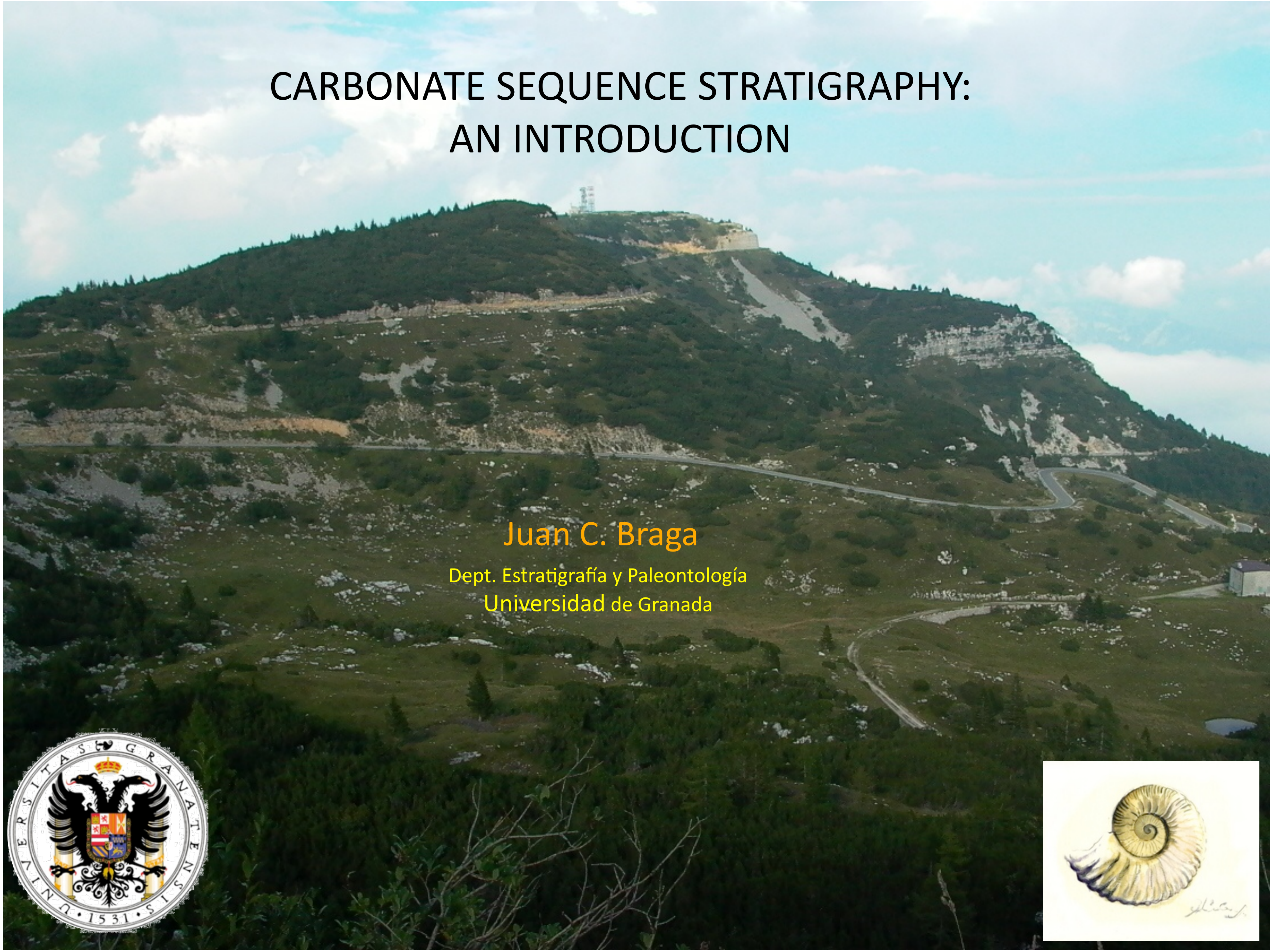
CARBONATE SEQUENCE STRATIGRAPHY: AN INTRODUCTION



