Seismic & Sequence Stratigraphy
Geophysical Logs & Coring Operations

a quick summary

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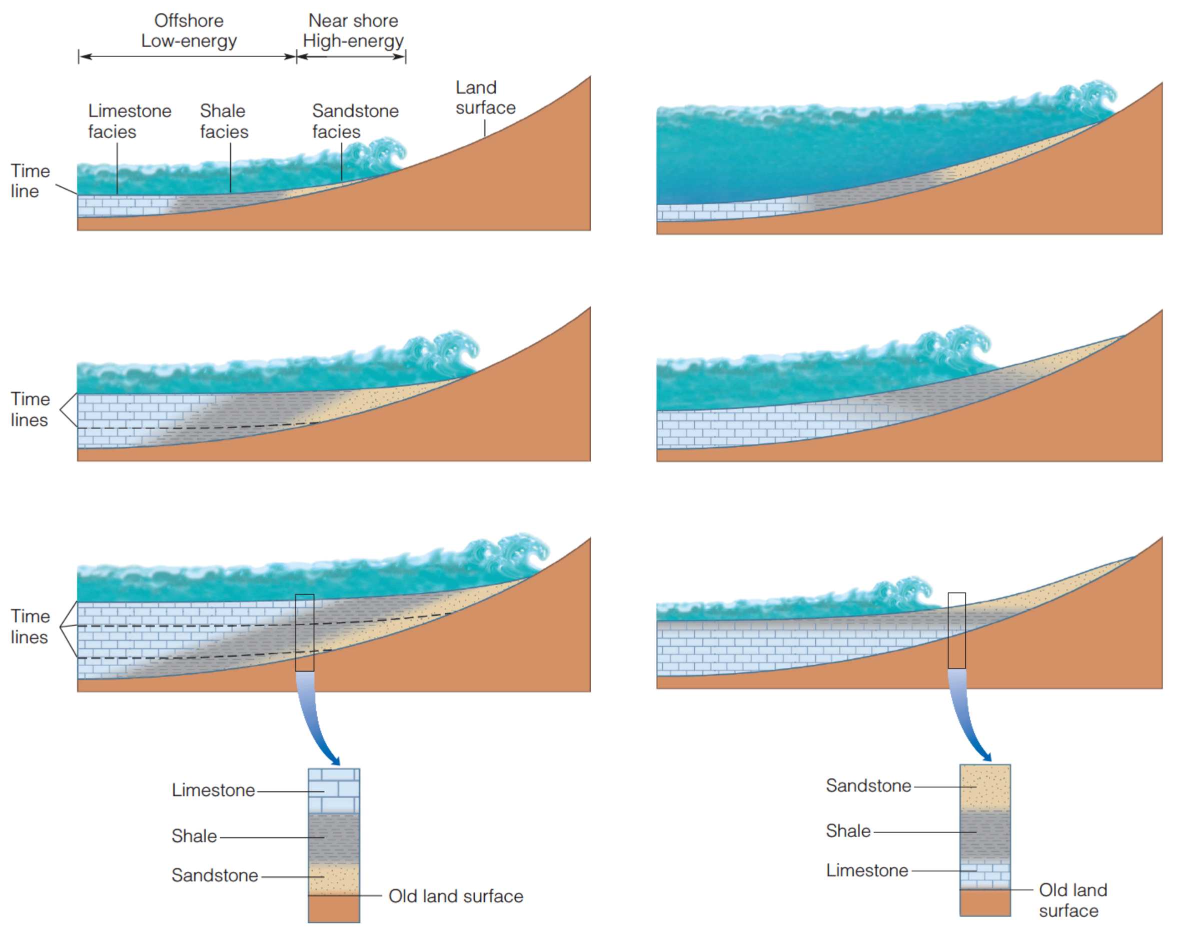
Introduction: Seismic Stratigraphy

– the study of stratigraphy and depositional facies
– based on seismic reflections data
– generated when artificially produced seismic (or acoustic) waves bounce off physical discontinuities within buried sediments

– Allows the identification of unconformities in rock sequences
  • unconformities are gaps in the record
  • they can be left during cycles of regression and transgression

Transgression and Regression

- A transgression is a *relative* rise in sea level
- A regression is a *relative* sea level fall, or drop
- They can be identified in the field by looking at sedimentary sequences:
  - fining-upward: transgression
  - coarsening upward: regression



fining upward sequence   coarsening upward sequence

Eustatic sea-level vs. Relative sea-level

- Eustatic sea-level is the global sea level (measured between the surface of the Ocean and the center of Earth

- Relative sea-level is a local condition that can also be affected by tectonic activity such as subsidence or uplift

- As a consequence, only eustatic sea-level has a global effect, and can leave its signature (unconformities) on a global scale

review: why would sea-level change?

