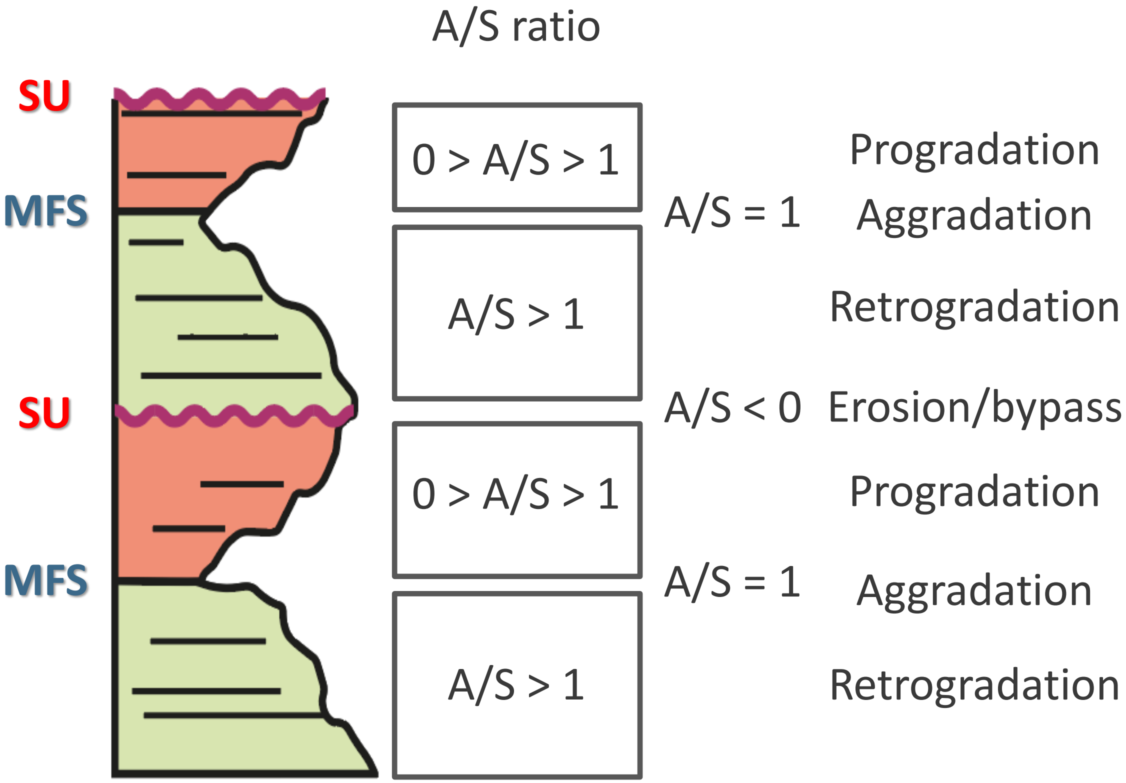
How do stratigraphic factors relate to sedimentary deposits?



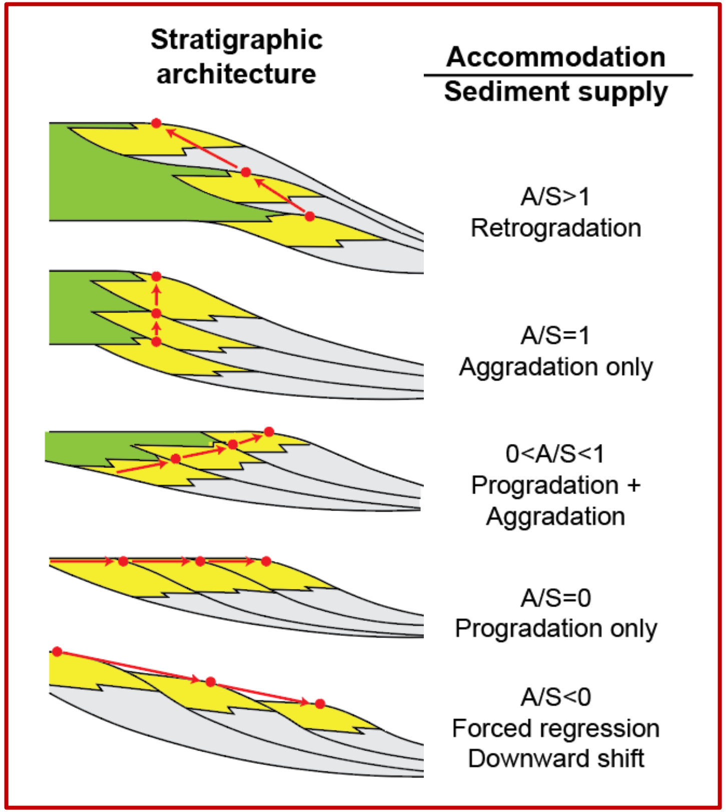
MFS: Maximum Flooding Surface
SB: Sequence Boundary

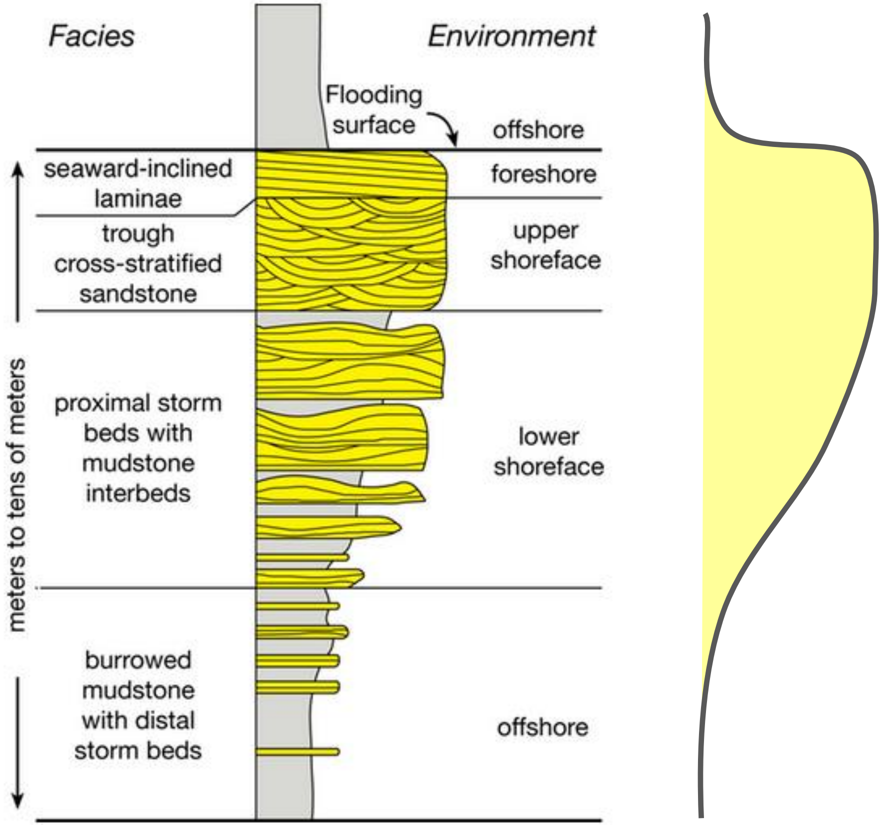
Decipher stratigraphic controls from sedimentary rocks



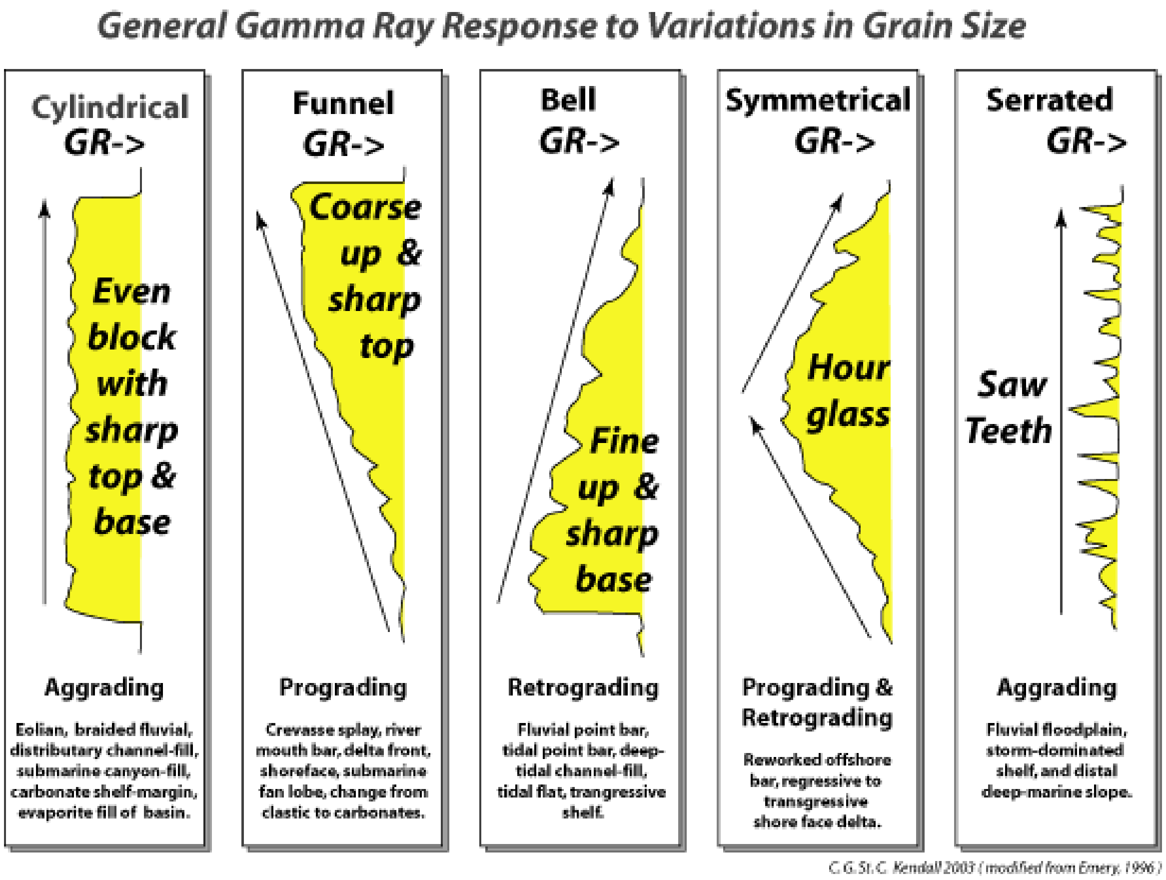


Stratigraphic architecture in sedimentary rocks?





Typical Gamma Ray log patterns in clastic deposits



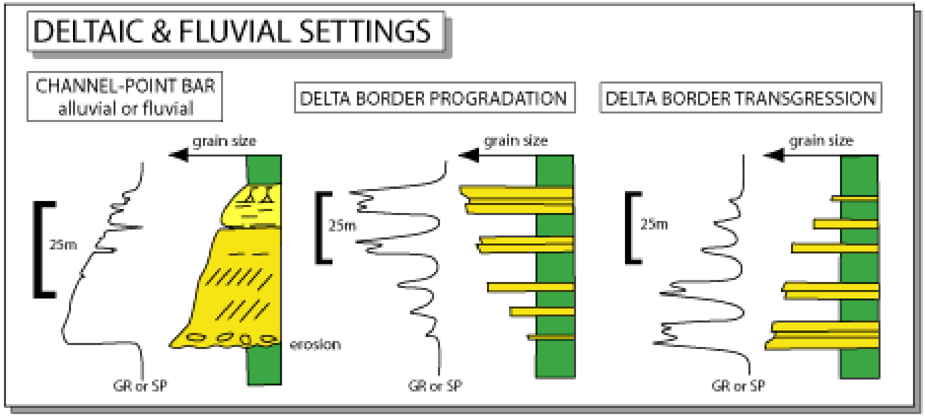
No scale intended

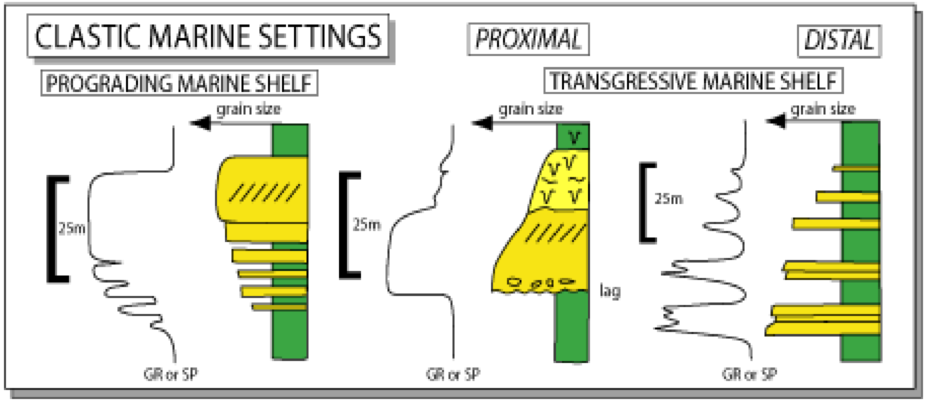
@Beicip-Franlab

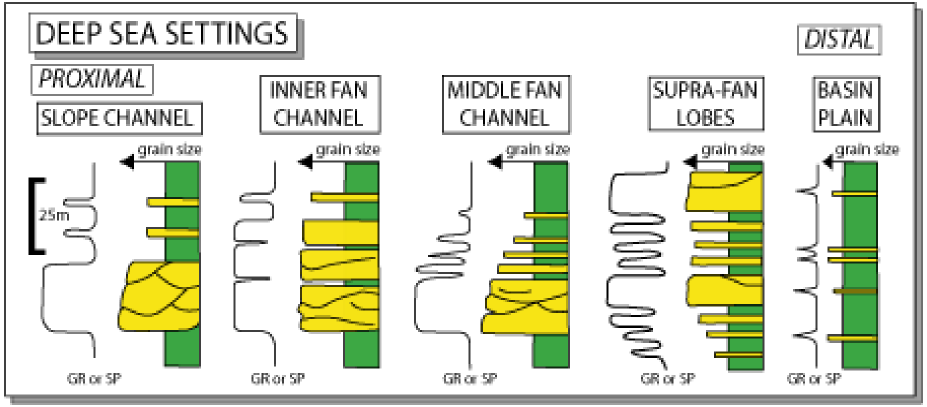
Gamma Ray log response and depositional setting

Log patterns characteristic of depositional settings have been proposed.

They are useful but, there are three problems to take into account: (1) they are average responses, (2) different depositional environments may have similar log responses and (3) it is easier to imagine the log response of a depositional environment than the other way around.

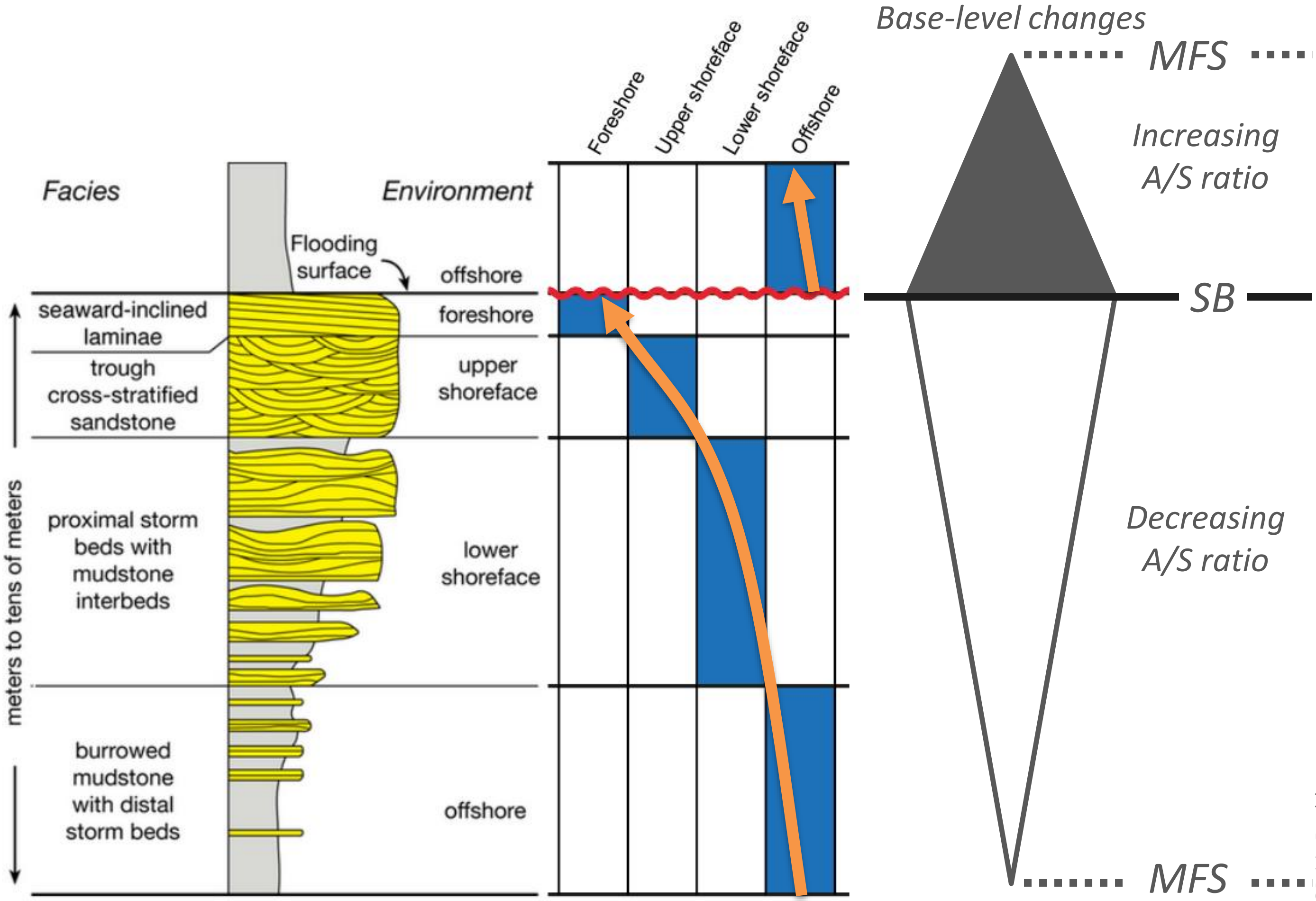






C. G. St. C. Kendall 2003 (modified from Malcolm Rider 1999)

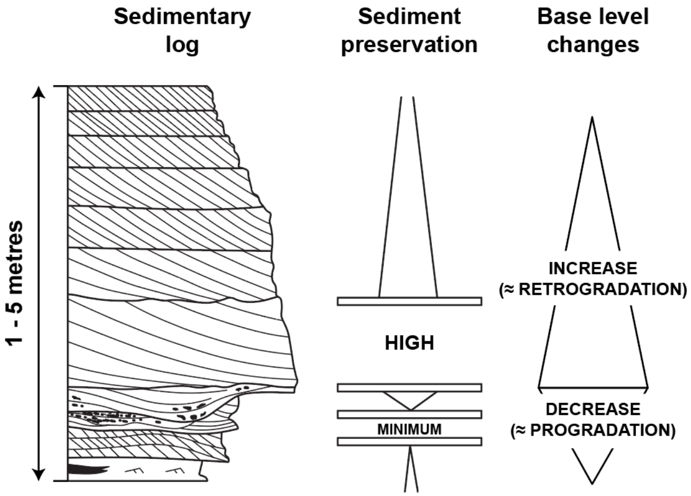
Sequence break down



Assumption: constant sediment rate

What about continental deposits?