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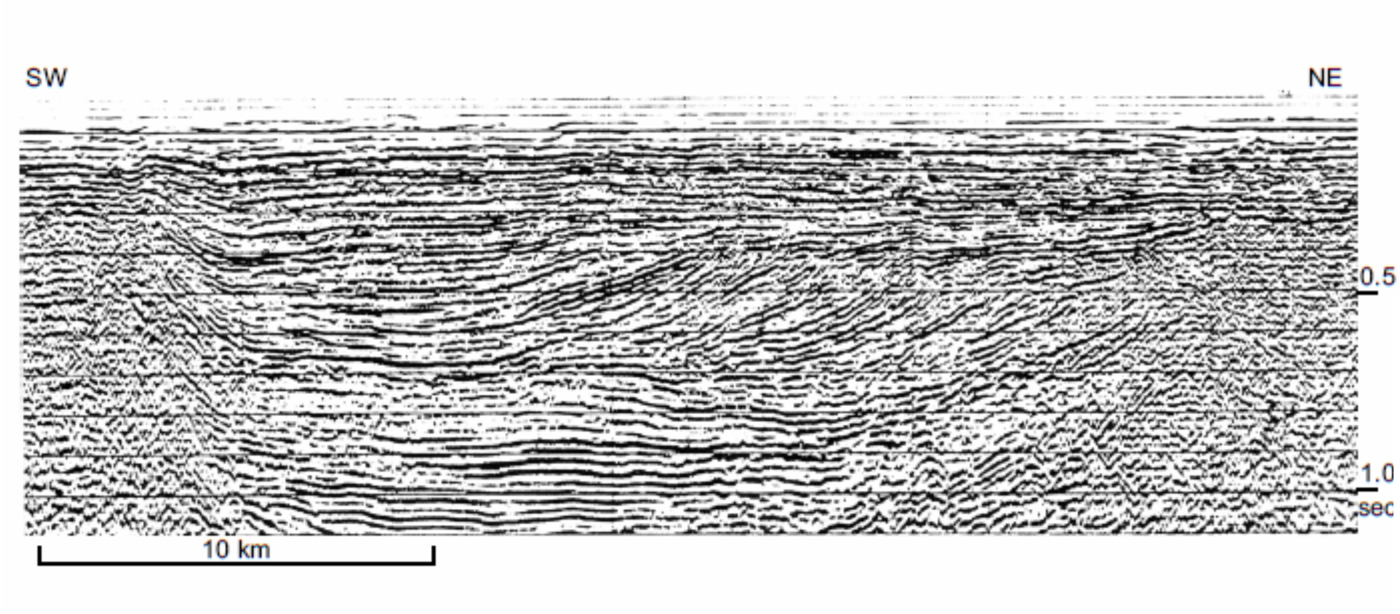
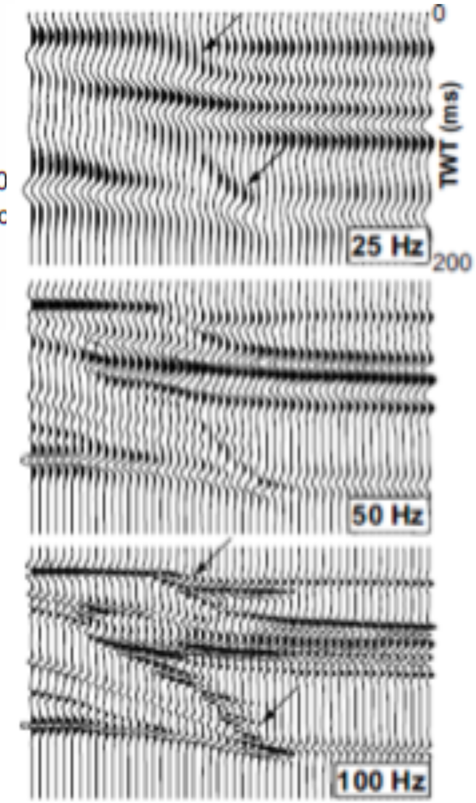
Sequence stratigraphy was originally developed from and for seismic stratigraphy analysis