- More or less water
  - Icehouse times vs. Greenhouse times
- More or less space for the water to be
  - Function of spreading rates at mid-ocean ridges
- Thermal expansion
  - Oceans at 25°C would occupy 10% more space than at today's temperature

from Seismic to Sequence Stratigraphy

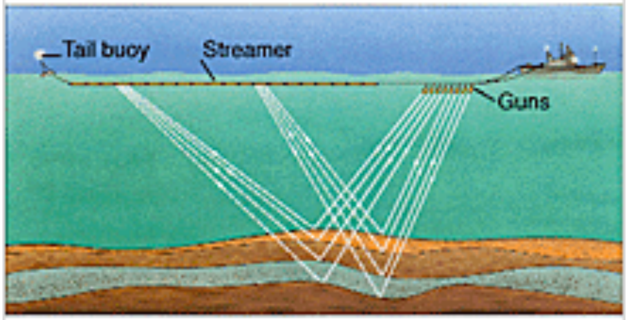
- Seismic Stratigraphy shows unconformities

- Unconformities identify eustatic regressions
  - A regression exposes a land mass, which gets eroded

- The package of strata between unconformities constitute a sequence
  - It is possible to identify cycles of transgression and regression on a global scale
  - The cycles happen synchronously and on a global scale
  - Hence, they are events that can be used for correlation
  - Sequences of cycles are the object of sequence stratigraphy

Seismic Stratigraphy

- Artificial seismic vibrations produced at Earth's surface (with seismic trucks) or in ocean water (by releasing compressed air) generate seismic waves

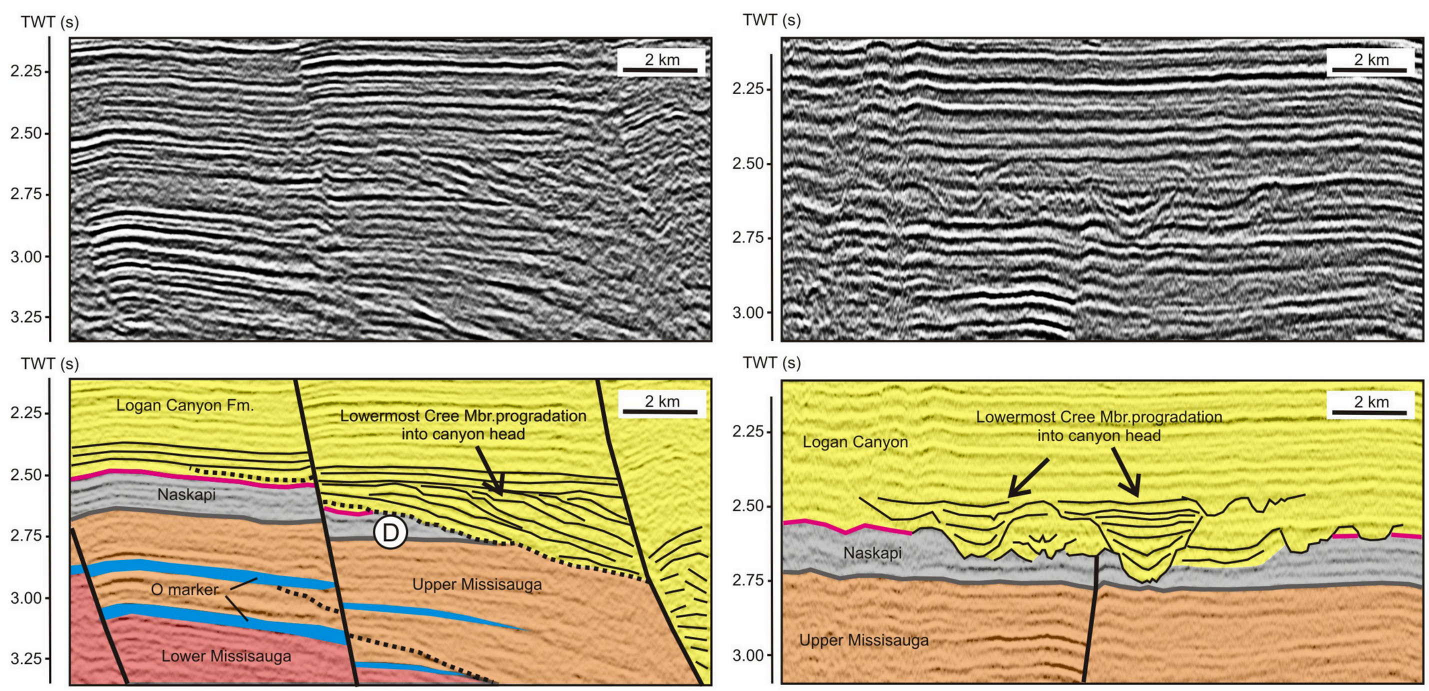


- Seismic waves can be refracted (transmitted through) and reflected (bounced back) by discontinuities encountered in their path (rocks, marker beds, or horizons - for instance, unconformities - buried underground, and not otherwise visible from the surface

- The seismic waves that bounce back to the surface are used to generate a **seismic profile**

- A seismic profile is then an underground image of Earth provided by the response pattern of seismic waves to rocks and discontinuities

- The seismic profile (which represent discontinuities in time and not in space) is then interpreted



- Reflections of seismic waves occur in general where there is a **vertical change in rock type**
  - by faulting
  - by bedding or layering surfaces
  - by unconformities
  - by facies boundaries

- It is then possible to divide a seismic profile into a package of similar reflections, and thus identify distinct **sequences**, which are interpreted and correlated

- Sequences are then studied individually as separate episodes of sedimentation or erosion and are at the heart of what we call **sequence stratigraphy**.