"Accommodation" = Relative Sea Level (RSL)
RSL = Eustasy + Subsidence
or
RSL = Pres'ed thickness + Water depth



Homewood et al. (1992)

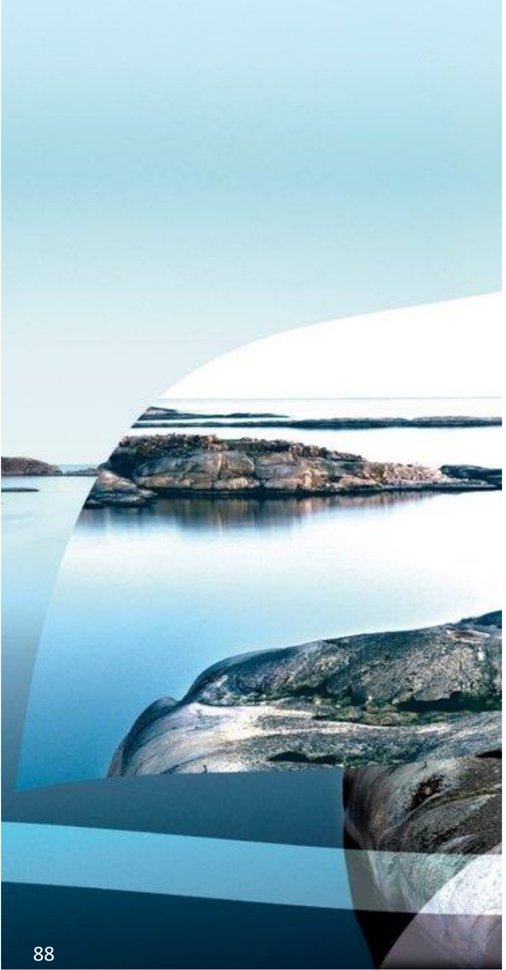
The principles

- Deposition is governed by the interplay of the Supply and the Accommodation.
- Assuming constant Supply, changes in sedimentary facies are controlled by changes in accommodation space.
- Vertical Stacking Pattern of facies reflects base level trends and correlatable stratigraphic surfaces.

Limitations

- Ideally, sedimentary facies (core or sed log) are needed.
- A-S ratio cannot be quantified in an easy way from geological data (qualitative approach).
- Robust sedimentological background required.

Summary



- **Vertical Stacking Pattern (VSP)** of sedimentary facies reflects changes in A/S ratio - Accommodation and Sedimentation through time (i.e., Walther's law)
- **Log patterns** provide information about VSP, but it is safer to interpret them from a depositional curve built from a sound **sedimentary facies analysis**
- In marine and lake systems, **changes in A/S ratio are deduced from bathymetric variations** resulting from the interpretation of depositional environments (assuming constant S)
- In fluvial systems, **changes in A/S ratio** are deduced from the **degree of amalgamation** of sedimentary deposits
- Availability of rock data interpretation is compulsory (wireline log is not enough)
- **Log-based sequence stratigraphy** can be carried out at **reservoir scale** (core data) or at **exploration scale** (biostrat data)

Log-based sequence stratigraphy

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Workflow

Method to break sequence down from sedimentary log

There are many examples of the application of the principles of sequence stratigraphy to the sedimentary record. Surprisingly, **few explain in detail the complete method for carrying out a sequence breakdown** from well or field data.

One of the few articles to present a method in its entirety is a publication by Homewood et al. (1992). Unfortunately, this publication is now hard to find on the web, and it is written in French.

It's a **practical guide to high resolution correlation** between vertical stratigraphic sections obtained from outcrop or from subsurface data.

[CITATION] Corrélations haute résolution et stratigraphie génétique: une démarche intégrée
P Homewood, F Guillocheau... - Bulletin des Centres ..., **1992** - pascal-francis.inist.fr
Pascal 001 Exact sciences and technology/001D Applied sciences/001D06 Energy/001D06B Fuels/001D06B02 Crude oil, natural gas and petroleum products/001D06B02B ...

HIGH RESOLUTION CORRELATIONS AND GENETIC STRATIGRAPHY : AN INTEGRATED APPROACH

Peter HOMEWOOD, François GUILLOCHEAU, Rémi ESCHARD et Timothy A. CROSS

HOMEWOOD, P., GUILLOCHEAU, F., ESCHARD, R. & CROSS, T.A. (1992). – Corrélations haute résolution et stratigraphie génétique : une démarche intégrée. [*High resolution correlations and genetic stratigraphy : an integrated approach*]. – *Bull. Centres Rech. Explor.-Prod. Elf Aquitaine,* **16,** 2, 357-381, 15 fig., 1 tab.; Boussens, December 24, 1992. – ISSN : 0396-2687. CODEN : BCREDP.

The aim of this paper is to provide a guide to one of the more practical applications of genetic stratigraphy, that of high resolution correlation between vertical stratigraphic sections obtained from outcrop or from subsurface data. The method requires knowledge of primary depositional features and comprises two phases. The first phase, putting the information together as a vertical "log", goes from : (1) observation of sedimentary facies, through (2) deduction of depositional processes, (3) identification of facies associations and interpretation of depositional environments, (4) setting up a sedimentological model, (5) distinguishing individual genetic units, to (6) establishing the stacking pattern of genetic units; the second phase, correlating between the various vertical sections produced in phase one, includes : (7) choice of a regional datum, (8) correlation of individual genetic units and sequences, and finally results in (9) mapping of sequences.

The method is illustrated by two examples. The first concerns correlation at the reservoir scale, while the second applies this sort of correlation to unravel the evolution of the intracratonic Paris Basin during the Jurassic.

The basic theory of genetic stratigraphy is not enlarged upon here, but a number of broader or more practical aspects are cursorily discussed. Some knowledge of primary depositional characteristics is fundamental to the genetic stratigraphy approach, and comparison between different scales of investigation or different data sets (e.g. sedimentological studies which focus on facies or seismic analysis which relies on geometries) may cause ambiguity. Care must be taken with respect to diagenetic masking of primary features, as well as to data (such as wireline logs and seismic) that have not been calibrated with outcrop or core. Feedback from sequence analysis to process sedimentology sets the limits to sedimentological models, emphasizing the recording of time either as facies or as surfaces. Genetic stratigraphy is arguably a central unifying theory for the whole field of sedimentary geology, putting time back into rocks as a fundamental feature.

Peter Homewood, Elf Aquitaine, Centre Scientifique et Technique Jean Feger, F-64018 Pau CEDEX; *François Guillocheau, Géosciences Rennes, UPR 4661 du CNRS, Université de Rennes I, Campus de Beaulieu, F-35042 Rennes* CEDEX; *Rémi Eschard, Institut Français du Pétrole, 1-4 Av. Bois Préau, BP 311, F-95506 Rueil-Malmaison* CEDEX; *Timothy A. Cross, Department of Geology, Colorado School of Mines, Golden, Colorado 80401, USA. – July 31, 1992.*

Key words : Correlation, Stratigraphy (Genetic stratigraphy), Sedimentology.

RÉSUMÉ

Cette article présente une démarche de corrélation à haute résolution (la résolution verticale est métrique à plurimétrique, pour des coupes séparées du kilomètre à plusieurs kilomètres) qui permet d'individualiser des marqueurs isochrones séparés de quelques dizaines à centaines de milliers d'années. La démarche, nécessitant la connaissance des faciès sédimentaires, s'effectue en neuf stades d'analyse, et s'applique tant à la géologie de terrain qu'à la géologie de subsurface. La première étape, effectuée sur une coupe verticale ou log, comprend : (1) l'observation des faciès sédimentaires, (2) la déduction des processus de dépôt, (3) l'identification des associations de faciès et la détermination du milieu de dépôt, (4) la construction du modèle sédimentologique, (5) la mise en évidence des unités génétiques, (6) l'agencement vertical des unités génétiques. La seconde étape, corrélation entre plusieurs coupes

0396-2687/92/0016-0357 $ 5.00

Method to break sequence down from sedimentary log

The method is two-folded:

Phase 1: creation of vertical log

1. Observation of sedimentary facies
2. Deduction of depositional processes
3. Identification of facies associations and GDE
4. Setting up the geological model
5. Distinguishing individual sequences
6. Establishing the stacking pattern of sequences

Phase 2: Correlating between vertical sections

1. Choice of a regional datum
2. Correlation of individual sequences
3. Mapping of sequences

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Cette article présente une démarche de corrélation à haute résolution (la résolution verticale est métrique à plurimétrique, pour des coupes séparées du kilomètre à plusieurs kilomètres) qui permet d'individualiser des marqueurs isochrones séparés de quelques dizaines à centaines de milliers d'années. La démarche, nécessitant la connaissance des faciès sédimentaires, s'effectue en neuf stades d'analyse, et s'applique tant à la géologie de terrain qu'à la géologie de subsurface. La première étape, effectuée sur une coupe verticale ou log, comprend : (1) l'observation des faciès sédimentaires, (2) la déduction des processus de dépôt, (3) l'identification des associations de faciès et la détermination du milieu de dépôt, (4) la construction du modèle sédimentologique, (5) la mise en évidence des unités génétiques, (6) l'agencement vertical des unités génétiques. La seconde étape, corrélation entre plusieurs coupes

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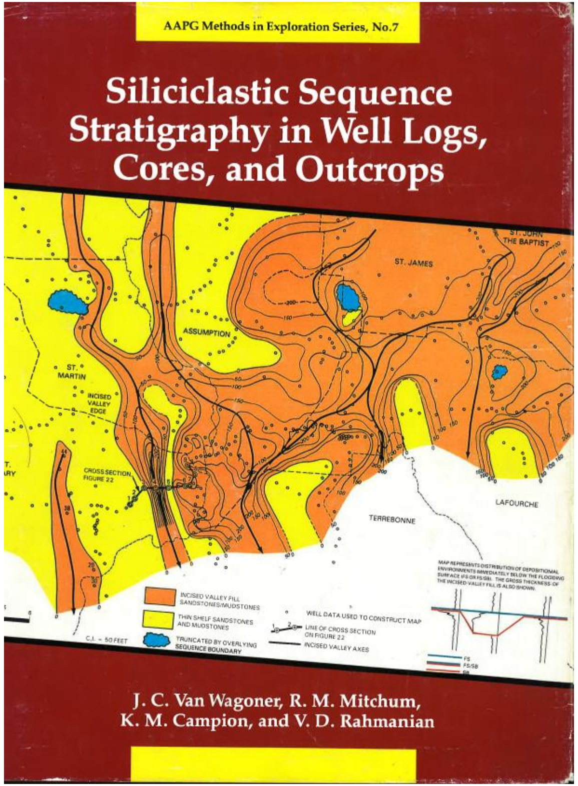
Method to break sequence down from sedimentary log

Method is applied to a case study proposed by Kendall (2003), adapted from Van Wagoner et al. (1988)

Phase 1: creation of vertical log

1. *Observation of sedimentary facies*
2. *Deduction of depositional processes*
3. **Identification of facies associations** and GDE
4. **Setting up the geological model**
5. **Distinguishing individual sequences**
6. **Establishing the stacking pattern of sequences**



Phase 2: Correlating between vertical sections

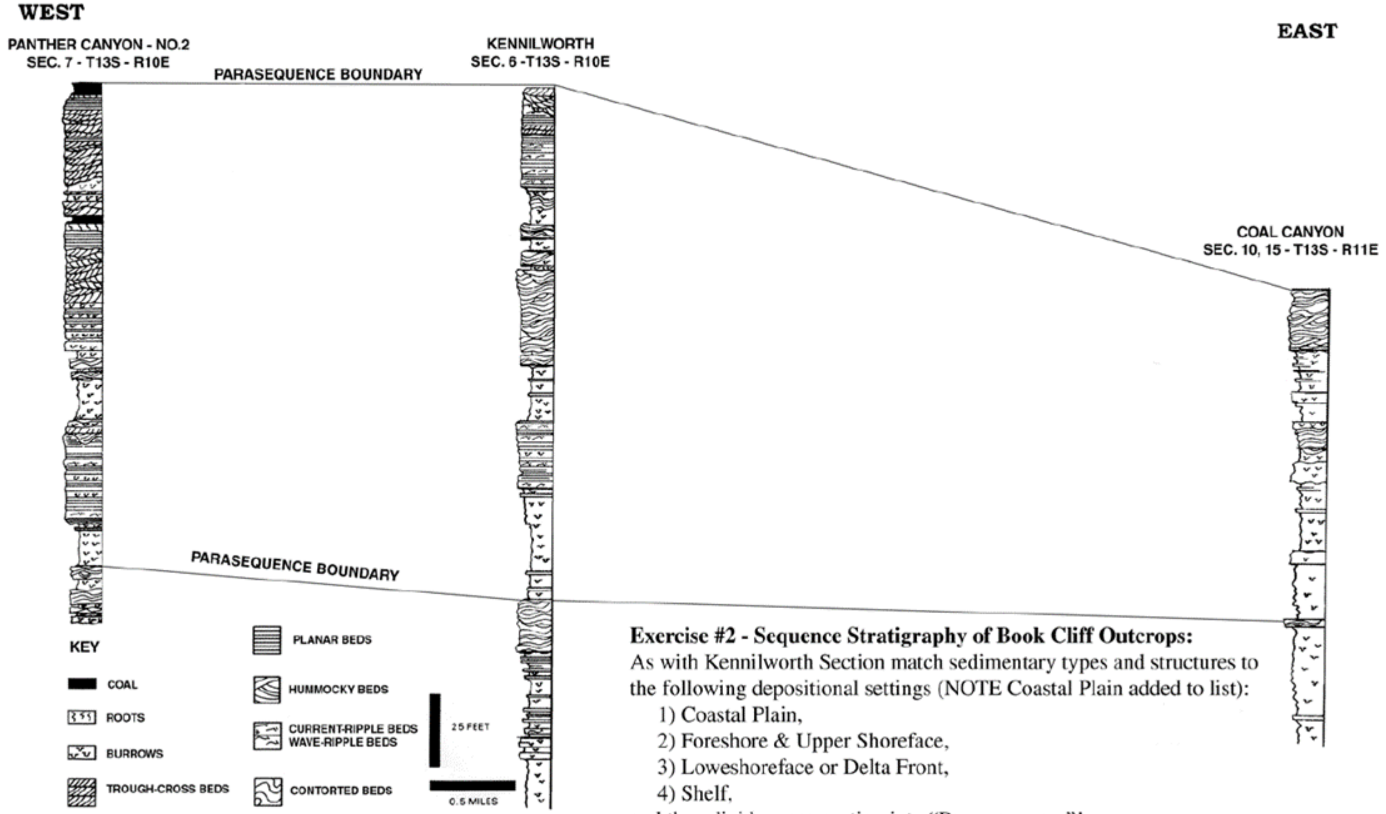
1. **Choice of a regional datum**
2. **Correlation of individual sequences**
3. Mapping of sequences

Book Cliff outcrops

PANTHER CANYON SECTION

KENILWORTH SECTION

COAL CANYON SECTION



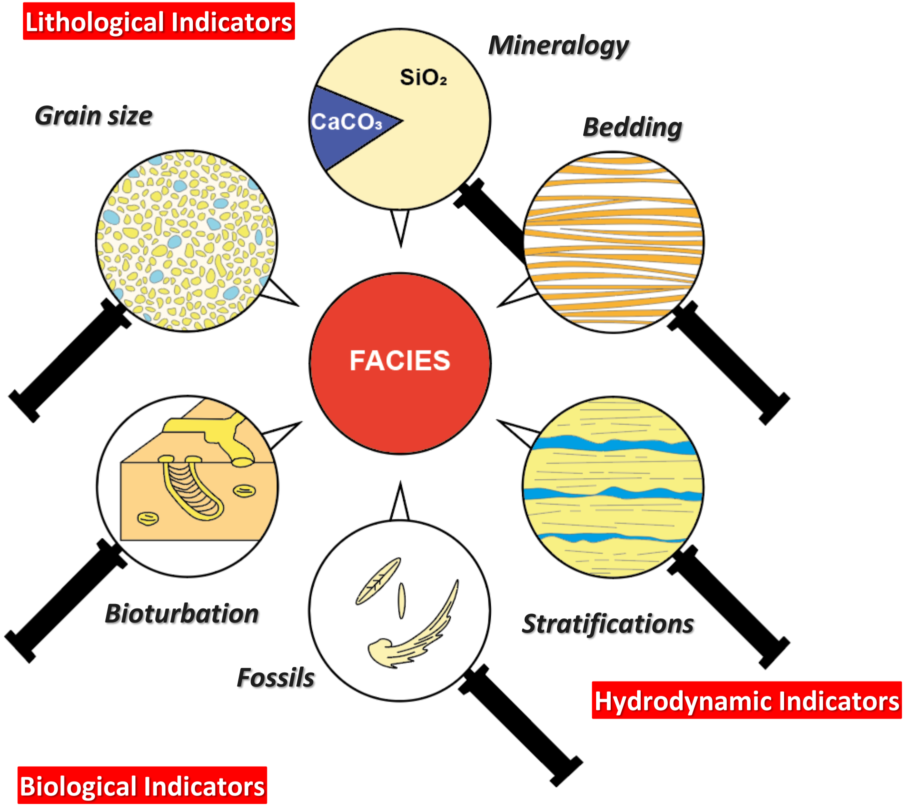
Exercise #2 - Sequence Stratigraphy of Book Cliff Outcrops:
As with Kennilworth Section match sedimentary types and structures to the following depositional settings (NOTE Coastal Plain added to list):

1) Coastal Plain,
2) Foreshore & Upper Shoreface,
3) Loweshoreface or Delta Front,
4) Shelf,

and then divide cross-section into "Parasequences"!

C.G.St.C.Kendall 2003

Phase 1.1 – Observation of sedimentary facies



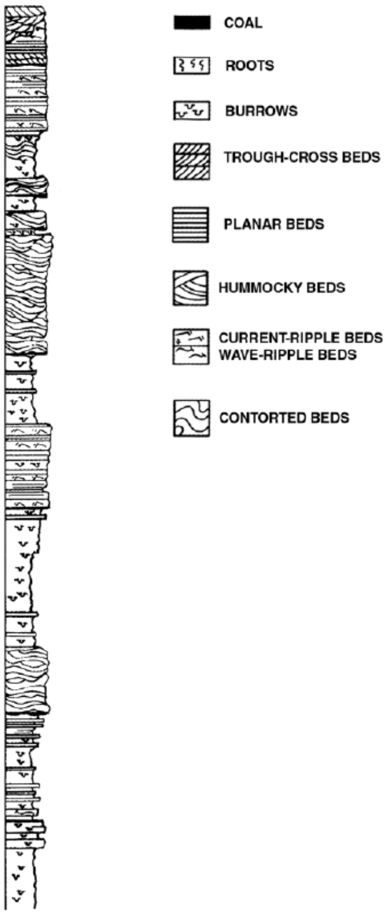
The sedimentary facies corresponds to the whole of the characteristics which make it possible to define the rock: mineralogy, lithology, grain size, textural parameters, sedimentary structures, bedding, fossil content and bioturbation.