(stratigraphy of subsurface rocks)



large scale seismic profiles



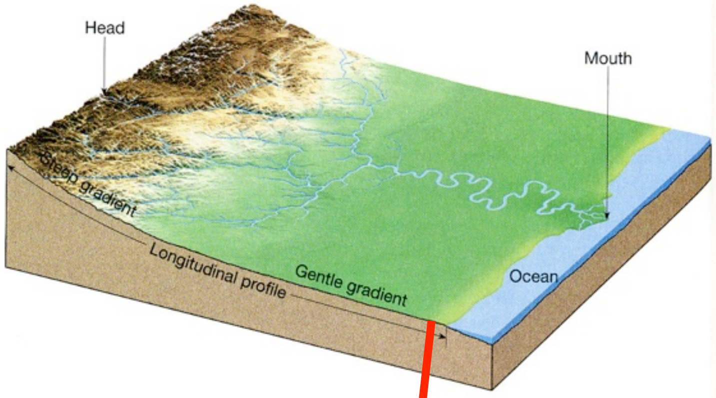
Its application to outcropping deposits is usually difficult

Fundamentals of sequence stratigraphy

The marine sedimentary record can be divided into depositional sequences

Depositional sequence is a “stratigraphic unit composed of a relatively conformable succession of genetically related strata and bounded at its top and base by unconformities or their correlative conformities” (Vail et al., 1977)

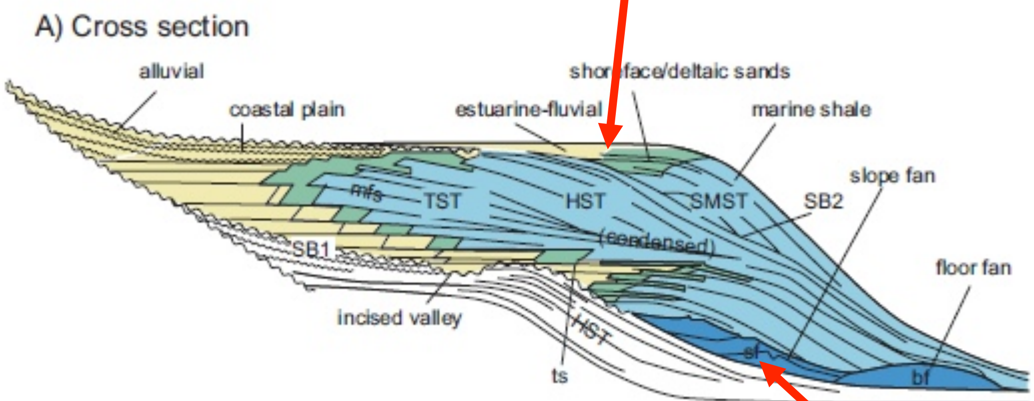
Sequence boundaries are “observable discordances . . . that show evidence of erosion or nondeposition with obvious stratal terminations but in places they may be traced into less obvious paraconformities recognized by biostratigraphy or other methods” (Vail et al.,1977)