Geophysical Log Stratigraphy and Coring Operations

- If seismic profile yields promising information, a well could be drilled

- The rocks encountered during the drilling operations are brought to the surface as cuttings, fragments obtained by crushing the rocks with diamond bits

- Cuttings are organized in their relative sequence according to the depth at which they were found, and a lithostratigraphic profile is reconstructed


GREY WOLF
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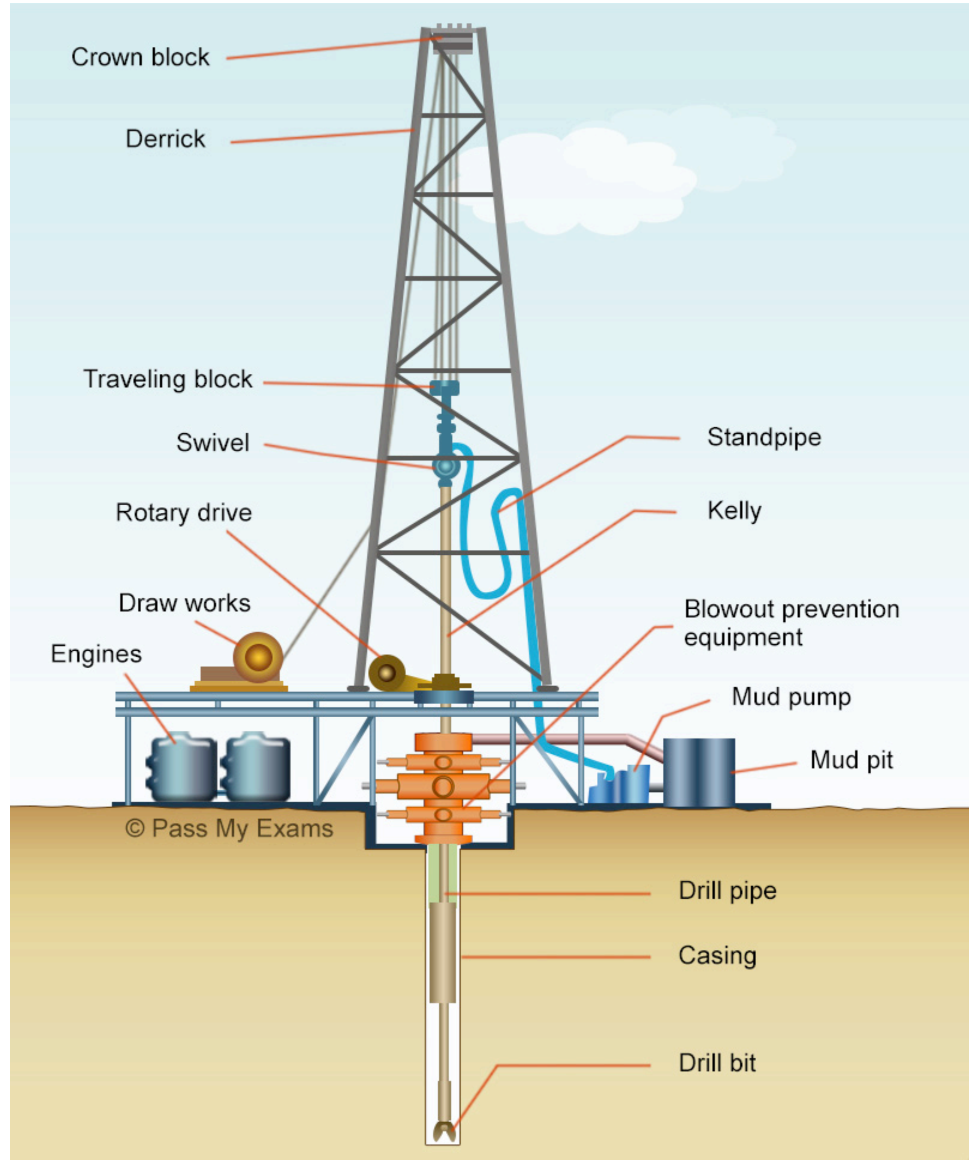
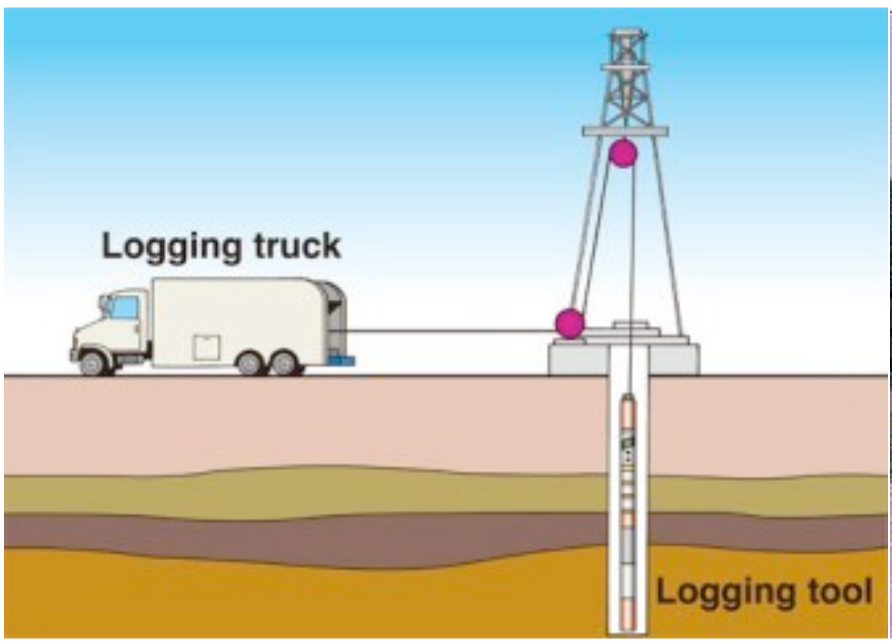