The accuracy of the geological model will depend on:

1. The quality of the facies analysis (how reliable described facies are?)
2. The quality of the dataset used to carry out the facies analysis:
   - Multi-proxy (cores, SWC, cuttings, logs, image logs) => reliable
   - Log-driven => questionable

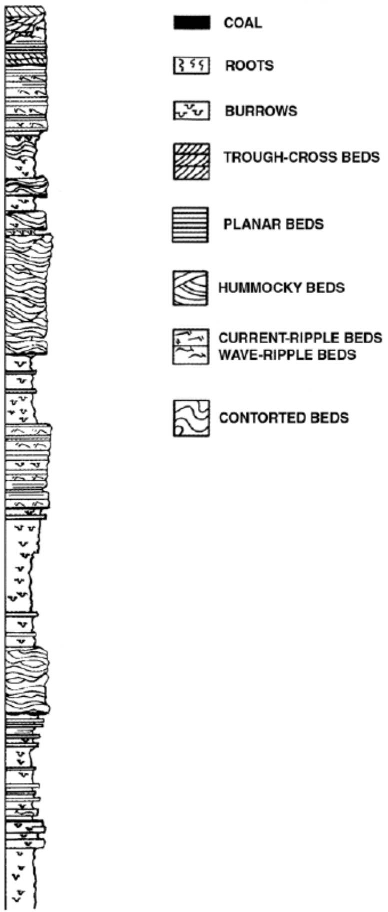
Phase 1.1 – Observation of sedimentary facies

KENILWORTH SECTION



Phase 1.1 – Observation of sedimentary facies

KENILWORTH SECTION



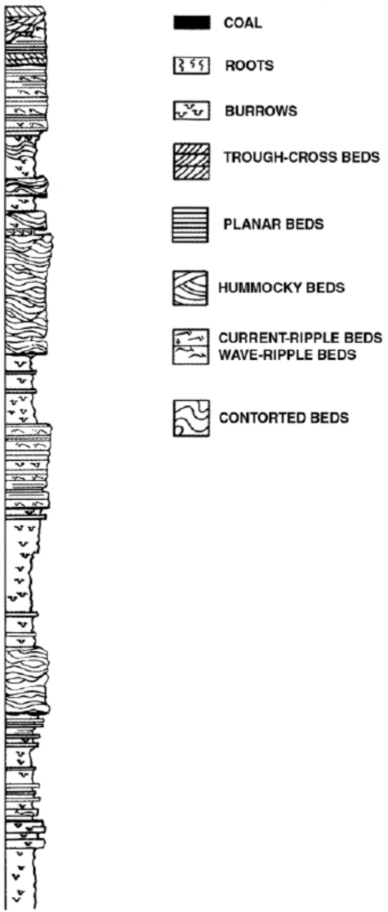
A series of sedimentary logs were described from a clastic outcrop in the Book Cliff Formation near Helper, Utah.

Primary sedimentary facies were described. They included:

- **Facies 1**: Well sorted, medium-grained sandstone with hummocky cross stratifications
- **Facies 2**: Moderately well-sorted, medium-grained sandstone with asymmetric ripple marks
- **Facies 3**: Moderately well-sorted, fine-grained sandstone with symmetrical ripple marks
- **Facies 4**: Well-sorted, fine-grained sandstone with planar lamination and parting lineation
- **Facies 5**: Moderately- to poorly-sorted, medium- to coarse-grained sandstone with trough cross-stratifications
- **Facies 6**: Thin bed of very fine-grained sandstone and siltstone with some contorted beds, encased into silty claystone
- **Facies 7**: Massive, bioturbated claystone with scattered shells

Phase 1.2 – Deduction of depositional processes

KENILWORTH SECTION

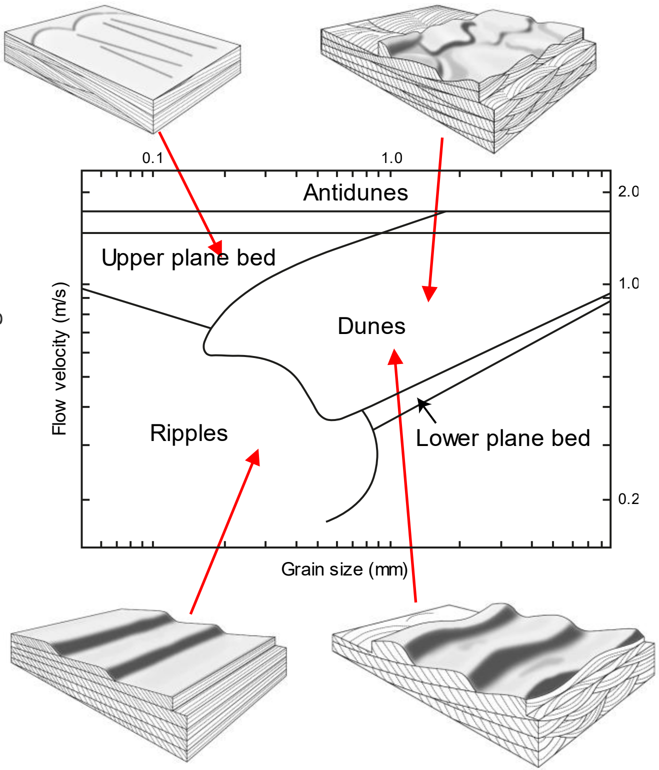


To interpret sedimentary facies in terms of depositional environments, depositional processes must be deduced from the facies description.

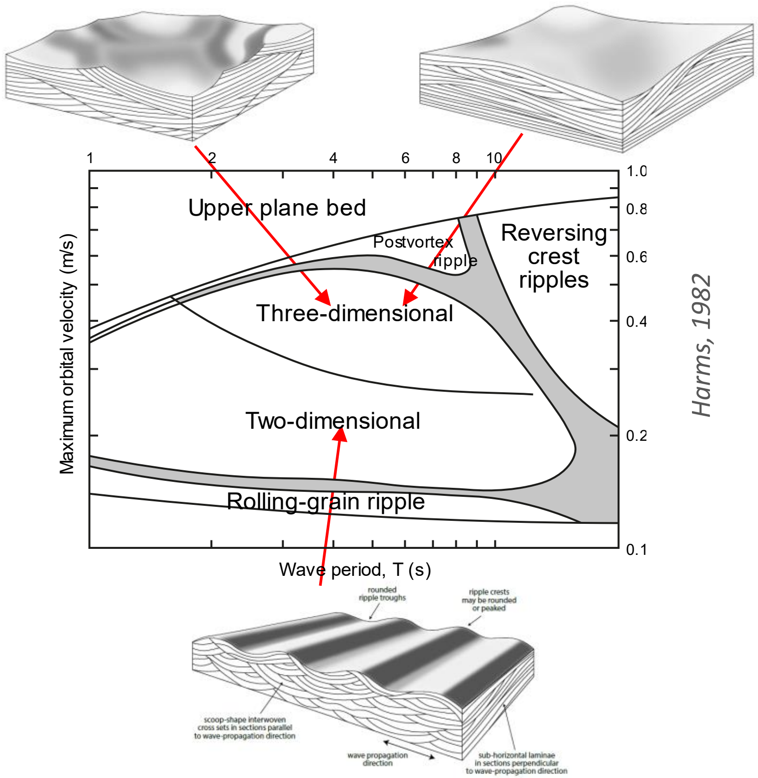
- **Facies 1**: Well sorted, medium-grained sandstone with **hummocky cross stratifications**
- **Facies 2**: Moderately well-sorted, medium-grained sandstone with **asymmetric ripple marks**
- **Facies 3**: Moderately well-sorted, fine-grained sandstone with **symmetrical ripple marks**
- **Facies 4**: Well-sorted, fine-grained sandstone with **planar lamination and parting lineation**
- **Facies 5**: Moderately- to poorly-sorted, medium- to coarse-grained sandstone with **trough cross-stratifications**
- **Facies 6**: **Thin bed of very fine-grained sandstone** and **siltstone** with some contorted beds, encased into silty claystone
- **Facies 7**: Massive, **bioturbated claystone** with scattered shells

Phase 1.2 – Deduction of depositional processes

Sedimentary structures form as a response to flow velocity interacting with grains (according to their size). They are a marker of energy conditions of the environment and they are commonly used to **estimate water depth**.

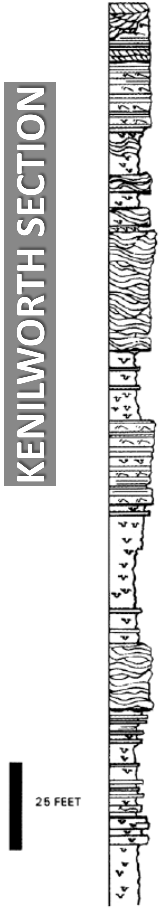


Southard and Boguchwal 1990



Harms, 1982

Phase 1.3 – Identification of facies associations and GDE



Sedimentary facies

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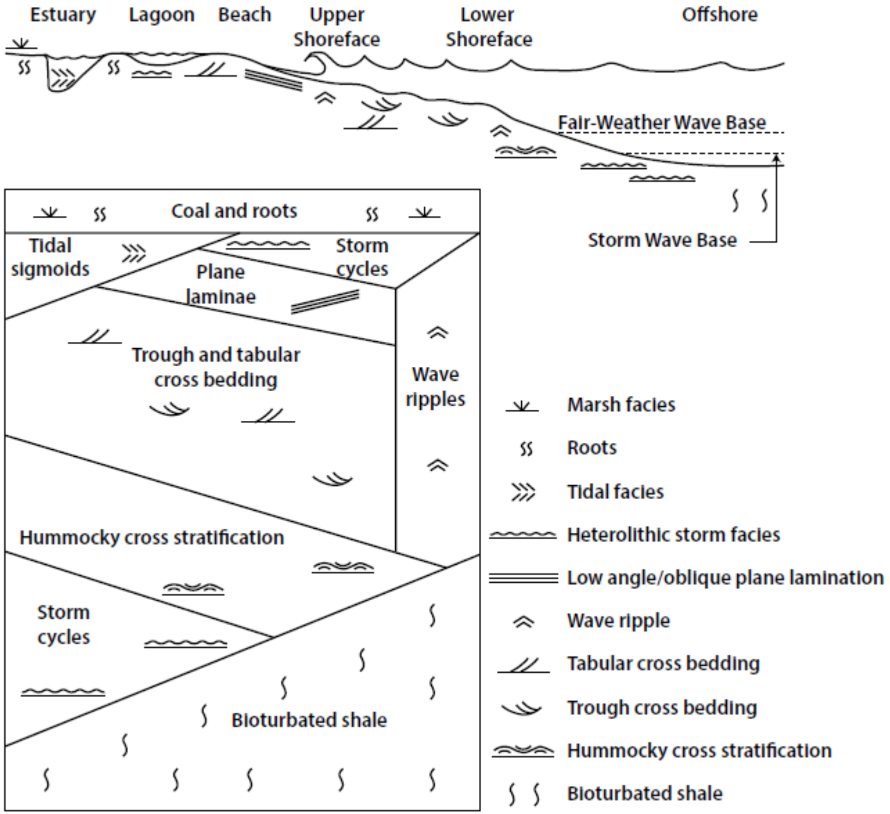
Facies 3: Moderately well-sorted, fine-grained sandstone with **symmetrical ripple marks**

Facies 4: Well-sorted, fine-grained sandstone with **planar lamination and parting lineation**

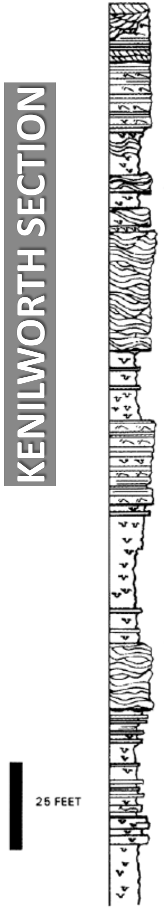
Facies 5: Moderately- to poorly-sorted, medium- to coarse-grained sandstone with **trough cross-stratifications**

Facies 6: **Thin bed of very fine-grained sandstone** and **siltstone** with some contorted beds, encased into silty claystone

Facies 7: Massive, **bioturbated claystone** with scattered shells



Phase 1.3 – Identification of facies associations and GDE



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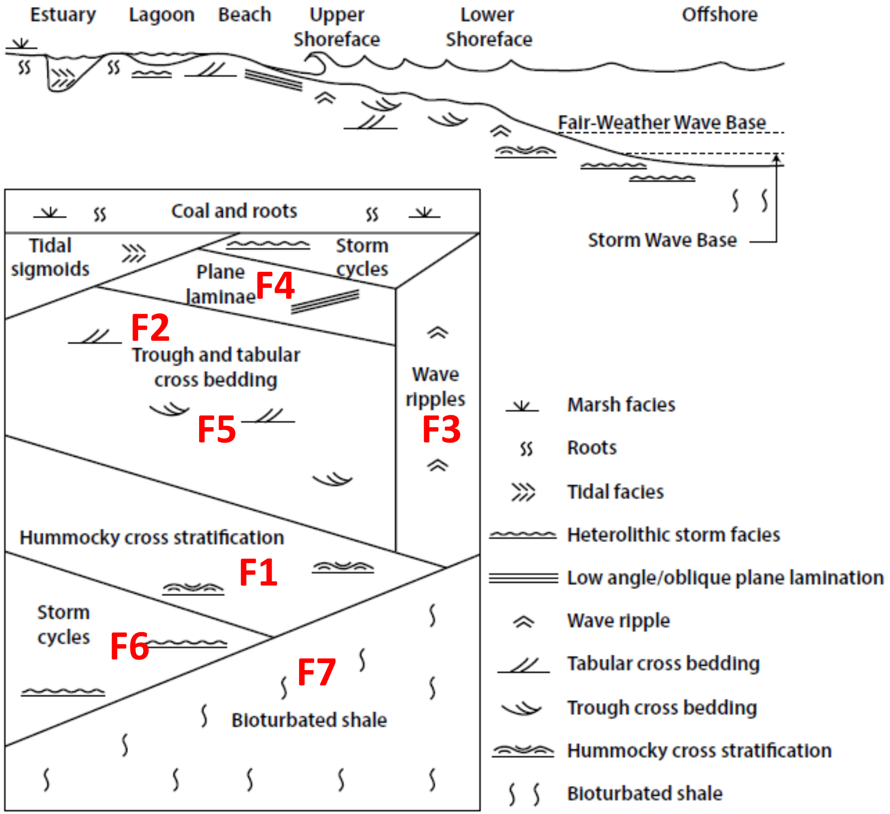

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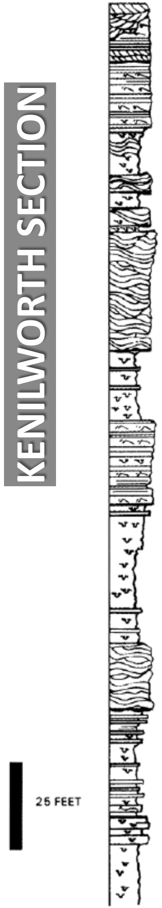

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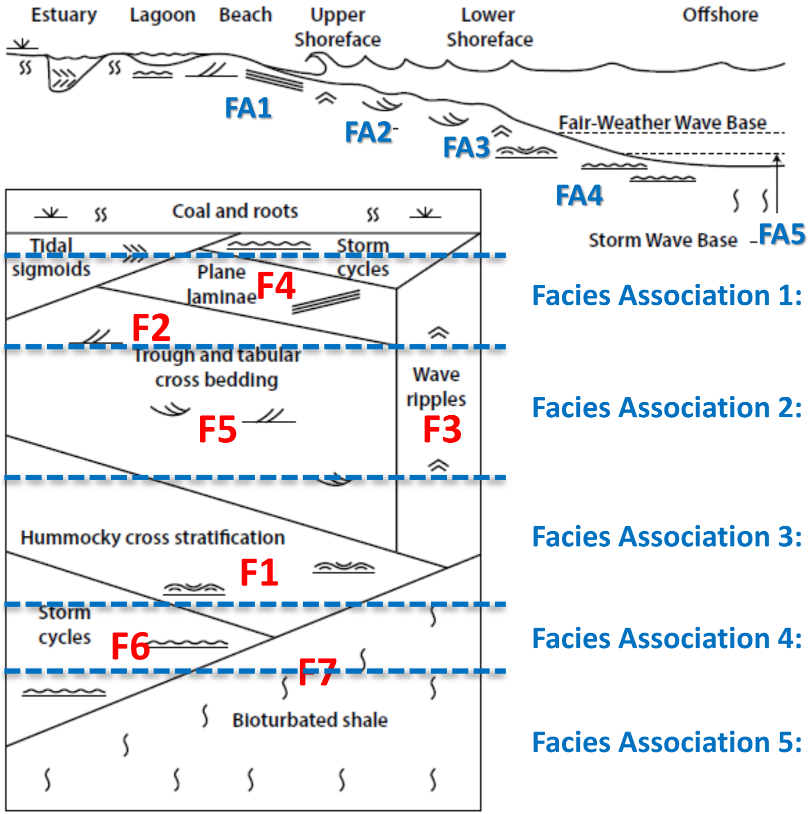


Facies Association 1: Foreshore

Facies Association 2: Upper shoreface

Facies Association 3: Middle shoreface

Facies Association 4: Lower shoreface

Facies Association 5: Offshore

Phase 1.4 – Setting up the geological model

The depositional model is a 2D or a 3D sketch which illustrates the spatial distribution of facies or facies associations within the Area of Interest. The depositional model is an "artist" view; it provides a conceptual view of the depositional system, not a realistic picture of the system. **The geological model must only illustrate genetically linked facies with a minimum of diachronism.**