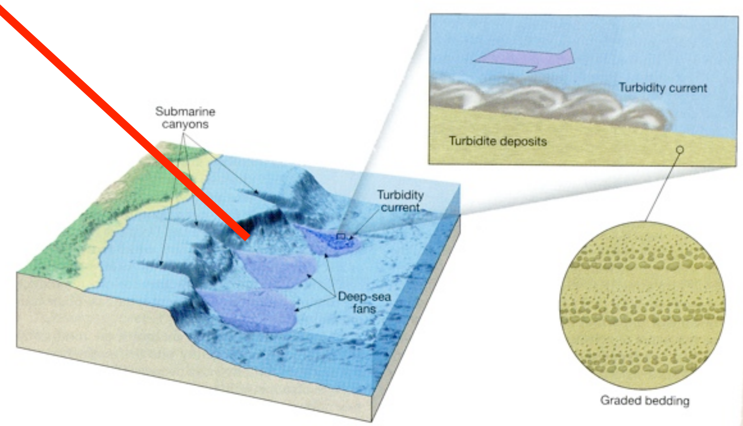
Standard Model

siliciclastic deposits

sediment comes from outside

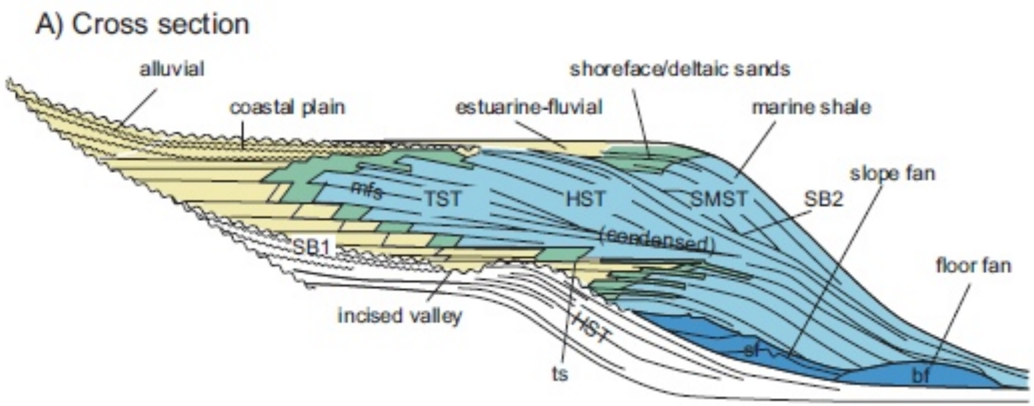


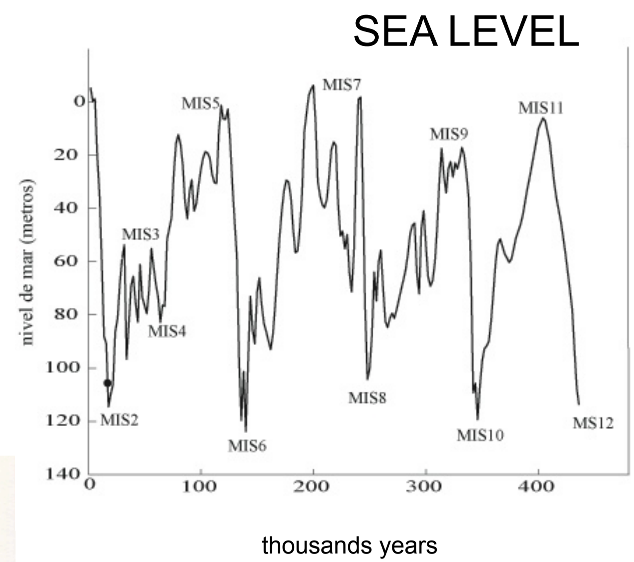
systems tract: coeval depositional systems linked by lateral transitions