Crown block
Derrick
Traveling block
Swivel
Rotary drive
Draw works
Engines
Standpipe
Kelly
Blowout prevention equipment
Mud pump
Mud pit
© Pass My Exams
Drill pipe
Casing
Drill bit

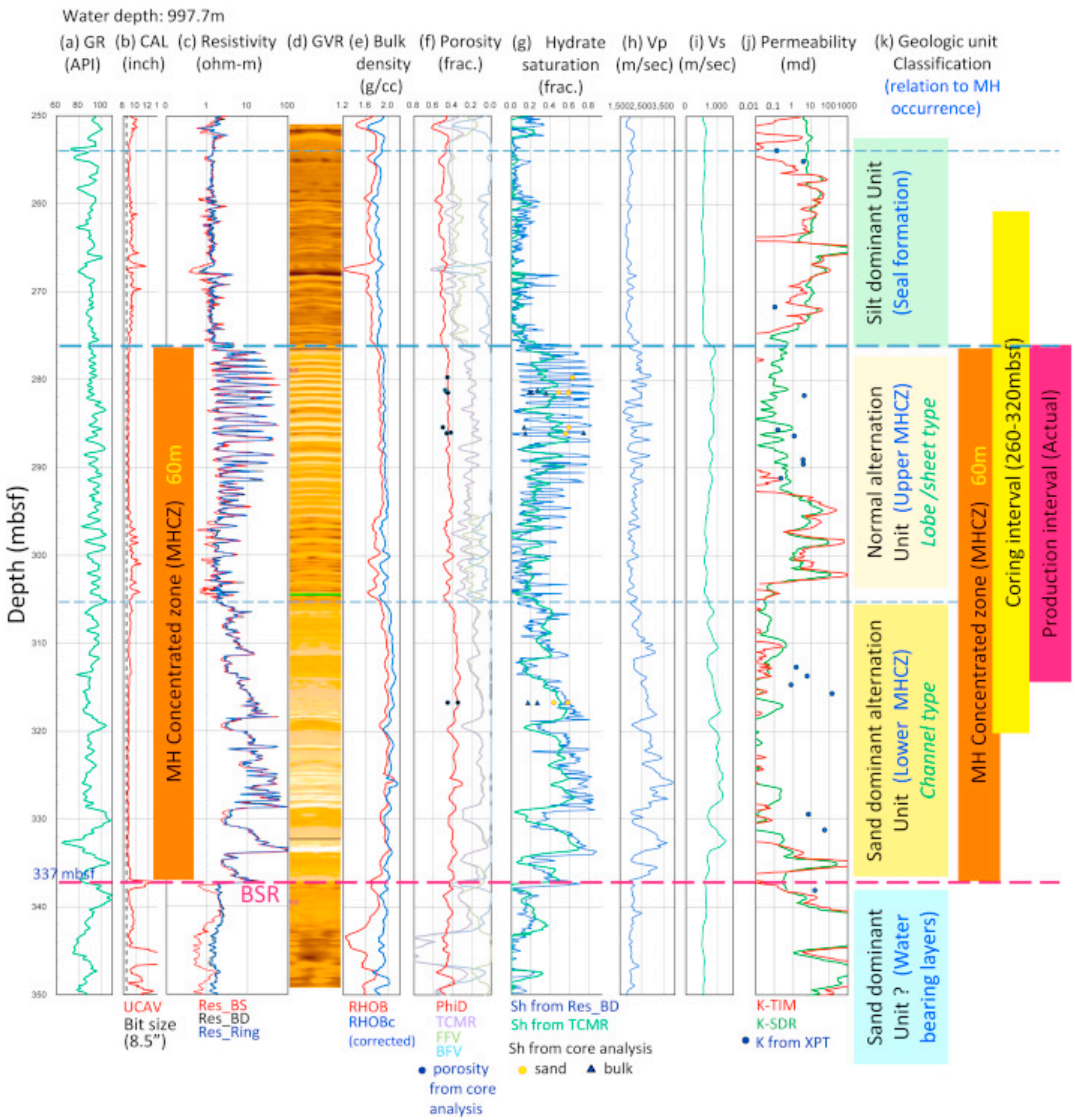
Above: circulation mud containing cuttings comes to the surface (left) and it is filtered for cutting collection (right)
Below: cuttings are prepared and organized stratigraphically according to drilling depth

- Cuttings are not enough: during drilling operations it is a common procedure to run geophysical wireline logs in the open well to collect borehole data and construct a geophysical log stratigraphy



What do we measure inside the well?

- Geophysical Proxy Data
  - subsurface pressure condition
  - subsurface analysis of fluids in rocks (water, salt water, oil, gas, etc.)
  - subsurface temperature measurements
  - size of the drilling borehole
  - electrical resistivity of the rocks encountered
  - spontaneous potential of the rocks encountered
  - subsurface radioactivity levels
  - subsurface rock porosity
  - subsurface rock density
  - speed of acoustic waves in the rocks encountered
  - tilting (inclination) of the layers