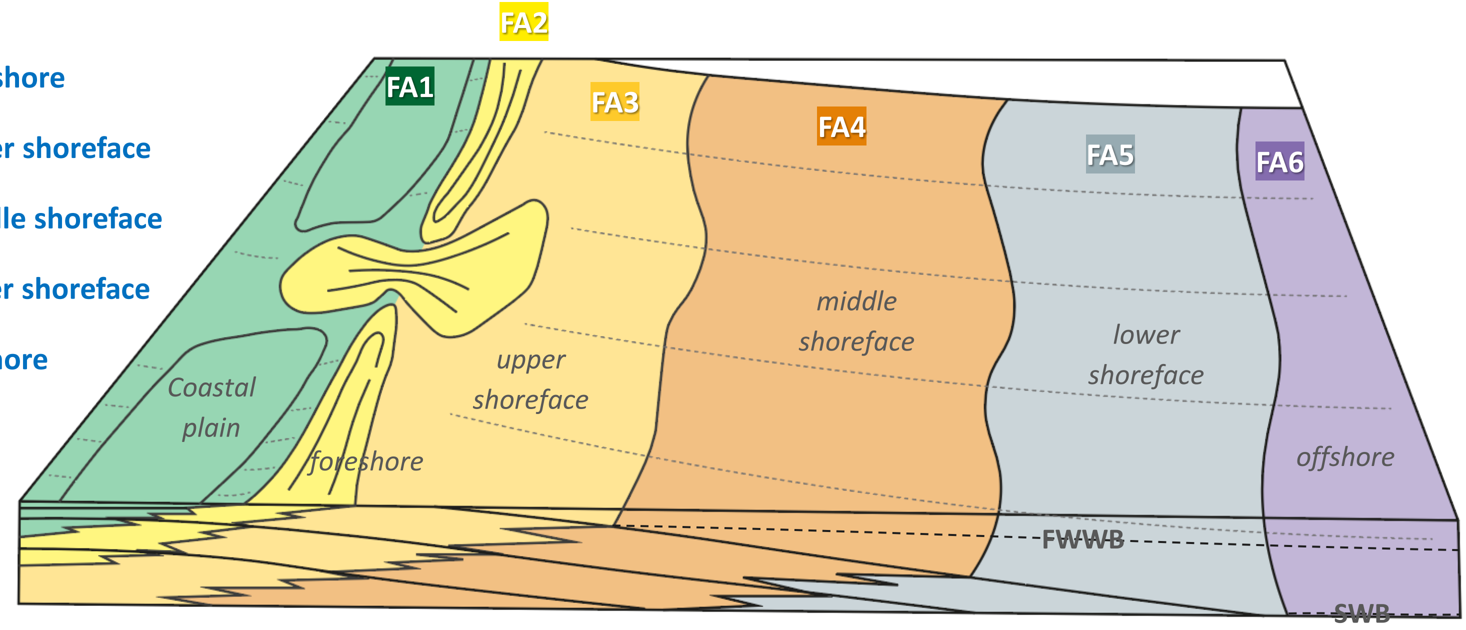
Facies Association 1: Foreshore

Facies Association 2: Upper shoreface

Facies Association 3: Middle shoreface

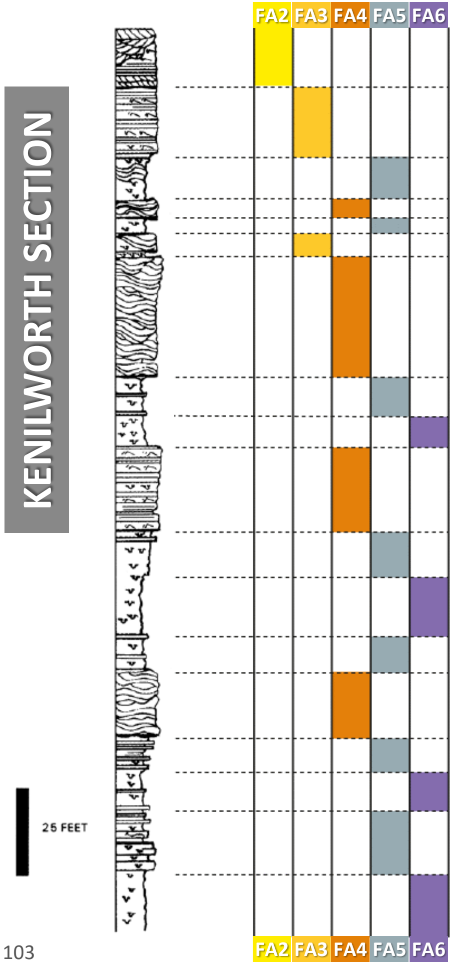
Facies Association 4: Lower shoreface

Facies Association 5: Offshore

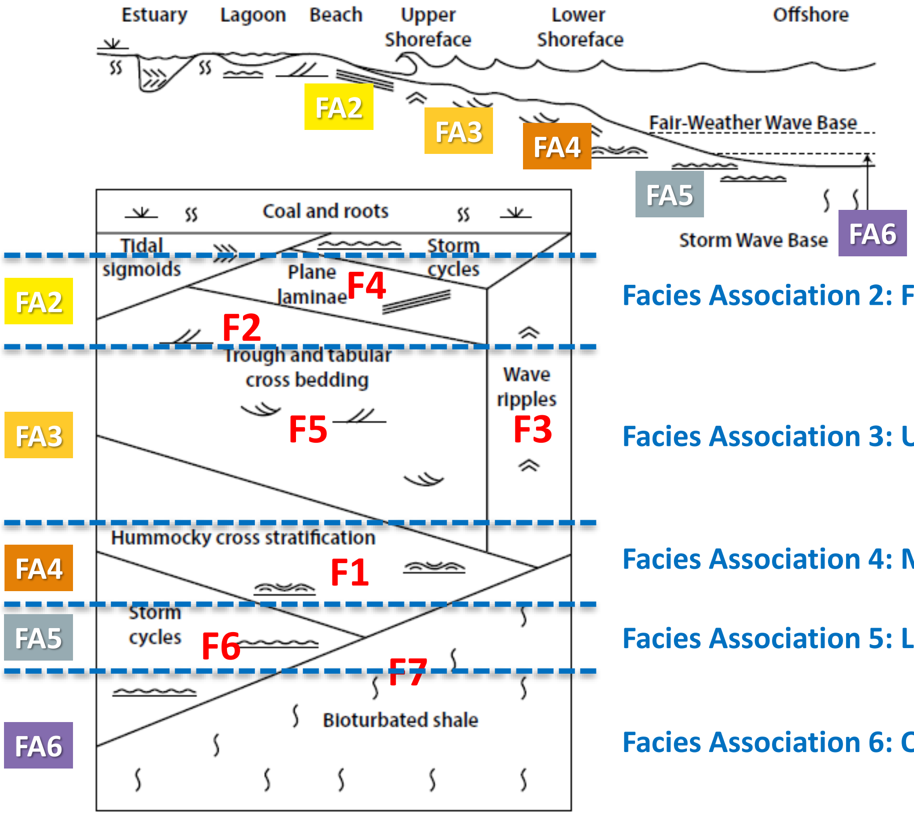


Adapted from Went et al. (2013)

Phase 1.5 – Distinguishing individual sequences



Depositional curve



Facies Association 2: Foreshore

Facies Association 3: Upper shoreface

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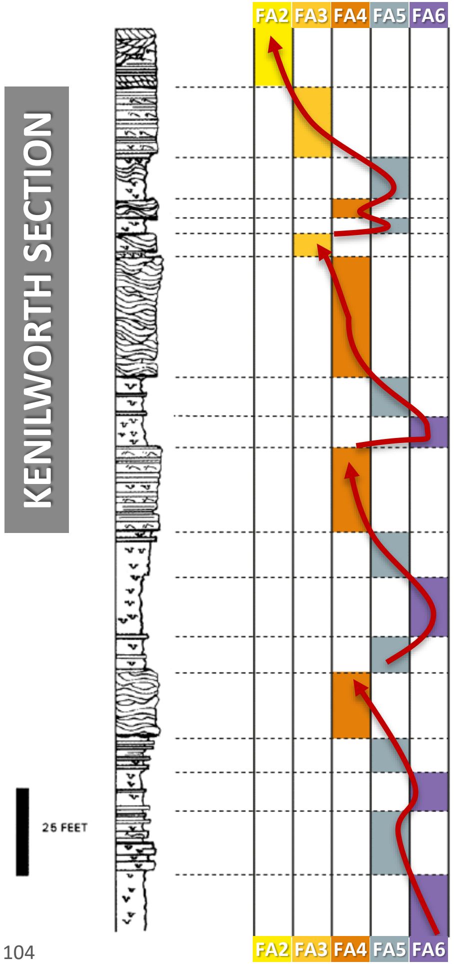
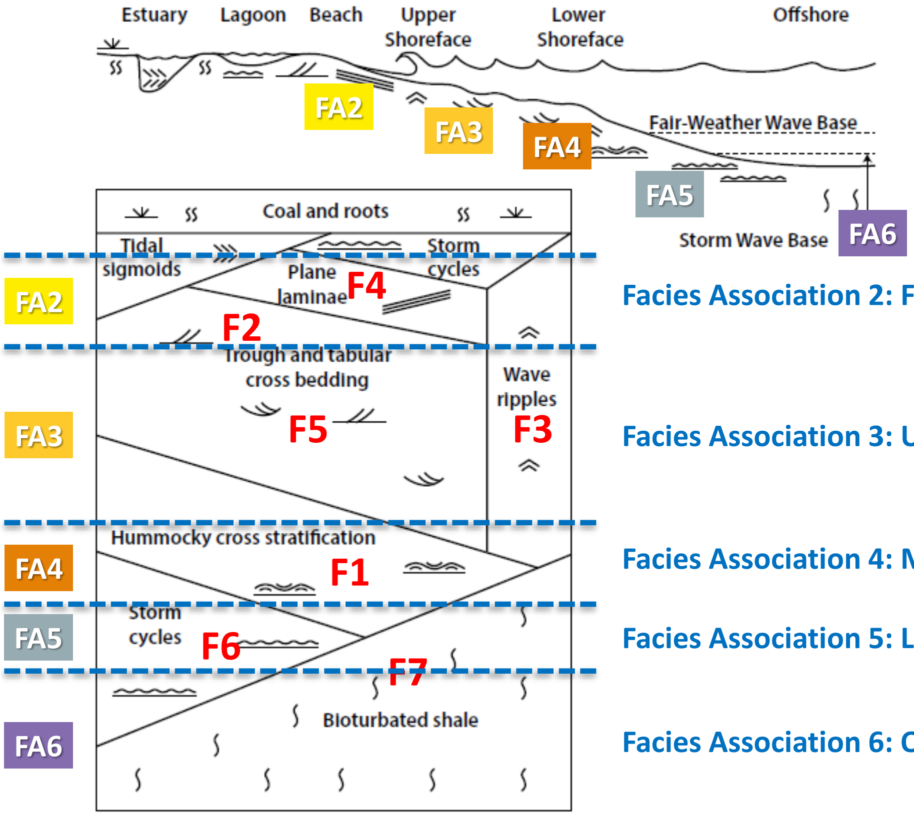
Facies Association 6: Offshore

Phase 1.5 – Distinguishing individual sequences



Depositional trends



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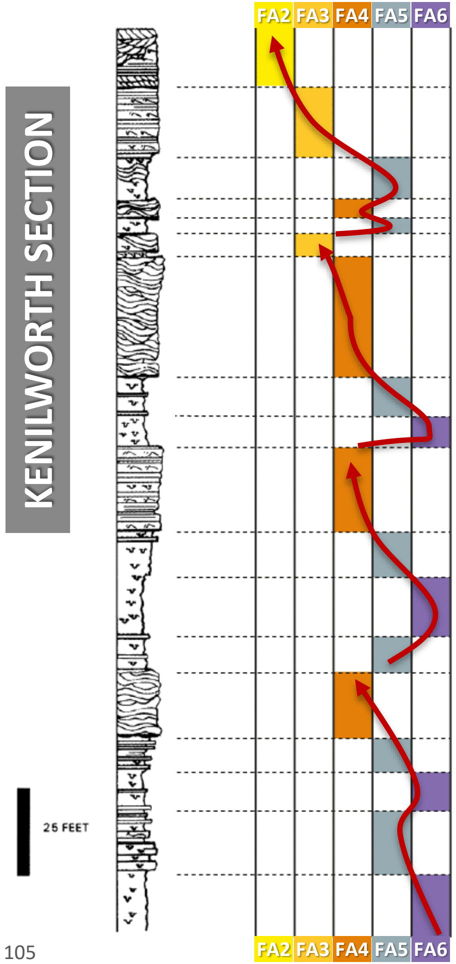
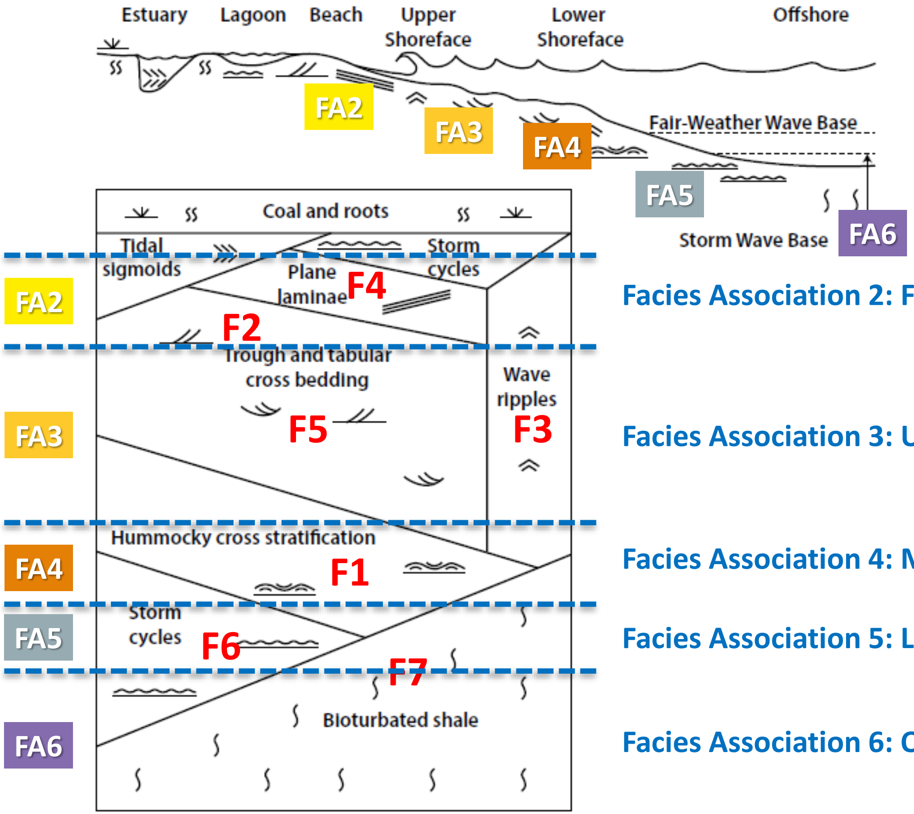


Identifications of surfaces and turnover points



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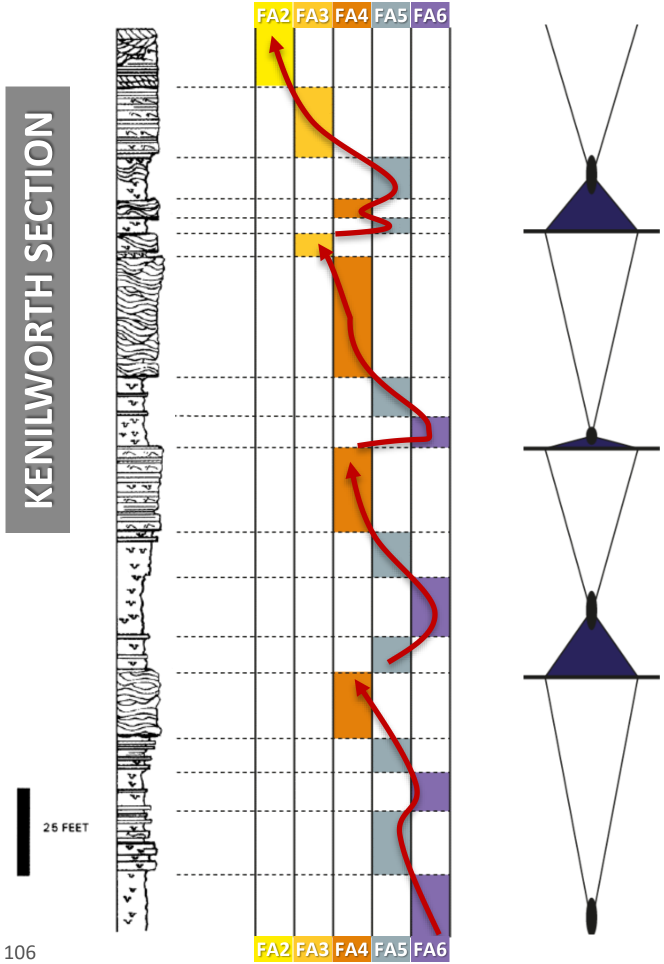
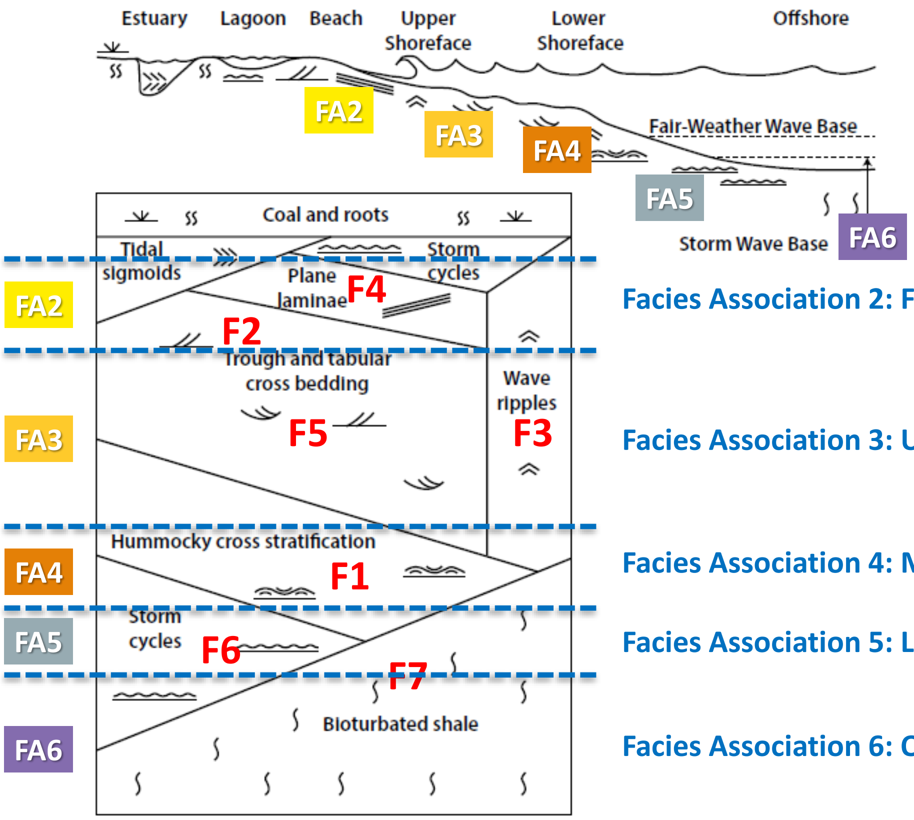


Interpretation of individual sequences



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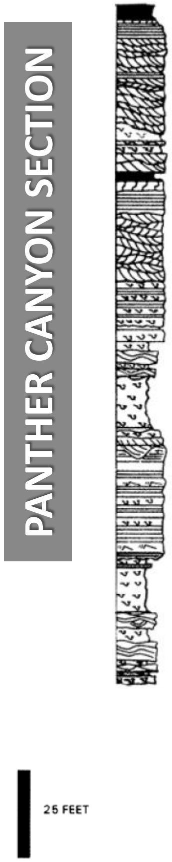
Facies Association 5: Lower shoreface

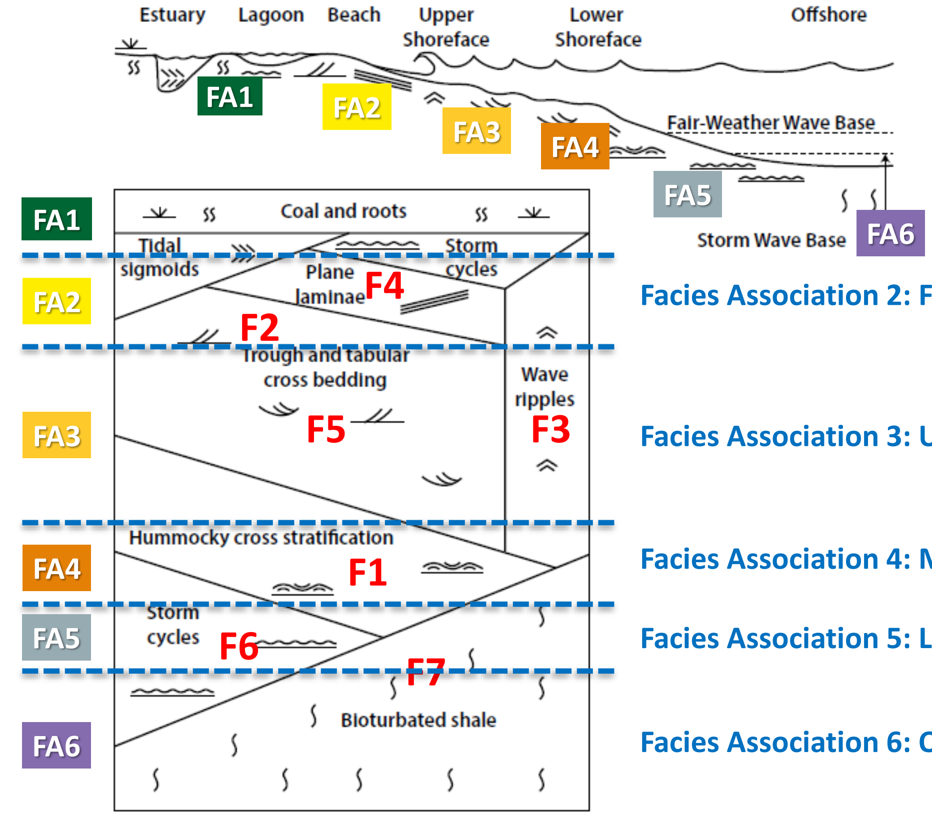
Facies Association 6: Offshore

Phase 1.5 – Distinguishing individual sequences

PANTHER CANYON SECTION



Analysis of the Panther Canyon Section



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Facies Association 5: Lower shoreface