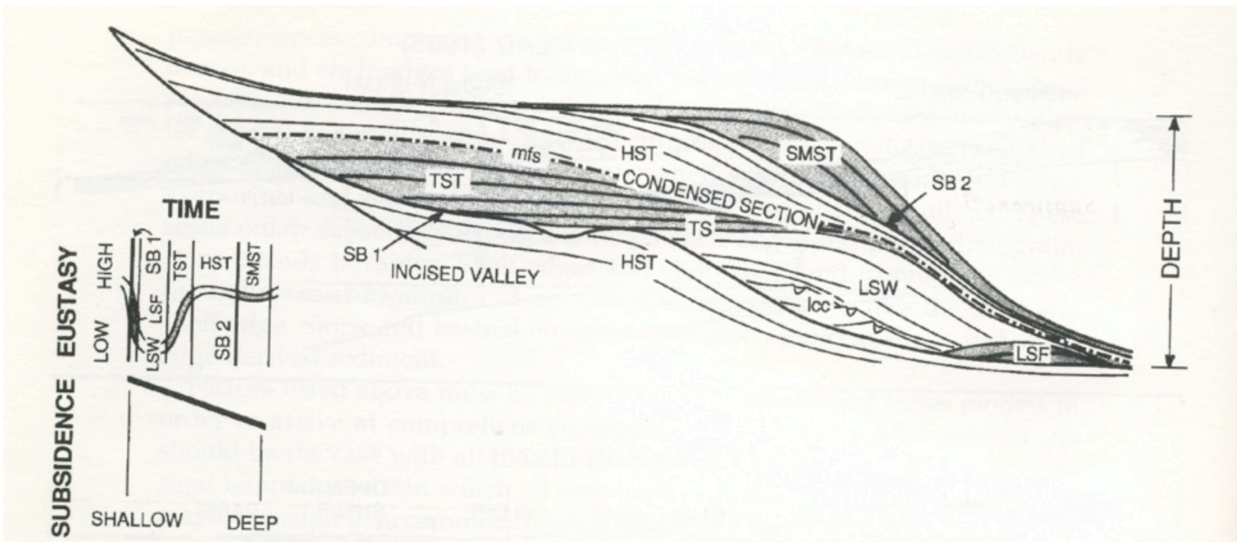


The Standard Model

The systems tract from basin margin to deep water varies in a systematic fashion during a sea-level cycle such that lowstand, transgressive and highstand systems tracts can be distinguished (Posamentier and Vail, 1988)