Water depth: 997.7m
(a) GR (API)
(b) CAL (inch)
(c) Resistivity (ohm-m)
(d) GVR
(e) Bulk density (g/cc)
(f) Porosity (frac.)
(g) Hydrate saturation (frac.)
(h) Vp (m/sec)
(i) Vs (m/sec)
(j) Permeability (md)
(k) Geologic unit Classification
(relation to MH occurrence)
Depth (mbsf)
MH Concentrated zone (MHCZ) 60m
337 mbsf
BSR
Silt dominant Unit (Seal formation)
Normal alternation Unit (Upper MHCZ) Lobe /sheet type
Sand dominant alternation Unit (Lower MHCZ) Channel type
Sand dominant Unit ? (Water bearing layers)
Coring interval (260-320mbsf)
Production interval (Actual)
UCAV
Bit size (8.5")
Res_BS
Res_BD
Res_Ring
RHOB
RHOBc (corrected)
PhiD
TCMR
FFV
BFV
porosity from core analysis
Sh from Res_BD
Sh from TCMR
Sh from core analysis
sand
bulk
K-TIM
K-SDR
K from XPT

Coring Operations

- In special cases, it might be necessary to obtain a core from our subsurface section
- A core consists in a cylinder of rock obtained from a drilling well through an empty drilling pipe with sawing diamonds on a drilling crown
- That is, we are sending into the well a hollow pipe that fills up with a cylinder of rock while going down
- Once we reach the desired depth, the bottom of the pipe is closed and the core is then extracted.

Sequence Stratigraphy

- Sequence stratigraphy seeks to explain the depositional patterns of sediments on a basin scale with reference to changing sea level and tectonic subsidence

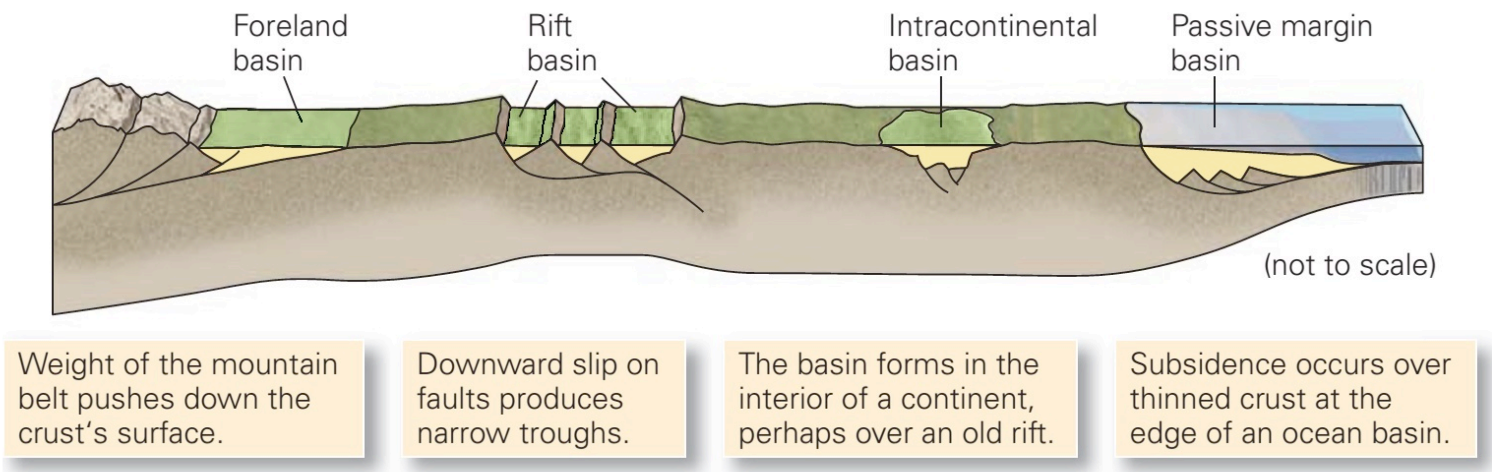
- Sequence stratigraphy uses unconformities (and their possible continuation in correlative conformities) to split sedimentary successions into unconformity-bounded sequences

but… what is a **Sedimentary Basin**?

- A sedimentary basin is, in general, a region at Earth's surface that is subject to a prolonged subsidence; that is a depression at Earth's surface that gets deeper and deeper

- Why would that happen?
  - Sedimentary basins form because of processes related to plate tectonics that may cause subsidence within the relatively cool and rigid lithosphere

- There are three main mechanisms that produce subsidence:
  - Mechanisms related to the temperature of Earth's lithosphere (as in the case of the cooling and subsidence of the oceanic crust when it moves away from the mid-ocean ridge)
  - Mechanisms related to the stretching of Earth's crust (as in the case of the subsidence caused by the thinning of the crust when continental rifting occurs)
  - Mechanisms related to loading of the crust (as in the case of the genesis of mountain chains or volcanoes: the increased weight causes the lithosphere to bend and slowly subside, creating a depositional basin)