Facies Association 6: Offshore

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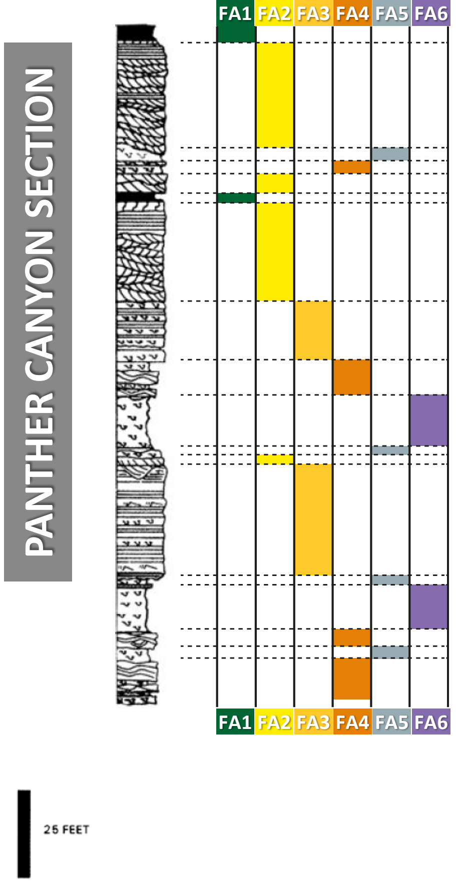
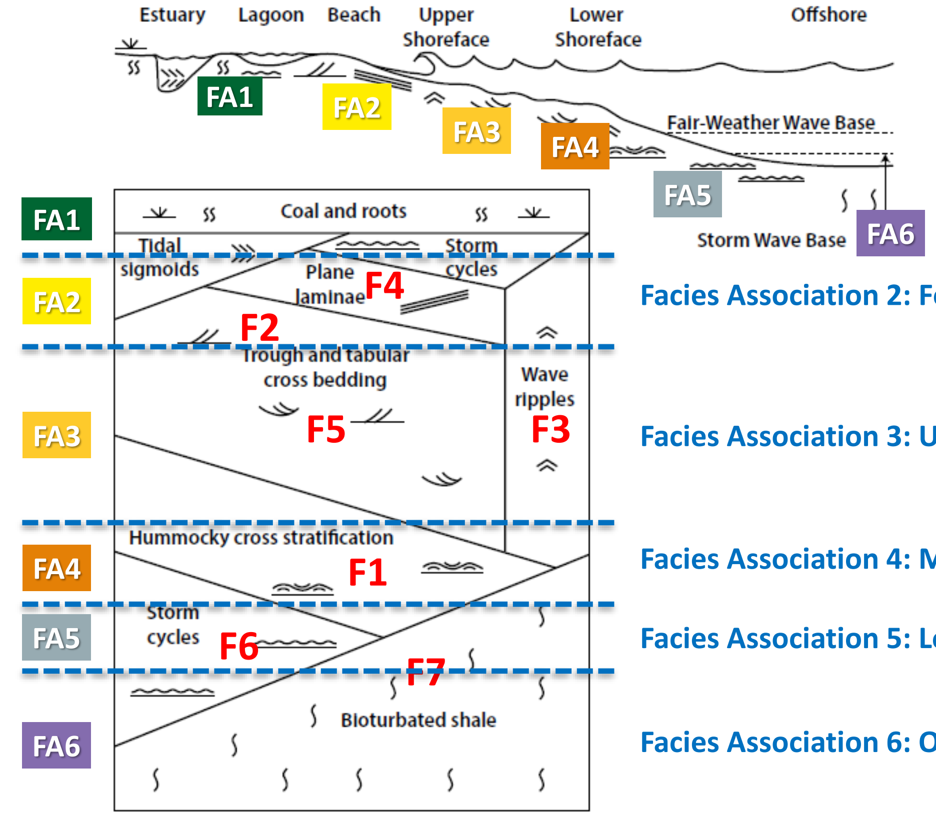
Phase 1.5 – Distinguishing individual sequences



New Facies Association is introduced: FA1 - Coastal Plain



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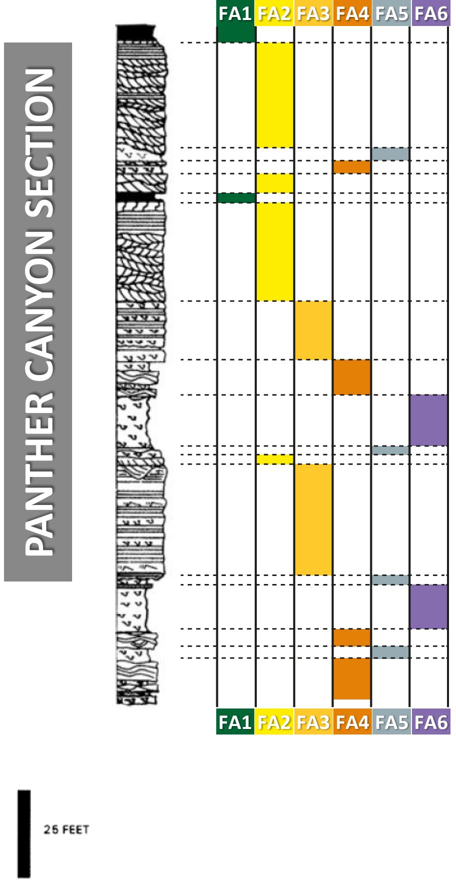
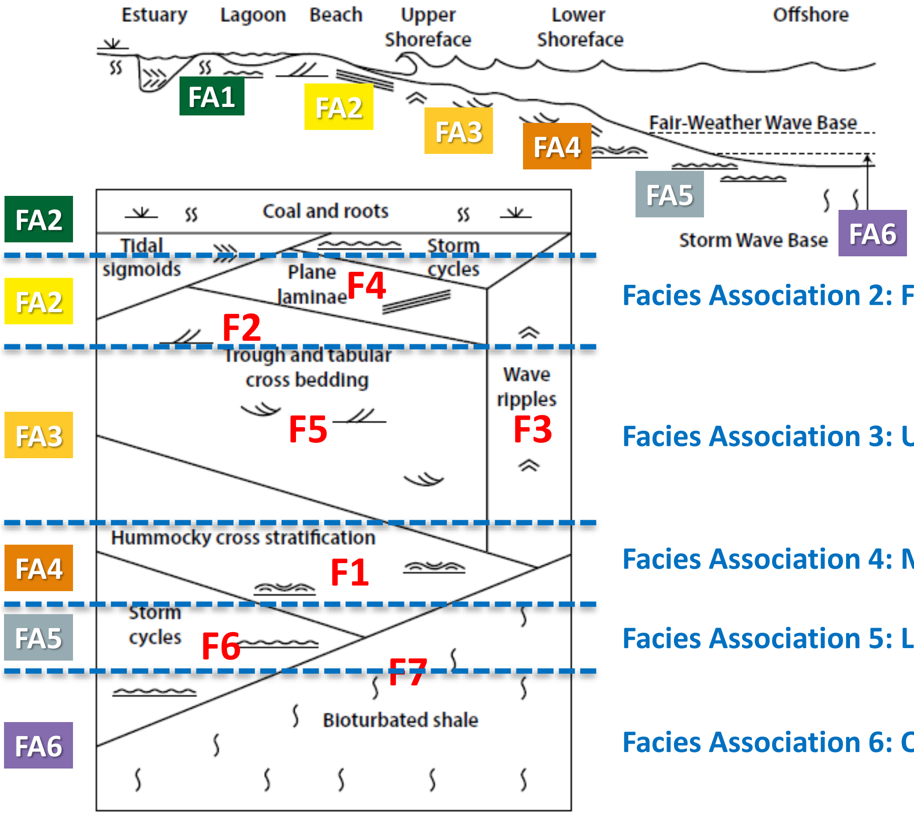
Facies Association 6: Offshore

Phase 1.5 – Distinguishing individual sequences



Interpretation of Facies Associations and depositional curve



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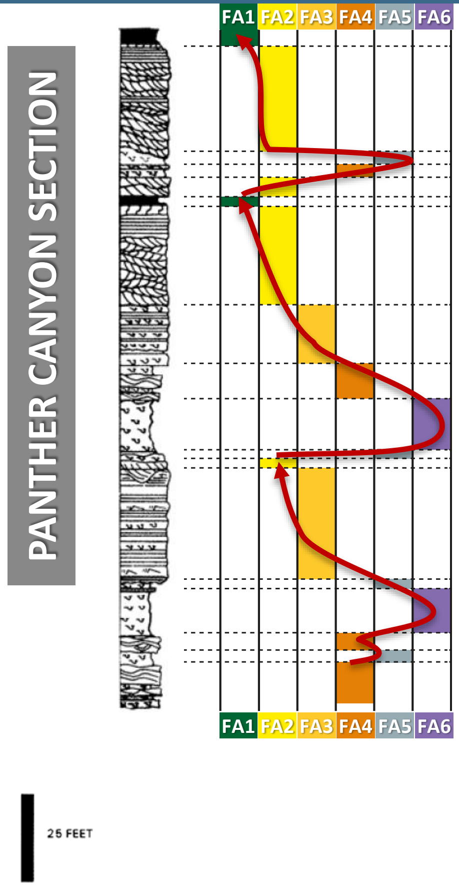
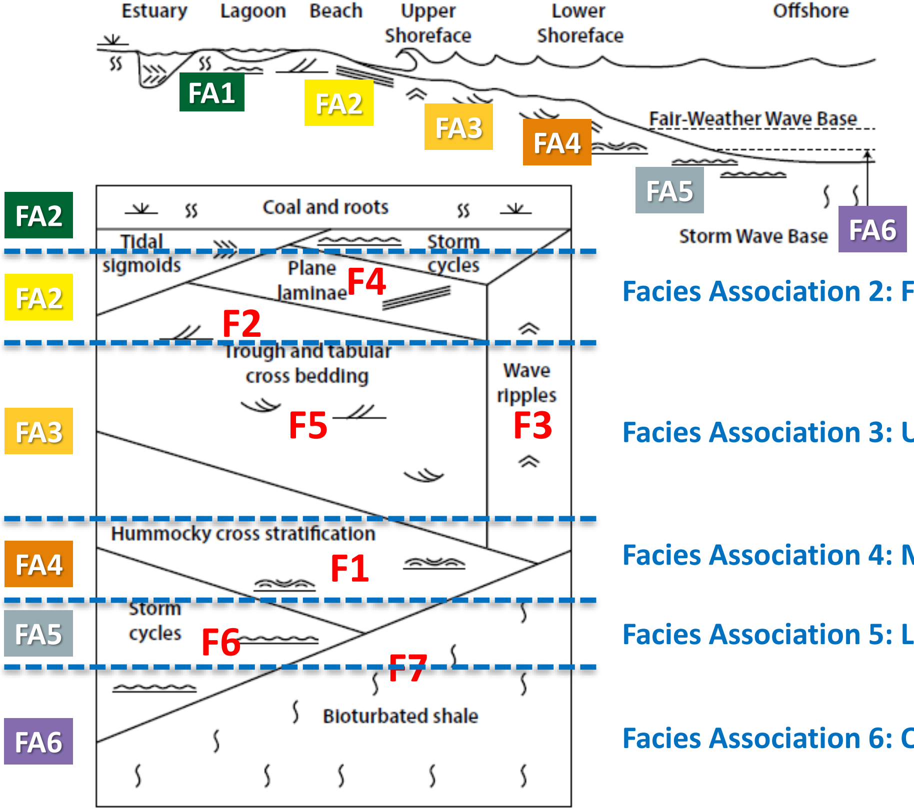
Phase 1.5 – Distinguishing individual sequences



Depositional trends



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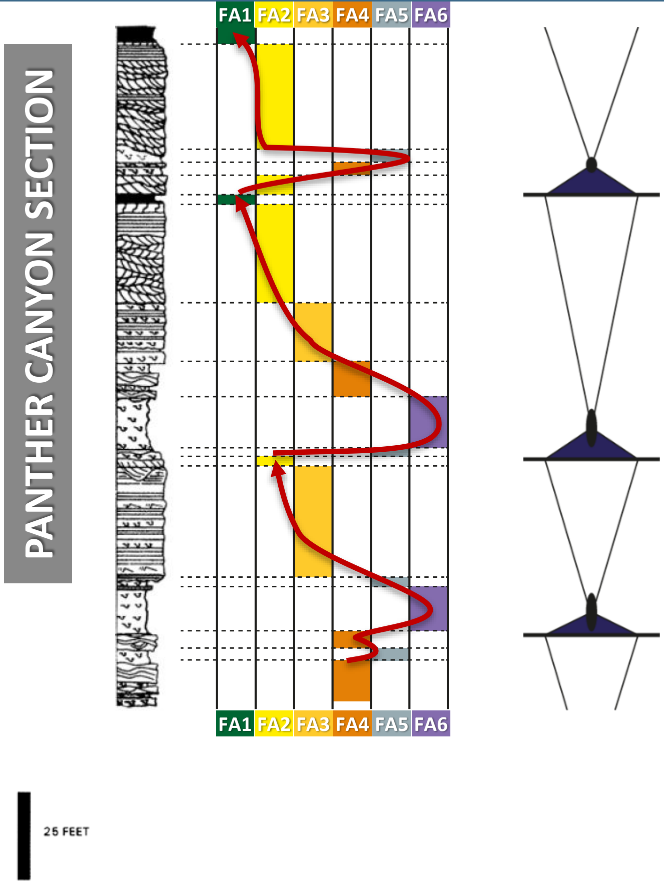
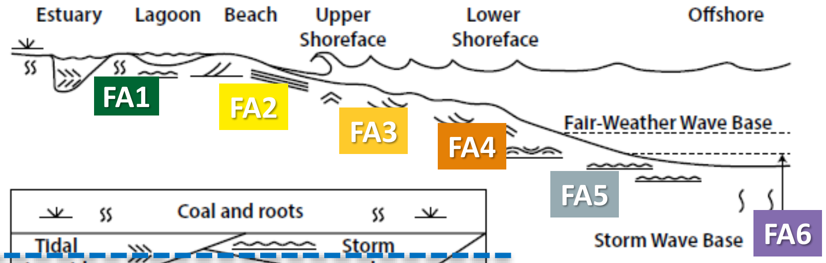
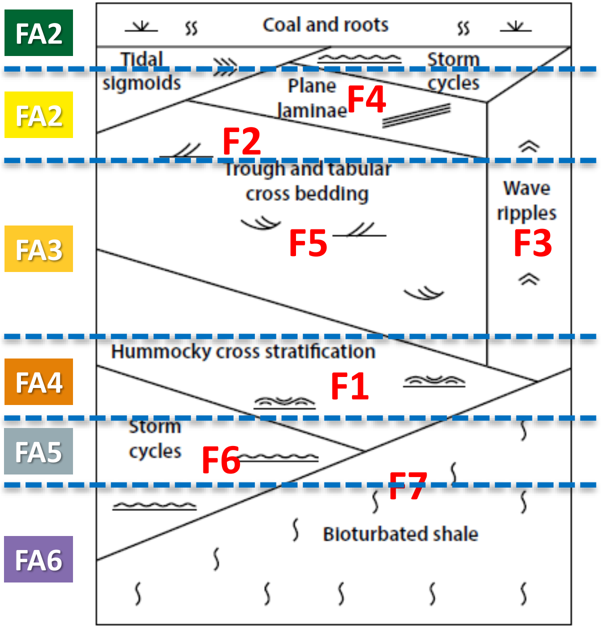
Phase 1.5 – Distinguishing individual sequences



Interpretation of individual sequences





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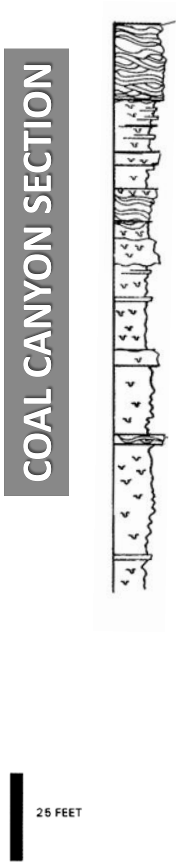
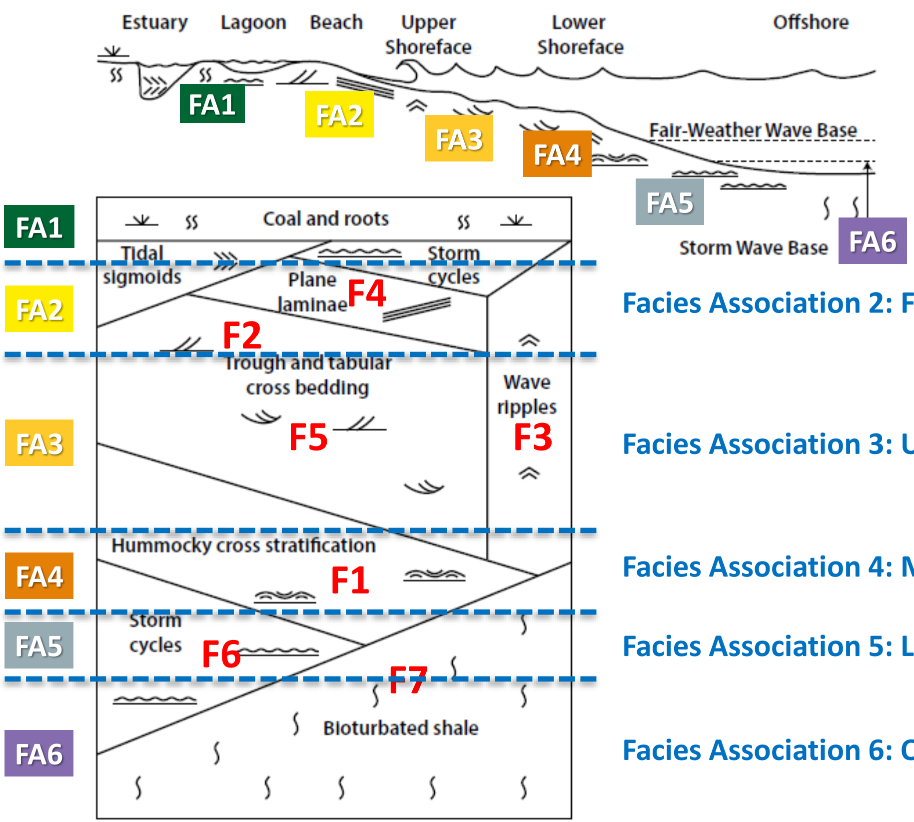
Phase 1.5 – Distinguishing individual sequences