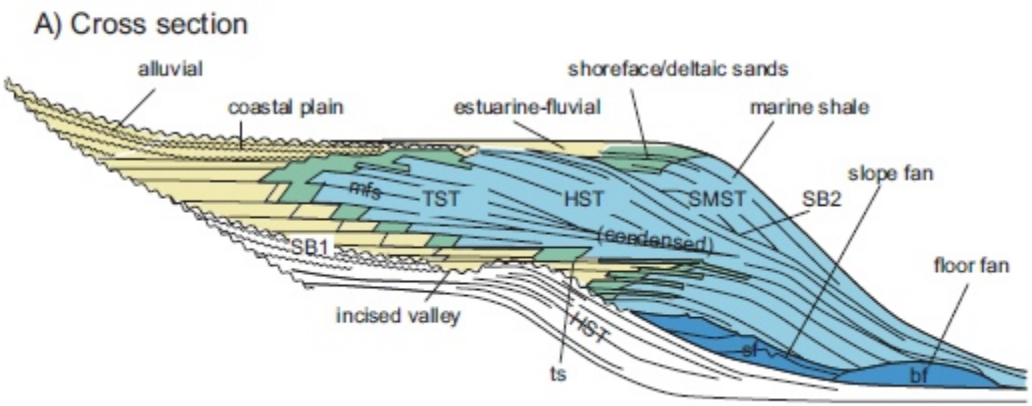


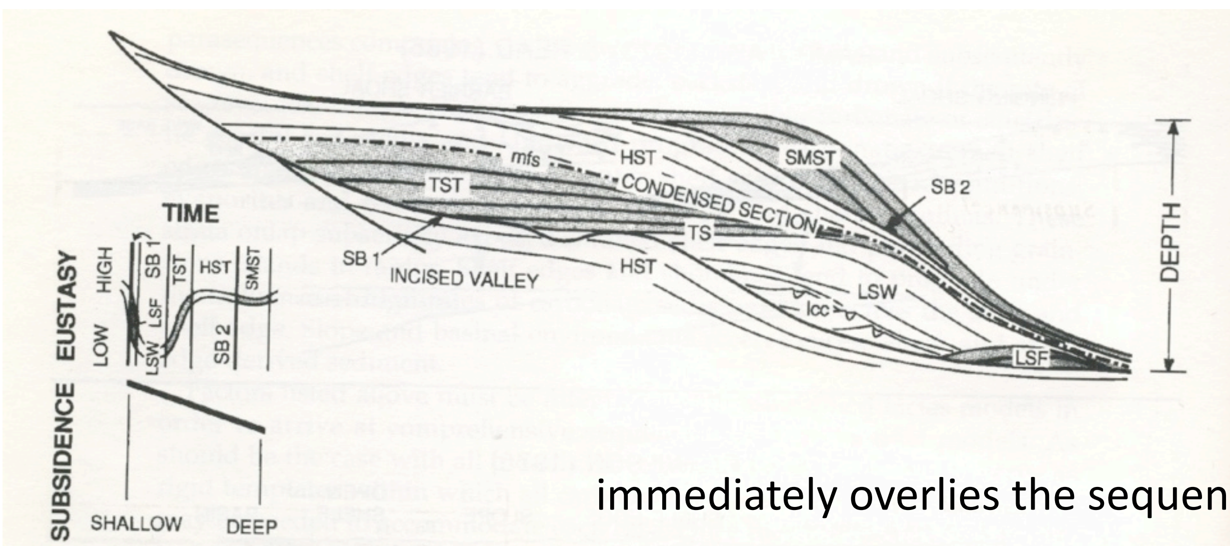


The Standard Model

Systems tracts follow each other in regular fashion

The lowstand systems tract consists of the suite of depositional systems developed when relative sea level has fallen below an earlier shelf margin.



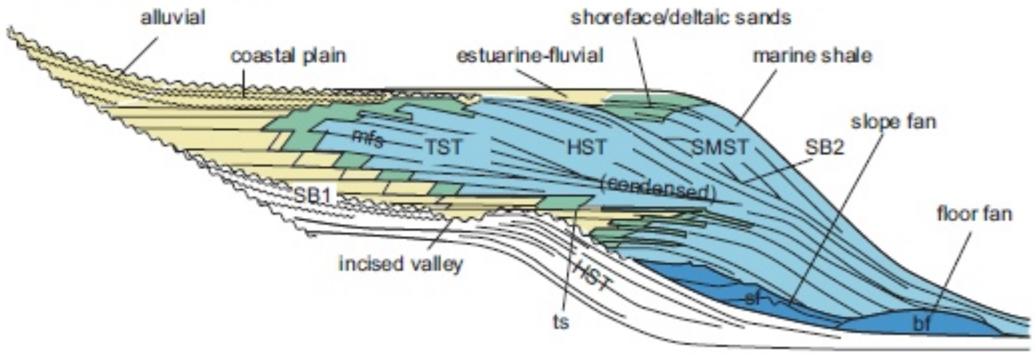


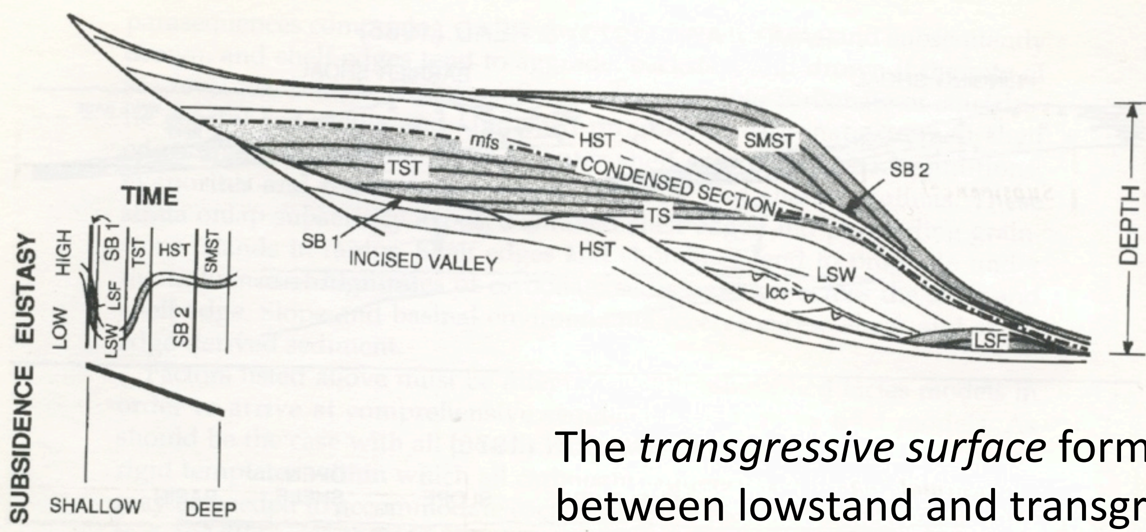
immediately overlies the sequence boundary