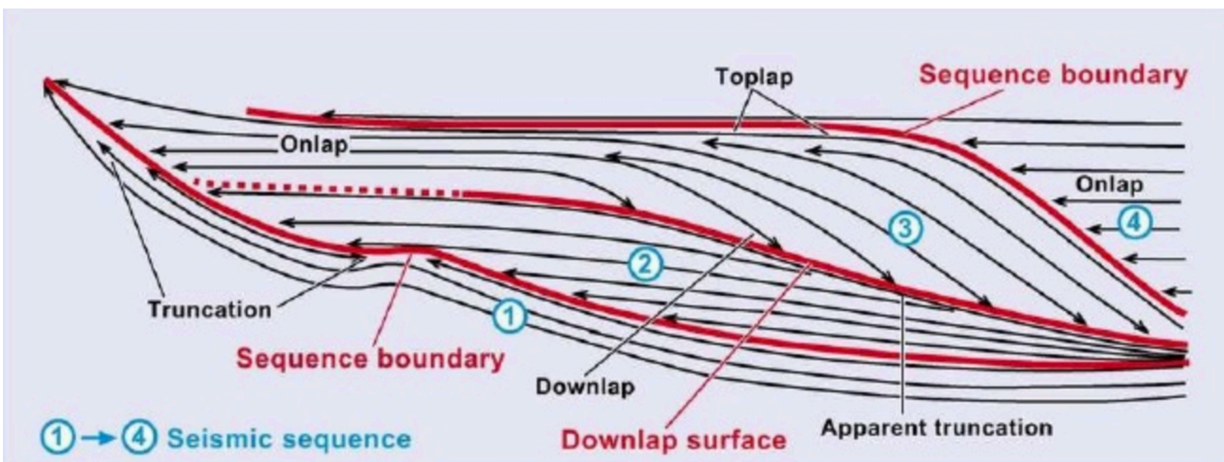


- These mechanisms produce different types of basins which can be filled with sediment (either marine or non-marine, or both) and water (seawater of freshwater)

How does it work?

- A rising or a falling sea level would leave a time-transgressive unconformity in the rocks.
  Such an unconformity will appear distinctly on a seismic section

- It is then possible to locate sequences bounded by unconformities on seismic sections

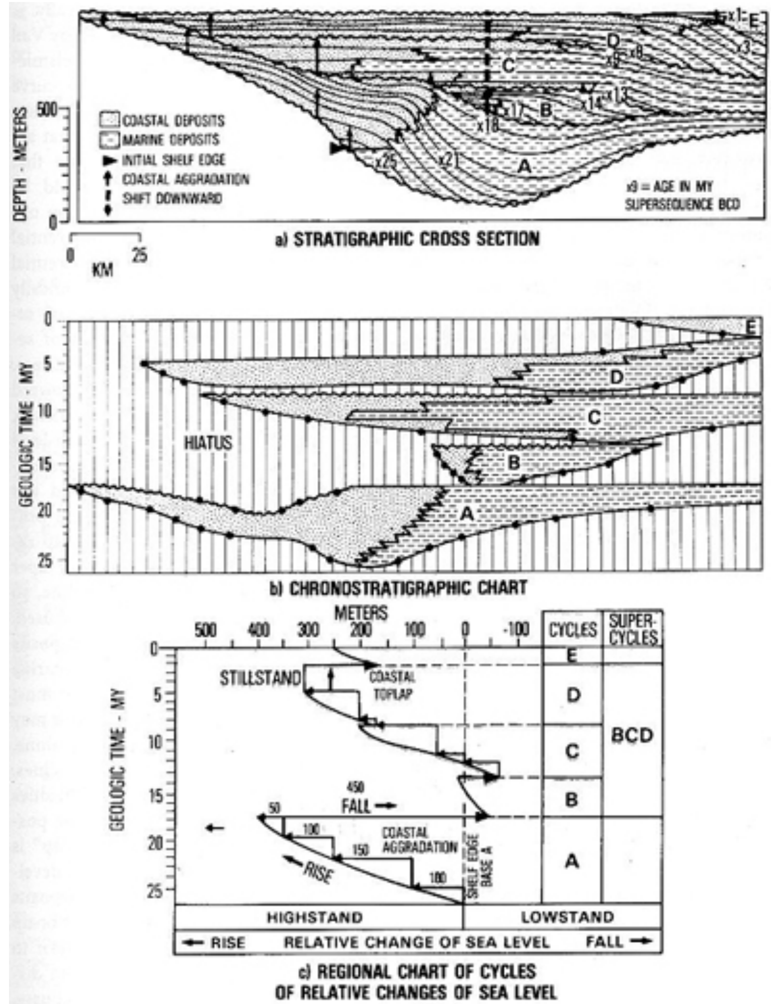


- The sequences, marked by unconformities, or their boundaries (the unconformities themselves) have been used with success in regional correlations

- By identifying sequences on a seismic section it is also possible to estimate their gross 3-D geometry, even if we do not know the exact type of rock we are dealing with. This is of great help in the interpretation of seismic sections when hunting for oil and natural gas

Global Eustatic Sea-Level Curve

- On seismic sections it is possible to study how sedimentary layers are deposited on top of the transgression surface (*onlap curve*)
- This patterns allows to reconstruct the variations of sea-level over geological time