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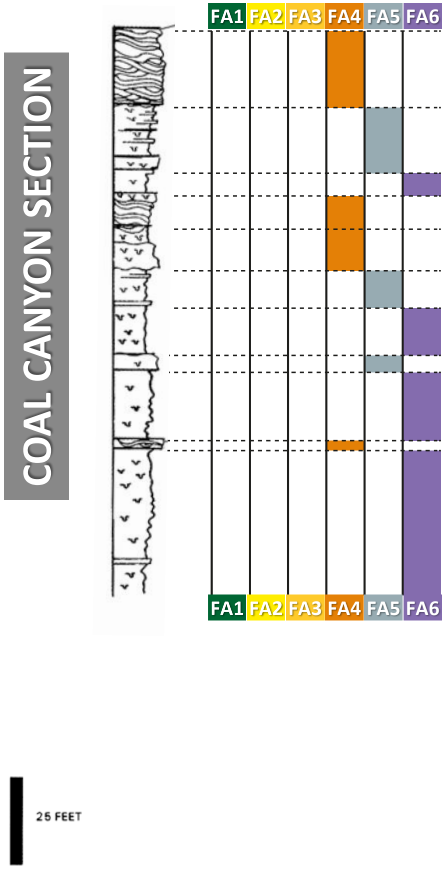
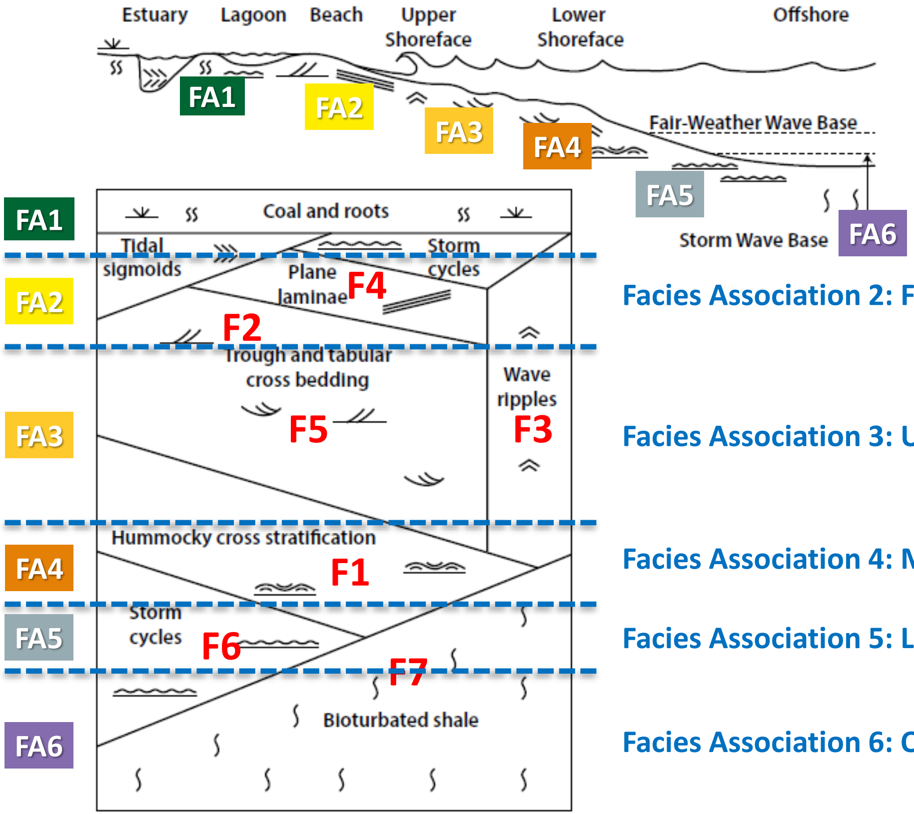
Phase 1.5 – Distinguishing individual sequences



Interpretation of Facies Associations and depositional curve



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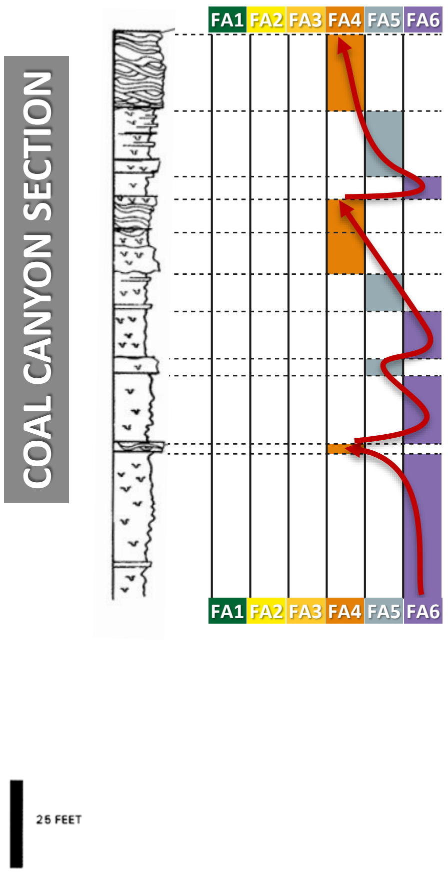
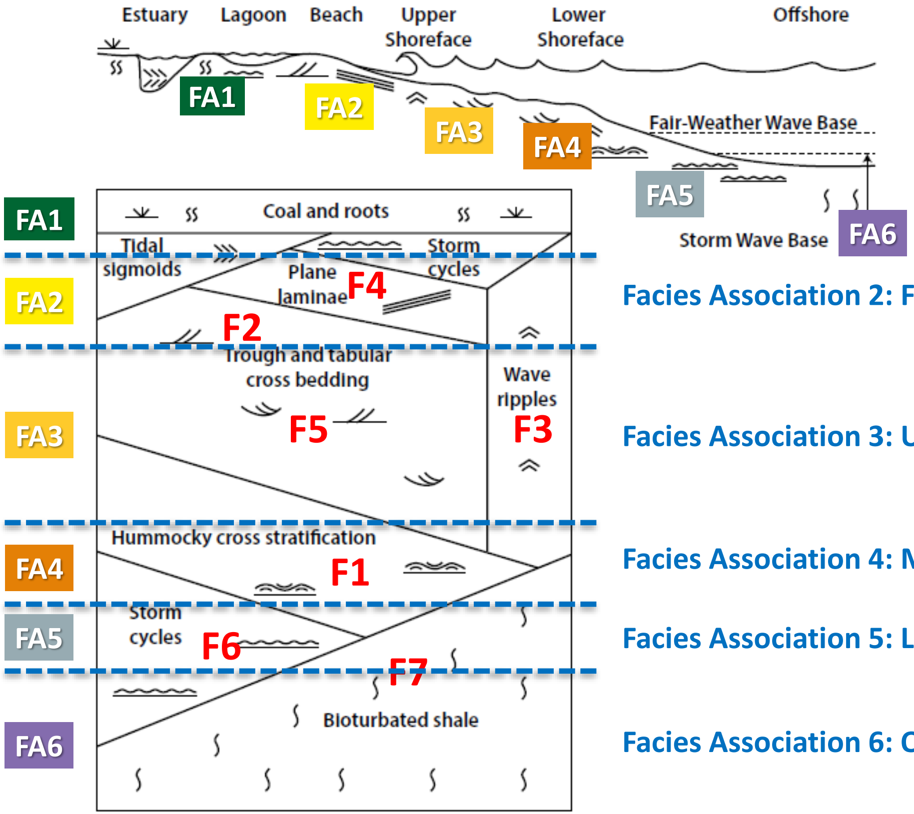
Phase 1.5 – Distinguishing individual sequences

COAL CANYON SECTION



Depositional trends



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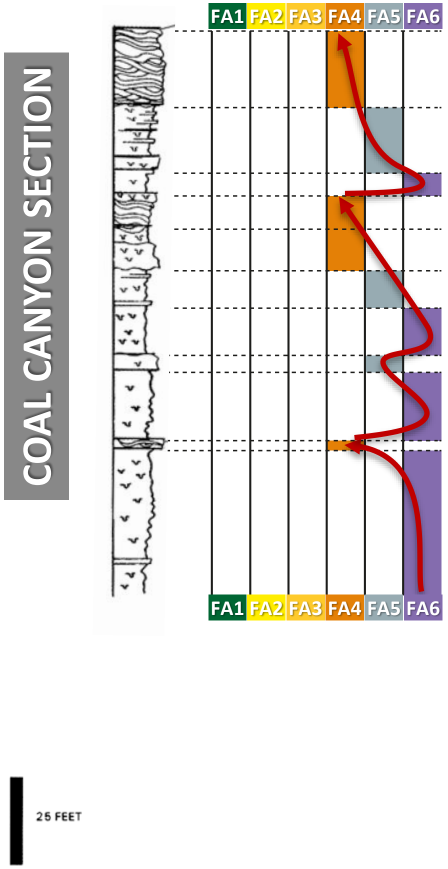
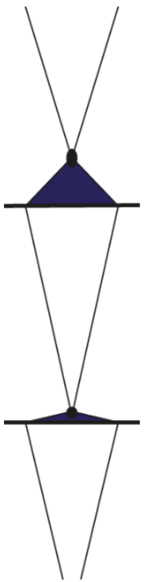
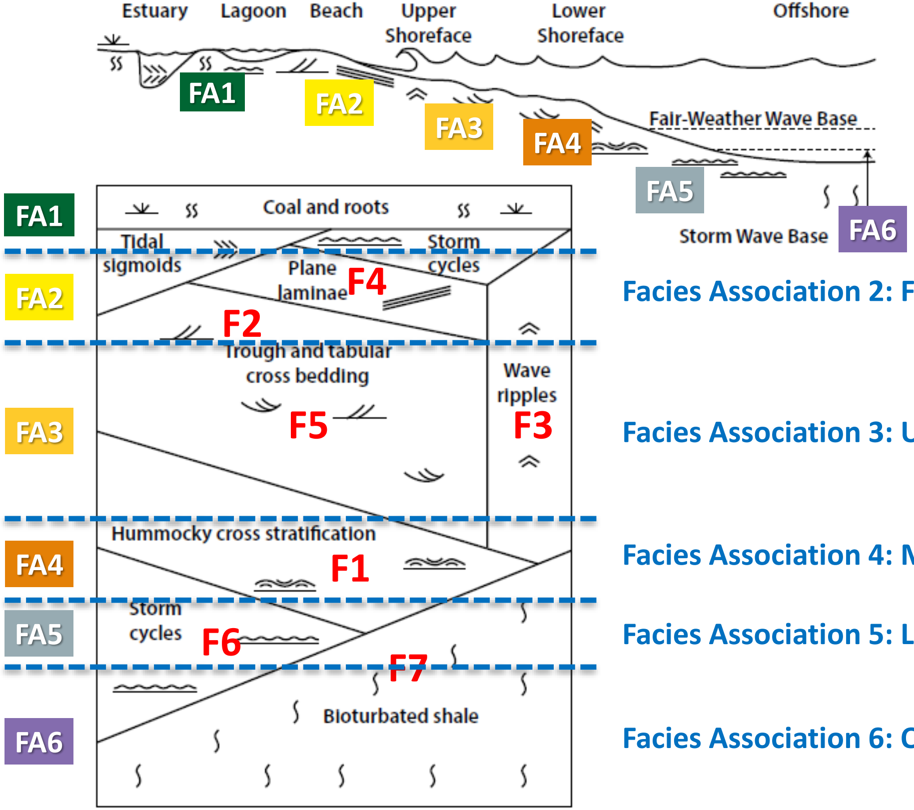
Phase 1.5 – Distinguishing individual sequences





Interpretation of individual sequences



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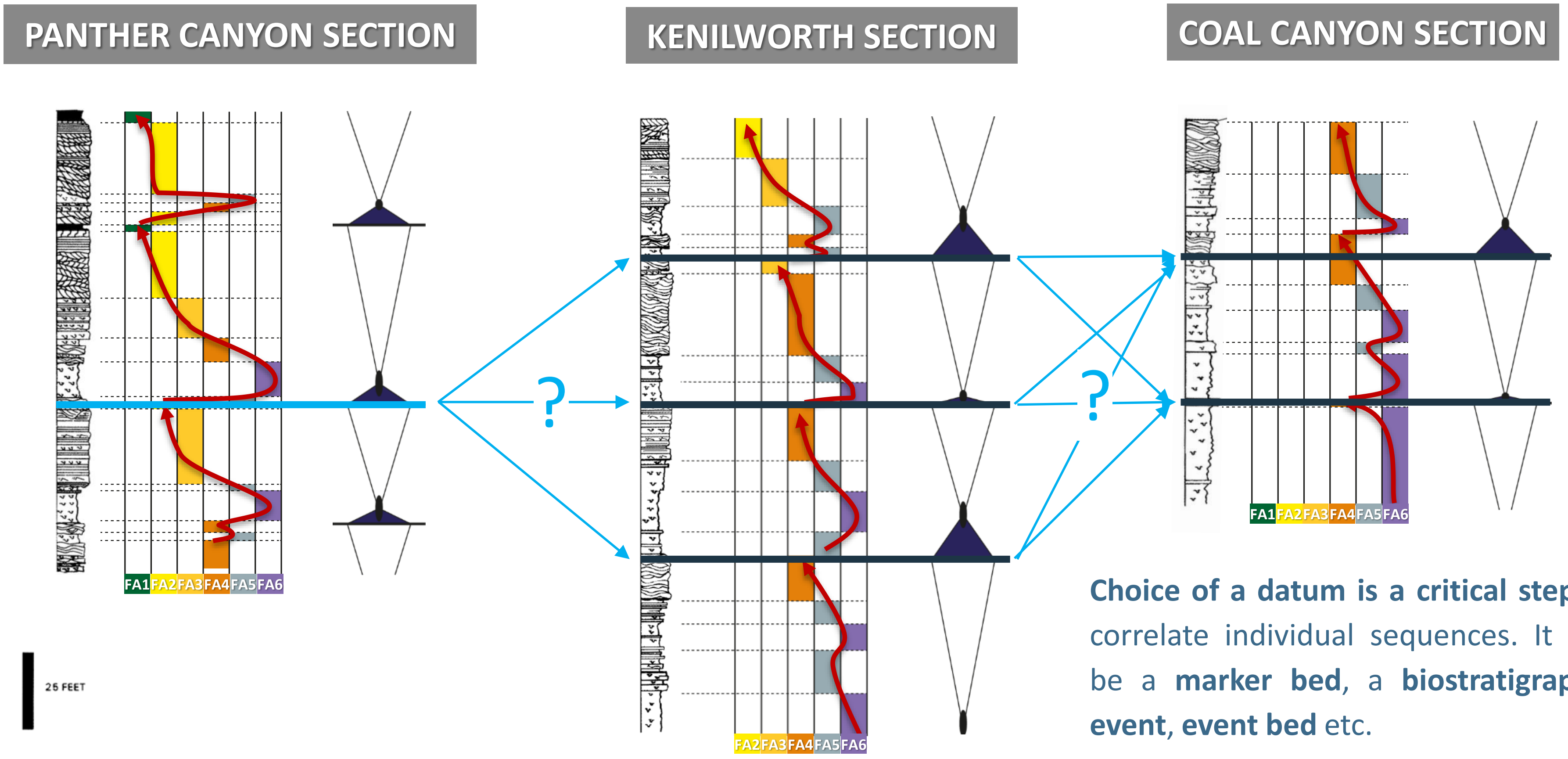
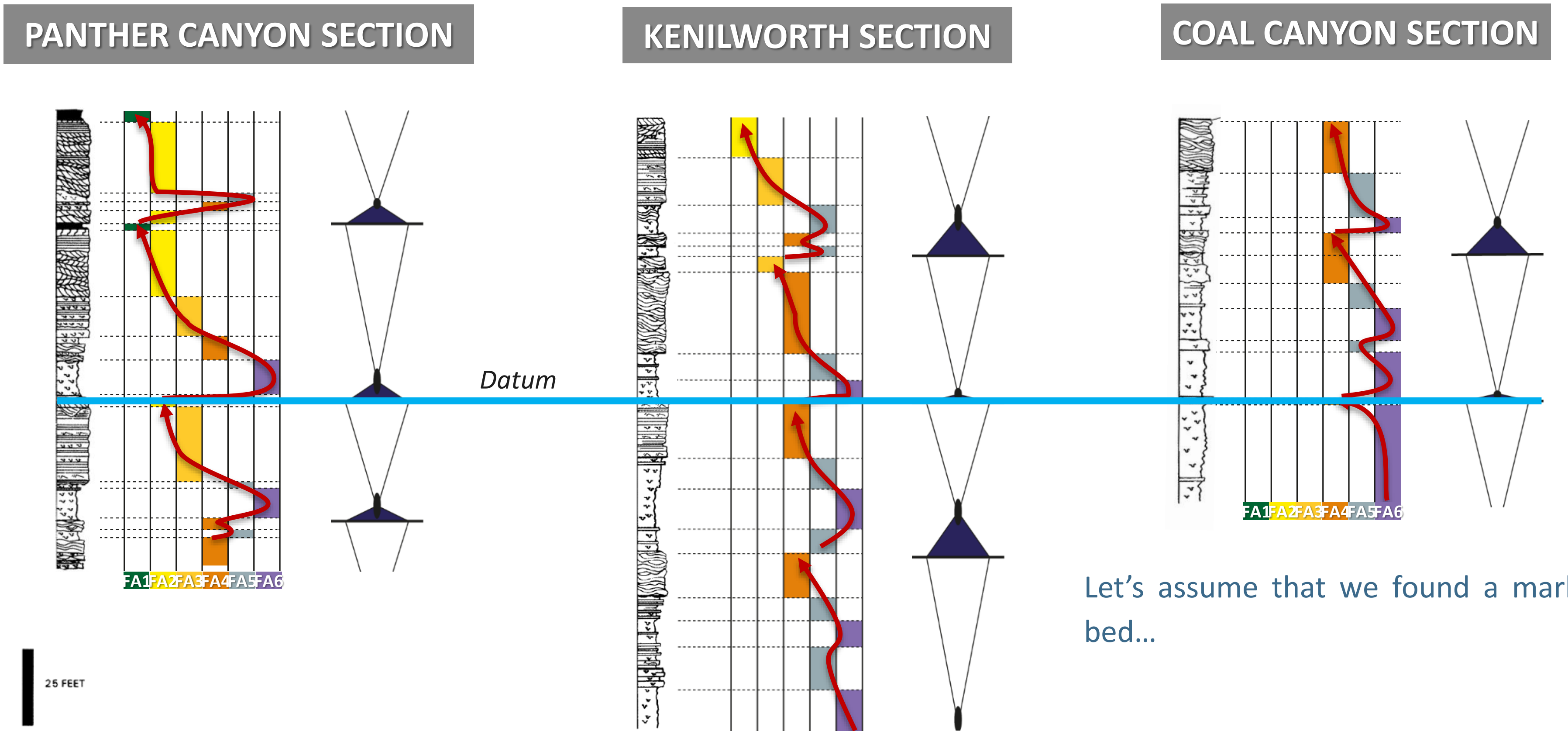
Phase 2.1 – Choice of a regional datum



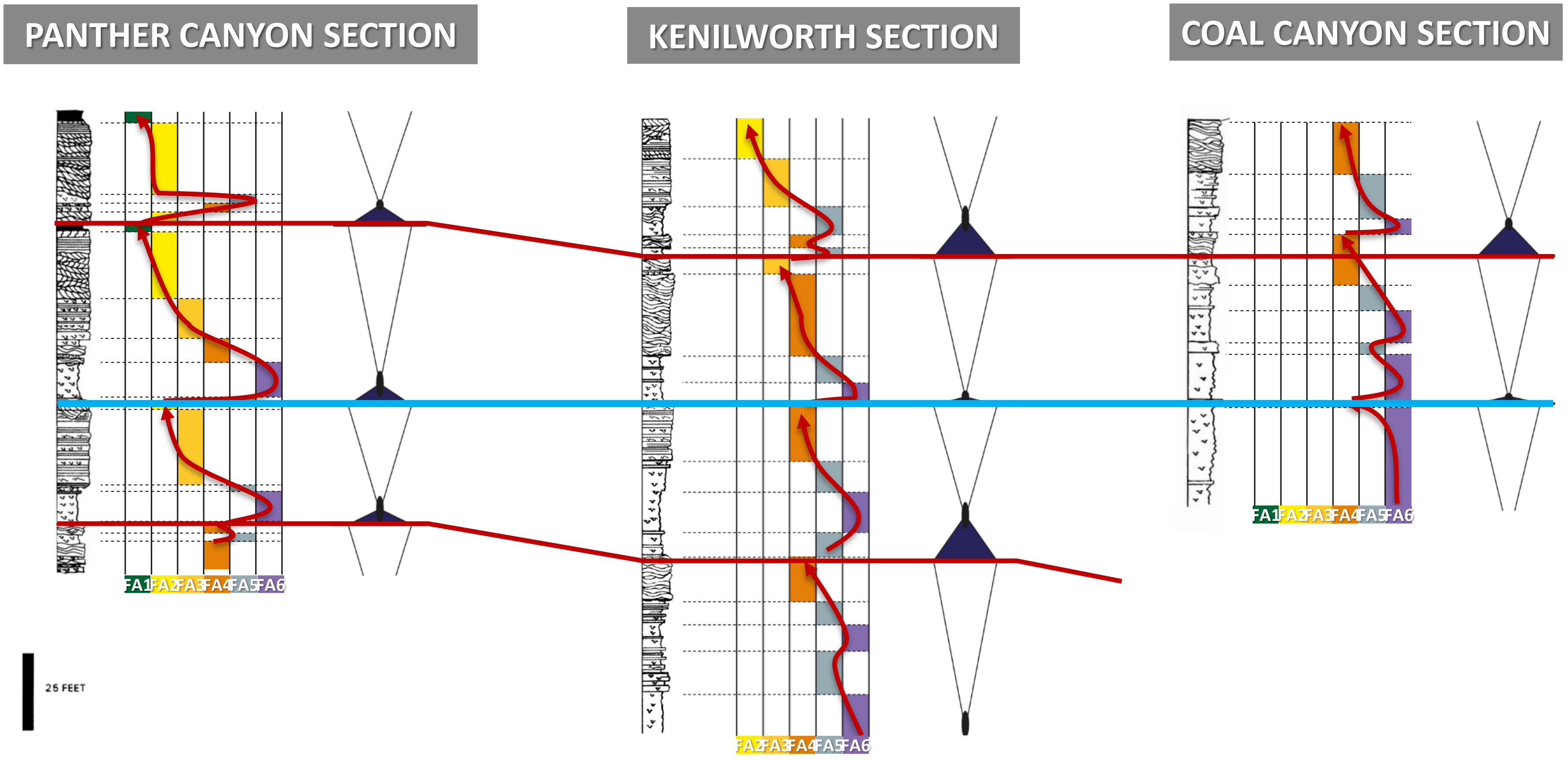
Choice of a datum is a critical step to correlate individual sequences. It can be a **marker bed**, a **biostratigraphic event, event bed** etc.