The Standard Model

The transgressive systems tract consists of the depositional systems developed when sea level rises from its lowstand position to an elevation above the old shelf margin and depositional environments shift landward

A) Cross section

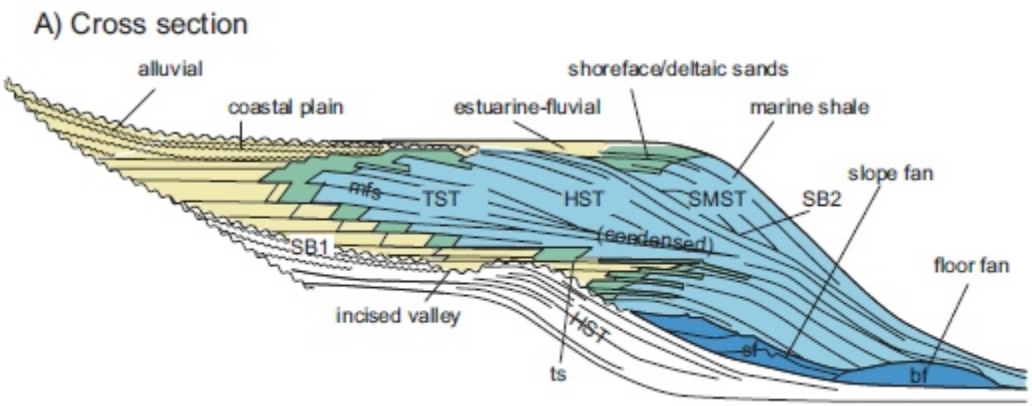


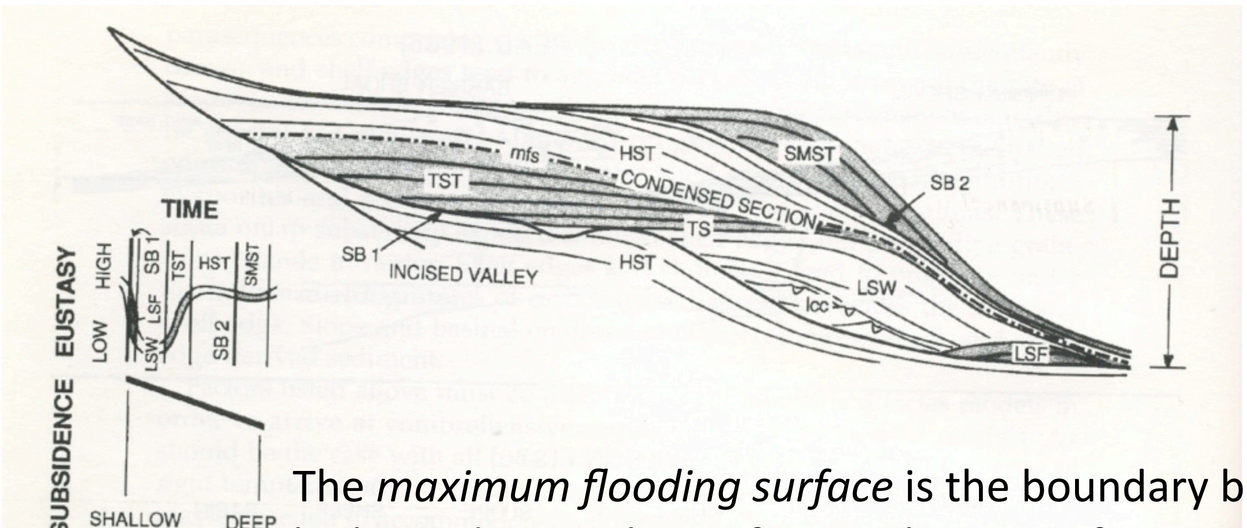


The *transgressive surface* forms the boundary between lowstand and transgressive tract