The procedure for the analysis of a seismic section

a - seismic section redrawn to show major reflectors and sequence boundaries

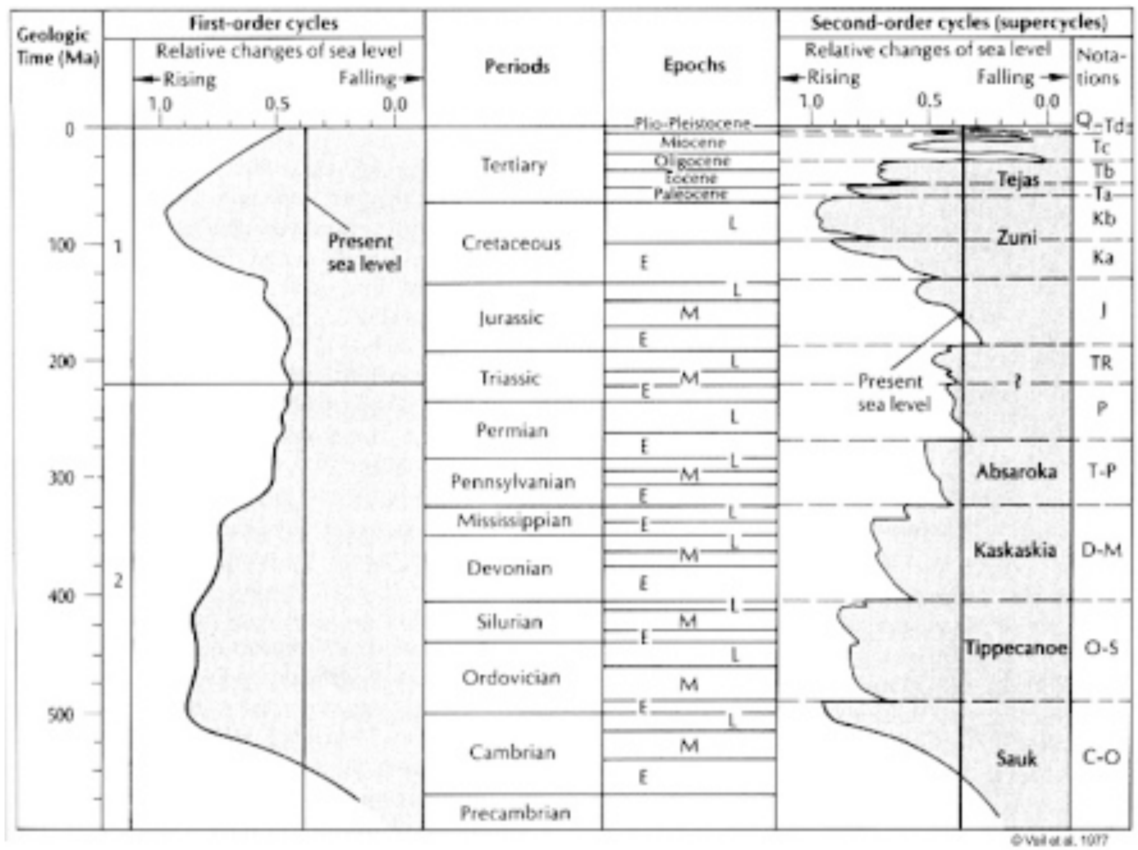
b - chronostratigraphic chart of the same section
(the sequence is put in temporal order)

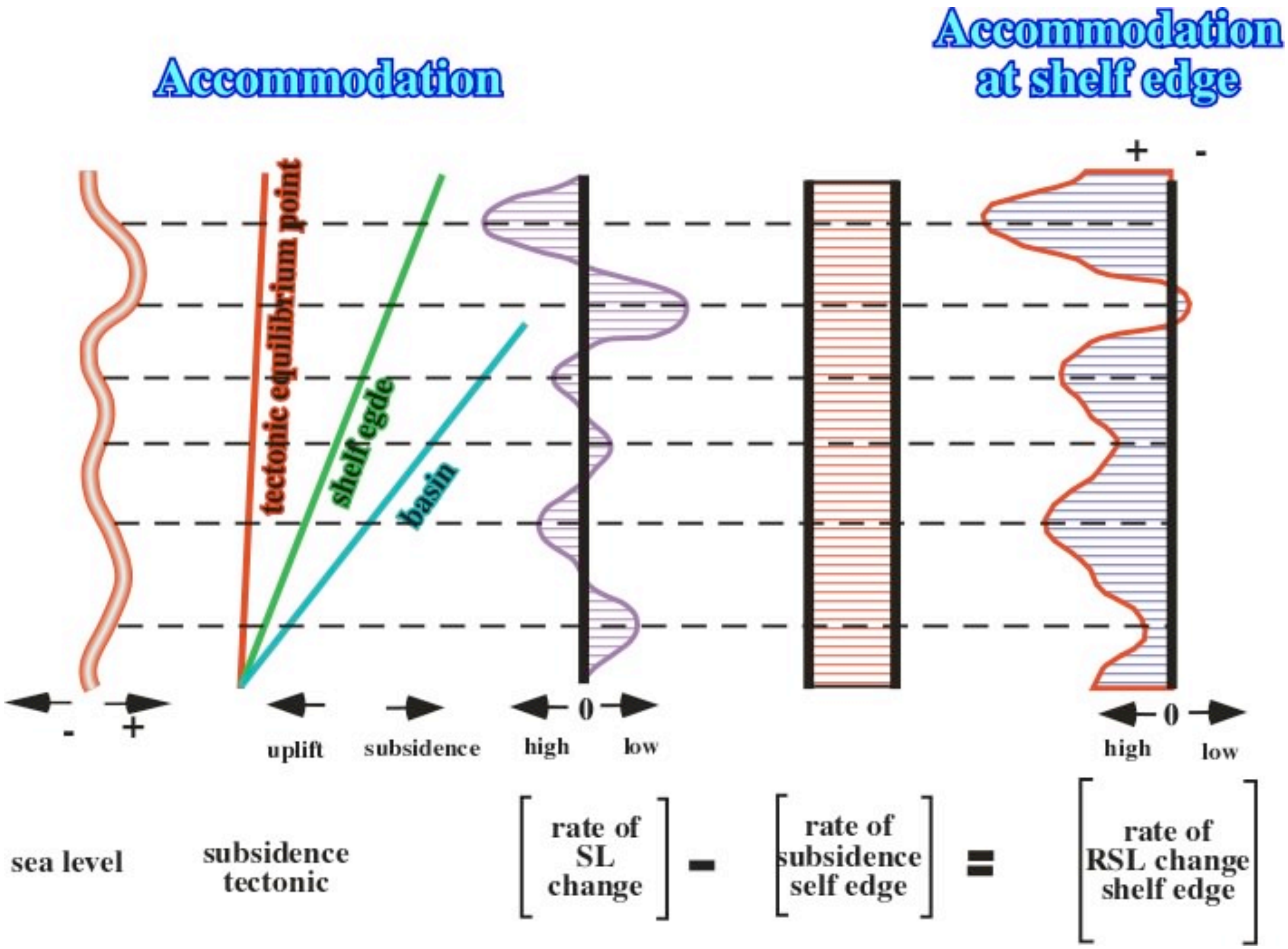
c - graph of relative changes in coastal onlap