Phase 2.1 – Choice of a regional datum

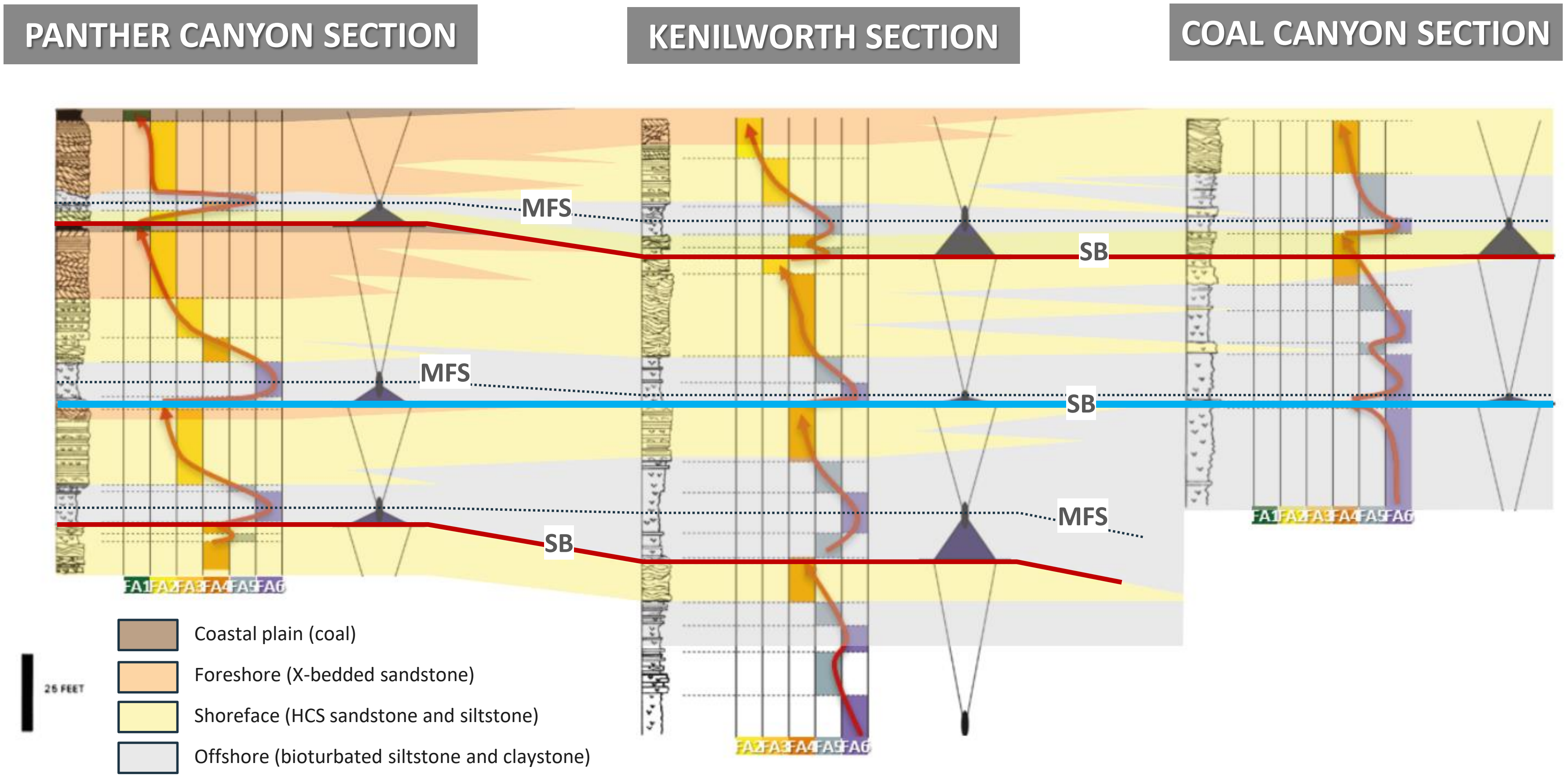


Let's assume that we found a marker bed…

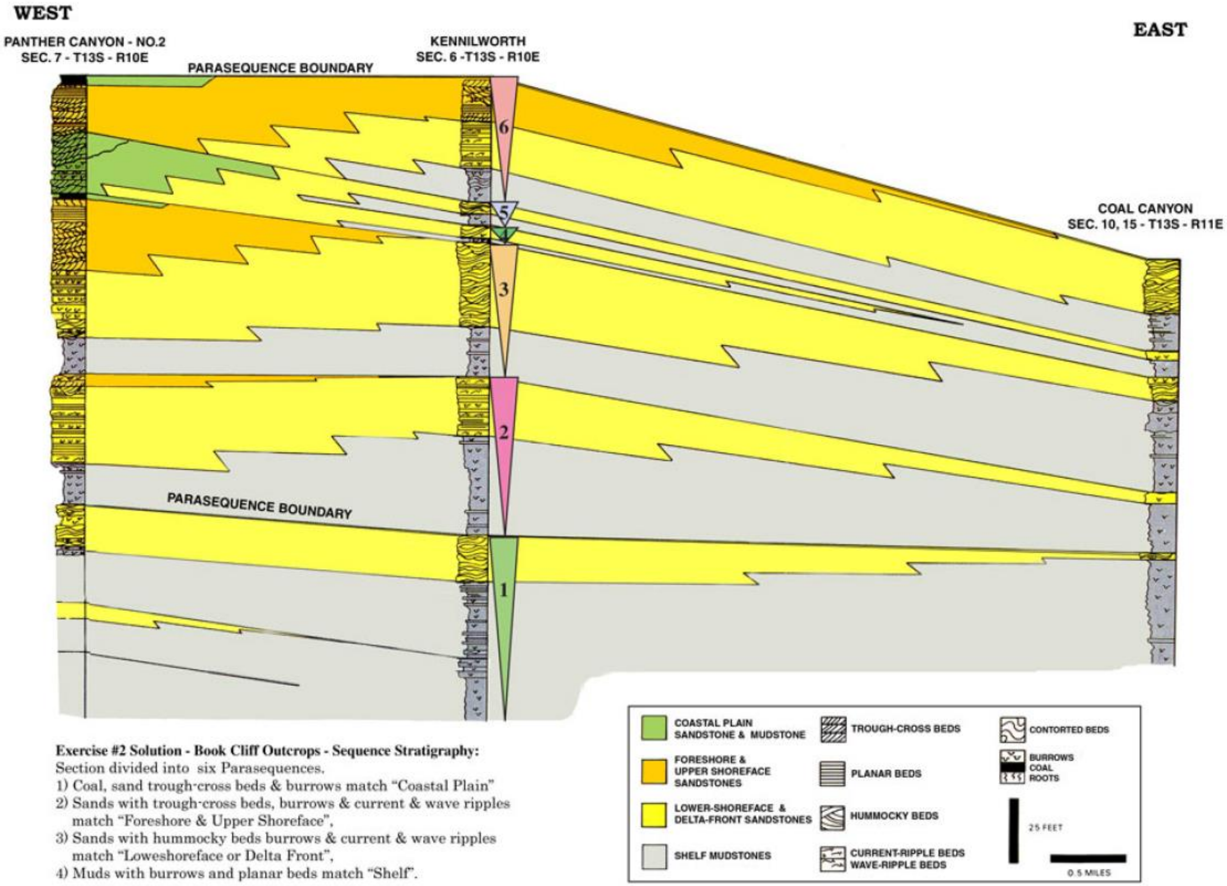
Phase 2.2 – Correlation of individual sequences



Phase 2.3 – Mapping of sequences (2D facies dress up)

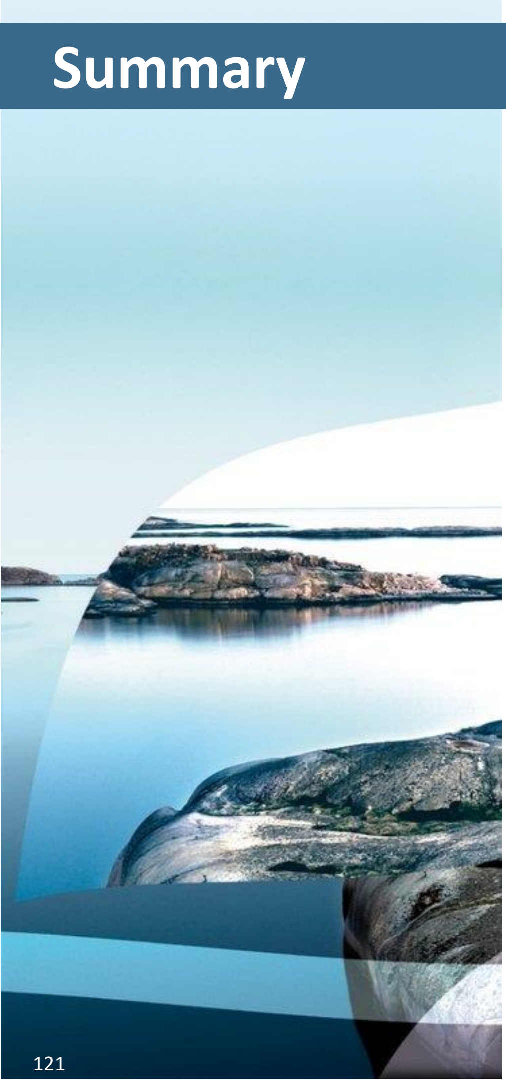


Interpretation is also a matter of taste…



Exercise #2 Solution - Book Cliff Outcrops - Sequence Stratigraphy:
Section divided into six Parasequences.
1) Coal, sand trough-cross beds & burrows match "Coastal Plain"
2) Sands with trough-cross beds, burrows & current & wave ripples match "Foreshore & Upper Shoreface",
3) Sands with hummocky beds burrows & current & wave ripples match "Loweshoreface or Delta Front",
4) Muds with burrows and planar beds match "Shelf".

Summary



- The proposed workflow applies to nearly all types of depositional systems.

- It involves a strong sedimentological component, and it includes the following steps:
  - Interpretation of facies, facies associations and GDEs
  - Interpretation of a depositional curve for each well / log
  - Definition of individual sequences
  - Choice of a robust regional datum
  - Correlation of sequences from well to well
  - Interpretation of stratigraphic surfaces
  - Definition of stratigraphic packages

Stratigraphic modeling

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an overview

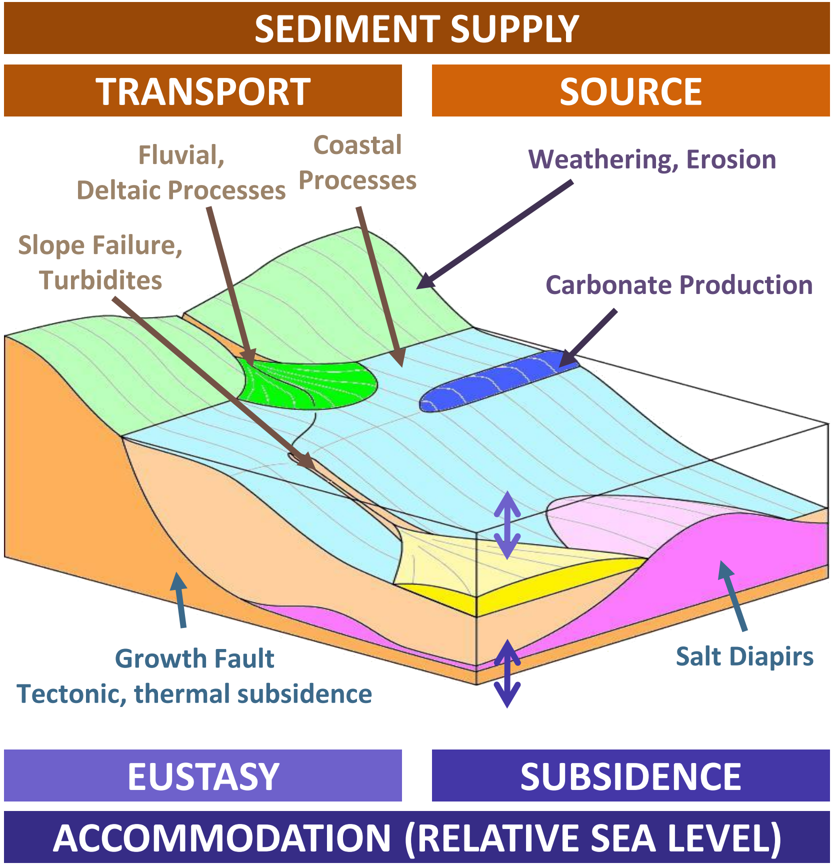
Principles

Accommodation
- Basin deformation history
- Subsidence and eustasy
- Flexure, Compaction

Sedimentary **supply**
- Fluvial input
- In situ marine carbonate production
- Organic Matter (**marine** and **terrestrial**)

Transport using macro-scale sediment transport laws
- Fluvial, deltaic (confined flow)
- Coastal processes (unidirectional currents, wave action)
- Turbidites

Calibrated to:
- Well data (facies, lithological log etc.)
- Seismically-derived maps (thickness, depth, facies etc.)



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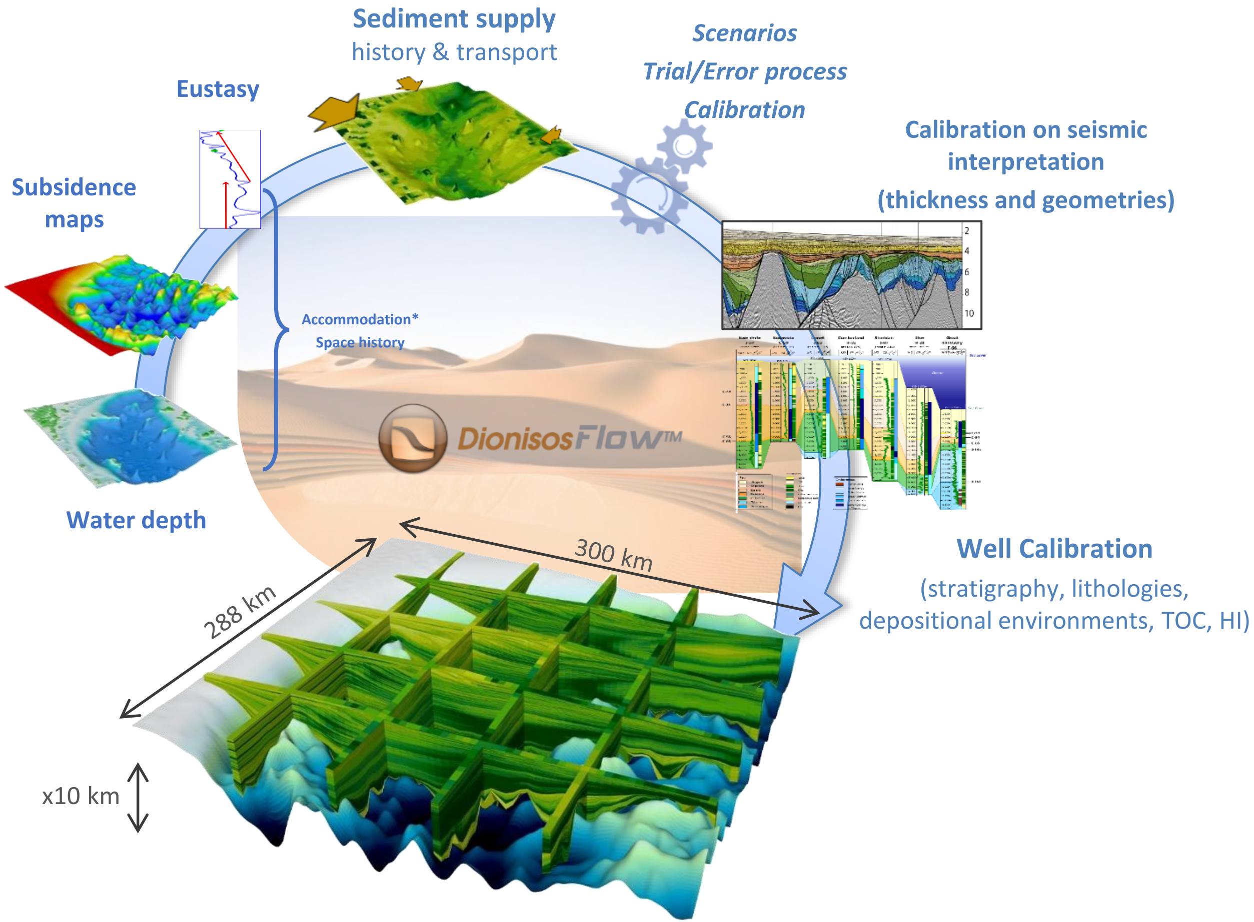
Forward Stratigraphic modeling within the PFA workflow



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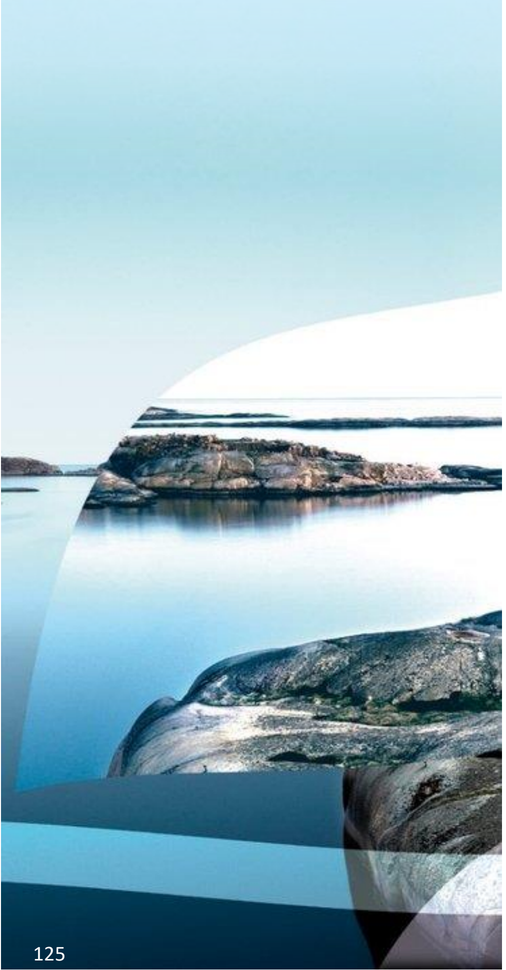
Stratigraphic forward modeling in short



- Stratigraphic forward modelling is a powerful tool for carrying out sequence stratigraphic analyses
- It integrates the controlling factors sequence stratigraphy is based on:
  - Accommodation space (RSL): Subsidence + Eustasy
  - Sediment supply: source and transport
- Numerical models are mostly designed to simulate the time and space distribution of sediments (facies and depositional environments)
- It can also be used to carry out sequence stratigraphic breakdown:
  - More accurate definition of plays
  - More accurate stratigraphic charts
  - Test concepts and hypothesis
- We can expect the development of numerical modeling for sequence stratigraphic purposes in the forthcoming years

Significance of sequence stratigraphy

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Pitfalls and limitations

Pitfalls and limitations

- The most common pitfalls of sequence stratigraphy generally stem from a misunderstanding or misapplication of the principles.