(from Vail et al., 1977, in Miall, A.D., 1997, The Geology of Stratigraphic Sequences)

- Some scientists interpreted the variations of sea-level observed on seismic sections as global, or eustatic variations, and built a global eustatic sea-level curve

- Other scientists observed that local factors have interfered deeply when we look at short time intervals, and the curve only works in providing general patterns over long time scales

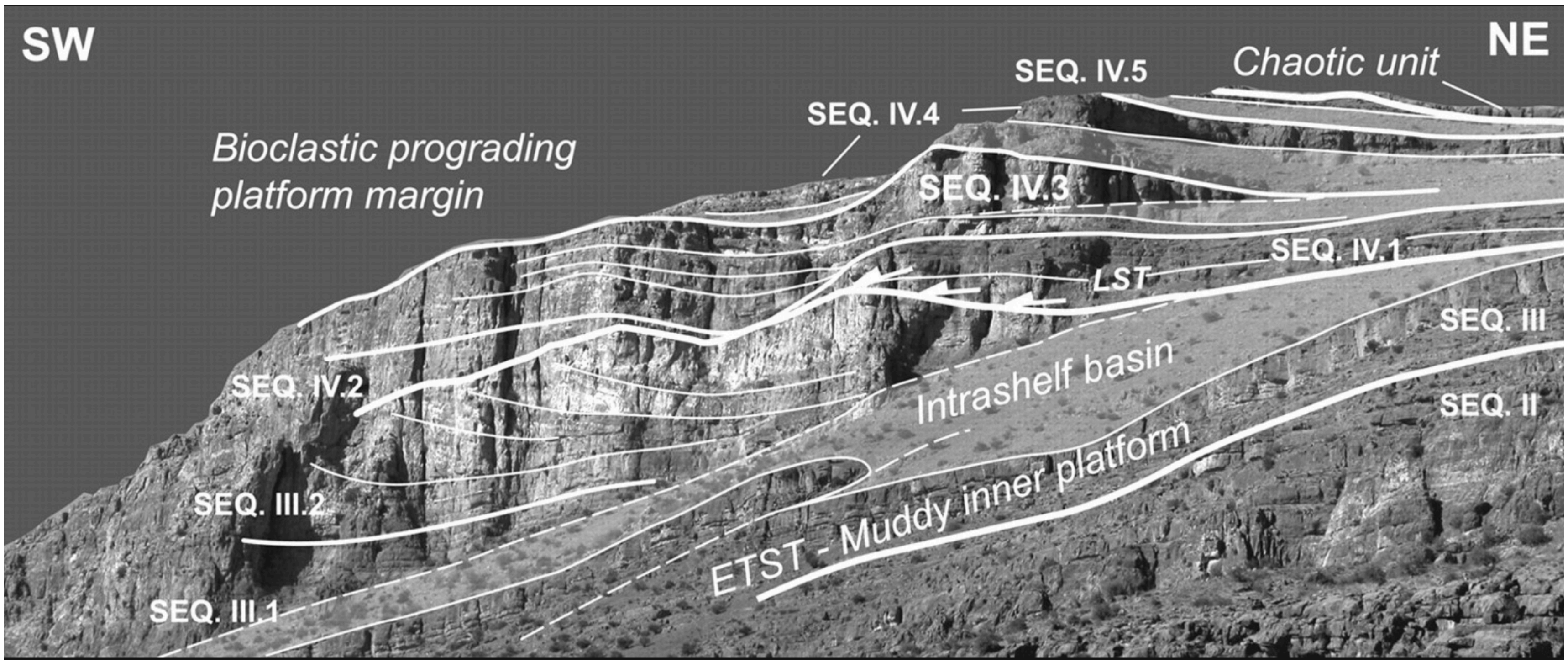



Accommodation
Accommodation at shelf edge
tectonic equilibrium point
shelf egde
basin
+
-
- +
uplift
subsidence
0
high
low
high
low
sea level
subsidence tectonic
rate of SL change
-
rate of subsidence self edge
=
rate of RSL change shelf edge

Seismic stratigraphy: conclusions

- Sequence stratigraphy grew from the interpretation of seismic stratigraphy
- The original concepts of sequence stratigraphy come directly from the work of a small research group led by Peter Vail at Exxon Production Research Company
- The basis of sequence stratigraphy rely on seismic, outcrop and subsurface data. In particular, for what concerns seismic data, the following fact have been deducted:
  - seismic reflectors are time lines, and not lithological boundaries (this is mostly true in the case of unconformities)
  - unconformities can be correlated with conformities (that is, the unconformity disappears) when we are moving from the edge of a basin towards its center
  - the sequences thus defined by the unconformities consist in lenticular (lens-shaped) units up to hundreds of meters thick and tens of kilometers wide

Sequence identification in outcrops



The End

El Morro National Monument, El Morro, New Mexico, U.S.A.