- The list of pitfalls is open and here are some of the most common:
  - Sequence stratigraphic breakdown based on Global Sea Level curve
  - Facies change misinterpreted as stratigraphic surface
  - Unnecessary sequence stratigraphic breakdown
  - Misinterpretation of seismic stratal terminations
  - The shortcomings of wireline log data
  - Mix observation and interpretation
  - The inappropriate use of terminology or concepts

Significance of sequence stratigraphy

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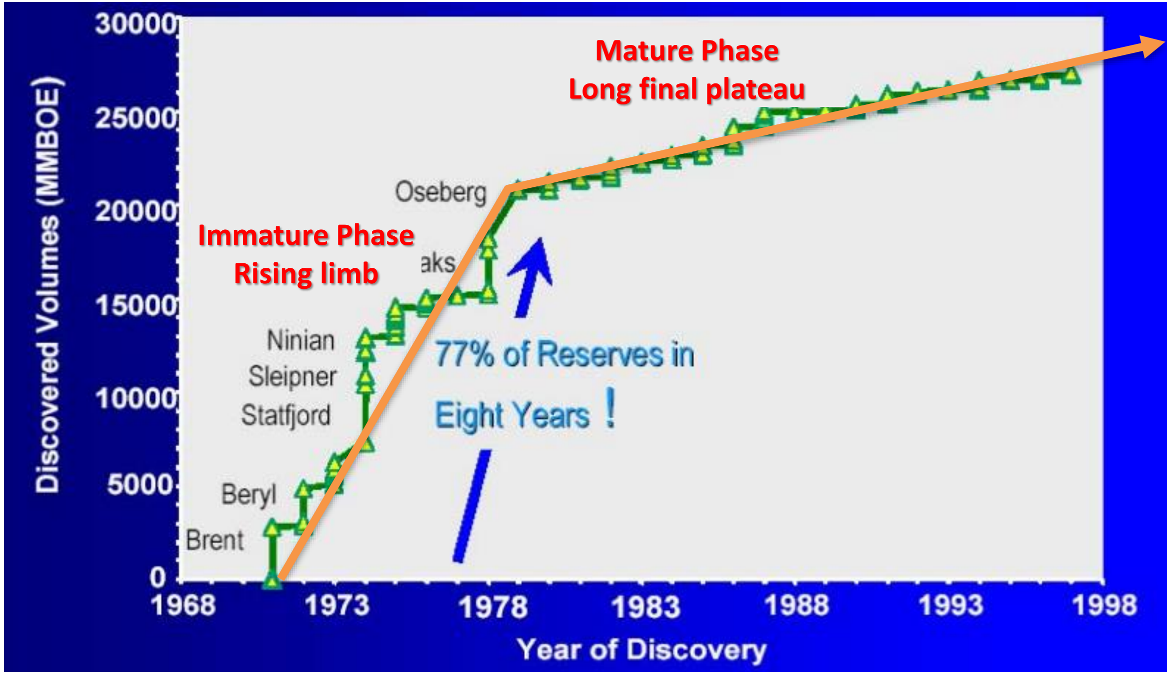
How useful could it be to you?

The perspective of the Creaming Curve

The creaming curve presents the exploration history and maturity of exploration of an area or play. It is commonly thought that the "cream of the crop" of any play or basin is found early in the drilling history (Snedden et al., 2003).

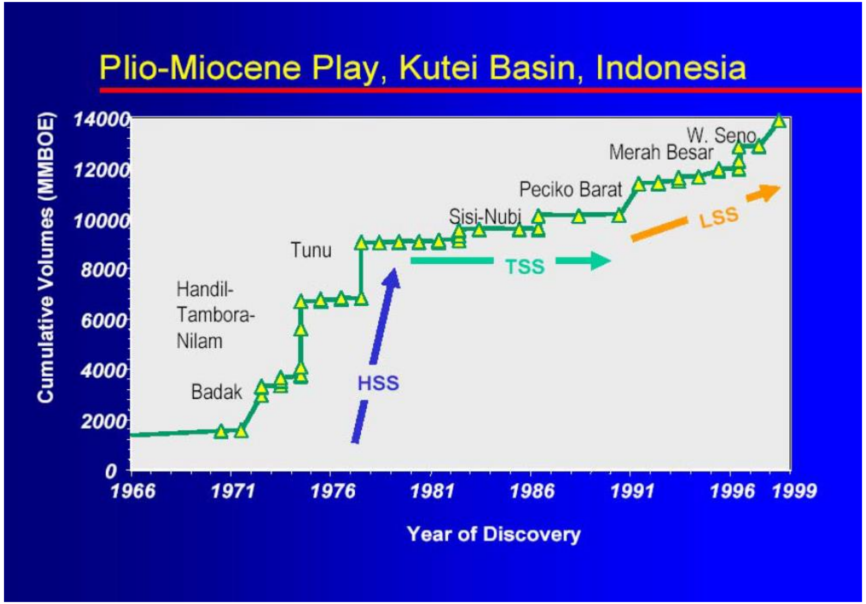
Classical petroleum exploration creaming curve (Mid Jurassic play Norway)

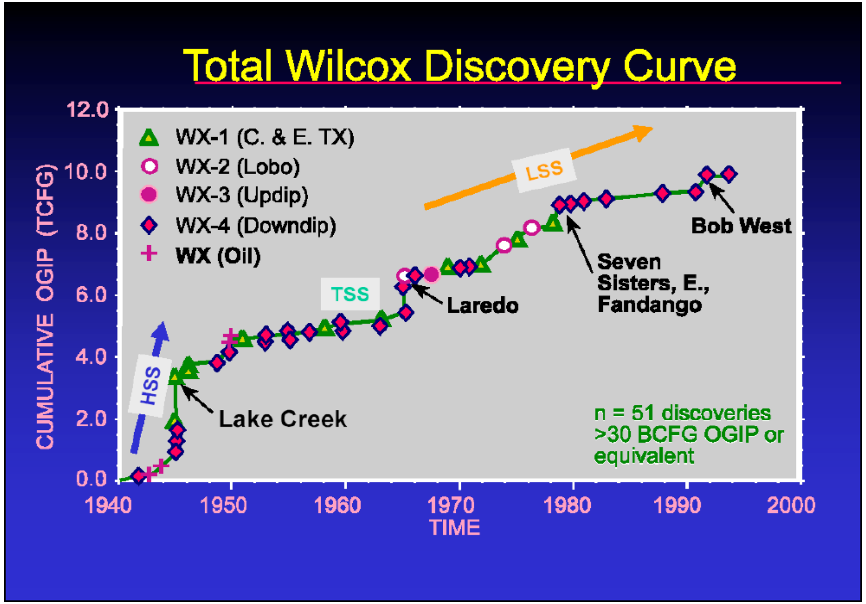


Source: Snedden et al. (2003)

The perspective of the Creaming Curve

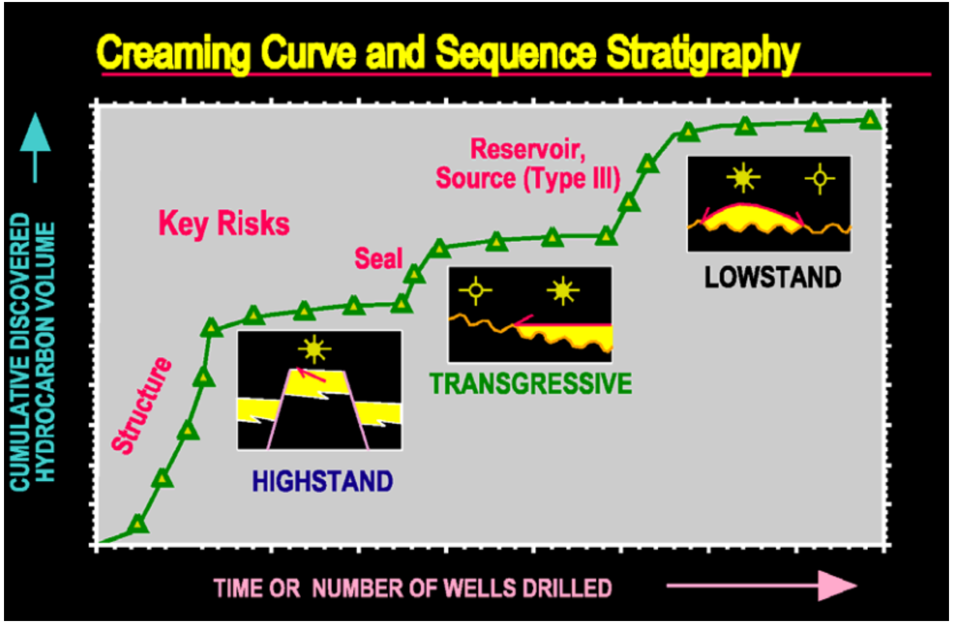
By examining plays or basins with sufficiently long drilling histories and range of reservoir paleoenvironment and trap types, Snedden et al. (2003) found that two or three "terraces" to the creaming curve.





Source: Snedden et al. (2003)

The perspective of the Creaming Curve



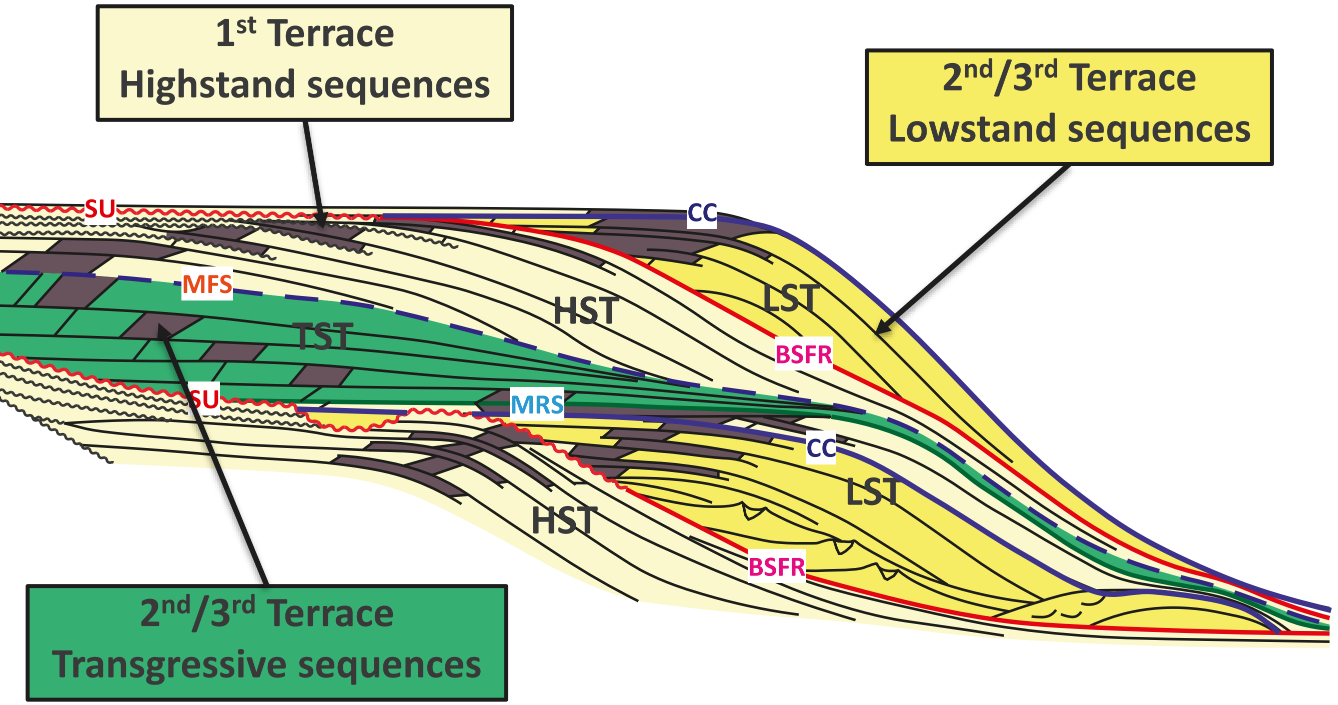
The **first string of successes** in a basin usually corresponds to **exploitation of the HST** or sequence set reservoirs developed in up-dip structural traps.

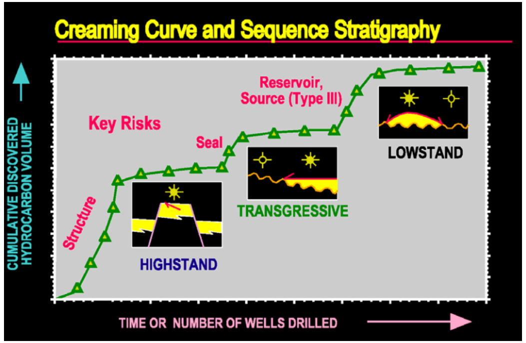
The second or third terrace in the creaming curve usually involves the **lowstand reservoir component** (systems tract or sequence set), which is often developed in downdip deep-water or slope paleoenvironments.

Transgressive (systems tract or sequence set) reservoirs, typically shallow marine shelfal sandstones that are sometimes self-sourced, are variably developed and may or may not occupy the second terrace of the creaming curve.

Source: Snedden et al. (2003)

The perspective of the Creaming Curve





The 4th Terrace: Near Field Exploration?

Source: Snedden et al. (2003), Vail et al. (1987)

Application in the Oil & Gas industry

Improve definition of plays

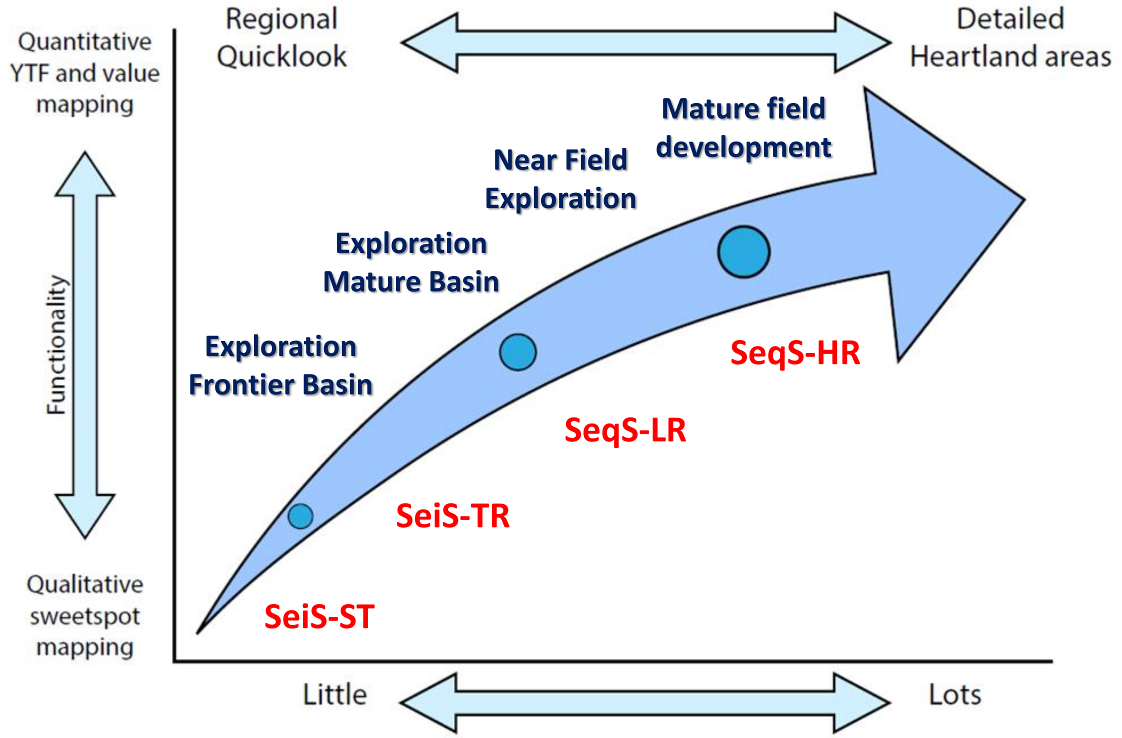
- More accurate surface for mapping and facies correlation
- Higher-resolution chronostratigraphy for improved definition of plays
- More integrated stratigraphic framework for risking new plays

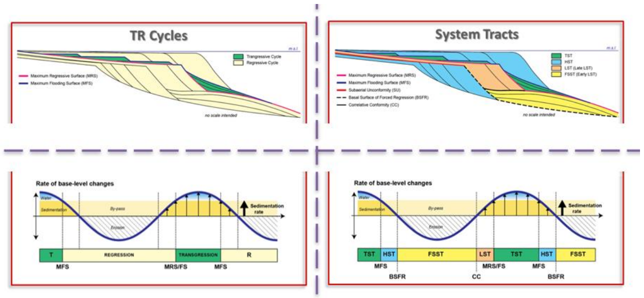
Look at mature plays in a fresh way

- New play types
- Improved ability to define and locate subtle traps
- Re-evaluation of producing fields to extend their lives and increase reserve

Application in the Oil & Gas industry

The Sequence Stratigraphic workflow must be adopted according to the volume, type and quality of the data as well as to the technical objectives to be reached and the dedicated time to do so.





SeiS-TR: Seismic Stratigraphy (T-R Cycles)

SeiS-ST: Seismic Stratigraphy (System Tracts)

SeqS-LR: Low resolution Sequence Stratigraphy

SeqS-HR: High resolution Sequence Stratigraphy

Economic potential of System Tracts

STs	Elements	Fluvial	Coastal	Shelf	Deep-water
HST	Reservoir	Channel fills, crevasse splay (Fair)	Deltaic and strandplain sands (Good)	Shoreface sands (Good)	Channel-levees (Poor)
	Source and Seal	overbank facies (Poor)	Coastal swamp (Poor)	Shelf fines (Fair)	Pelagic facies (Good)
FSST	Reservoir	Undefined (Poor)	Detached shoreline sands (Fair)	Shoreface sands (Fair)	Turbidites (slope and basin floor) (Good)
	Source and Seal	Undefined (Poor)	Undefined (Poor)	Shelf fines (Fair)	"Overbank" pelagics (Fair)
LST	Reservoir	Channel fills (Good)	Deltaic and strandplain sands (Good)	Shoreface sands (Good)	Debris flows and high-density turbidity flows (Poor)
	Source and Seal	Undefined (Poor)	Undefined (Poor)	Shelf fines (Fair)	"Overbank" pelagics (Fair)
TST	Reservoir	Channel fills, crevasse splay (Fair)	Estuarine, deltaic and beach sands (Good)	Shelf sands, healing phase wedges (Fair)	Turbidites (basin floor) (Fair)
	Source and Seal	overbank facies (Poor)	central estuary facies (Poor)	Shelf fines (Good)	Pelagic facies (Good)

Good potential — Fair potential — Poor potential

From Catuneanu (2006)

Concluding comments

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Concluding comments

- The principles of sequence stratigraphy add up to an **intellectual guide** but do not provide a cookbook
- Sequence stratigraphy is not a black box technic but really is a major evolution in the **concepts underlying sedimentary geology**
- The key idea of the concept is the **integration of data** within a consistent spatial and temporal framework
- A **sequence stratigraphic** model should **honor the data** (not the way around)
- The integration of many specialties provide a better understanding of sedimentary systems, thus **making prediction a more accurate process**