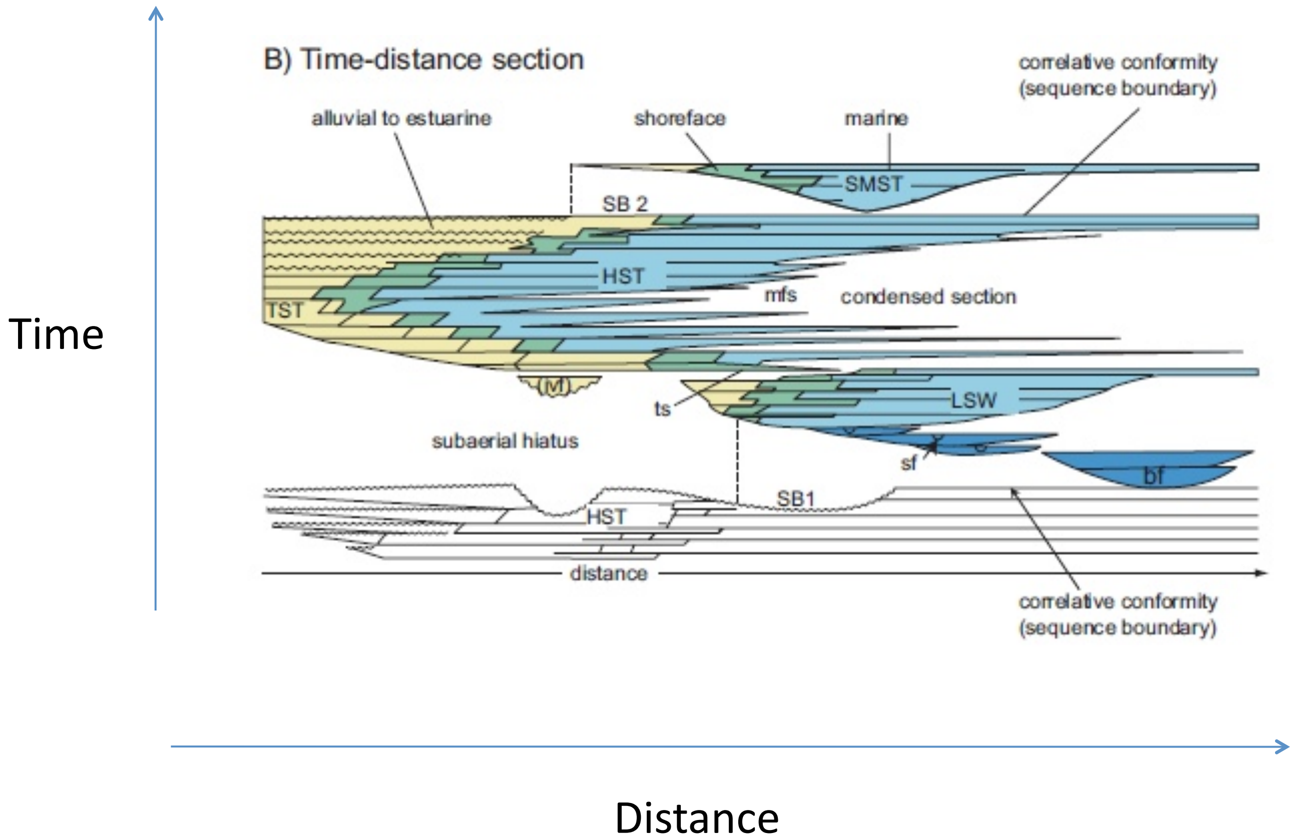
The Standard Model

The highstand systems tract consists of the depositional systems developed when sea level stands above the old shelf margin and depositional environments and facies belts prograde seaward.





The *maximum flooding surface* is the boundary between transgressive and highstand tract: the surface at the time of maximum transgression of the shelf

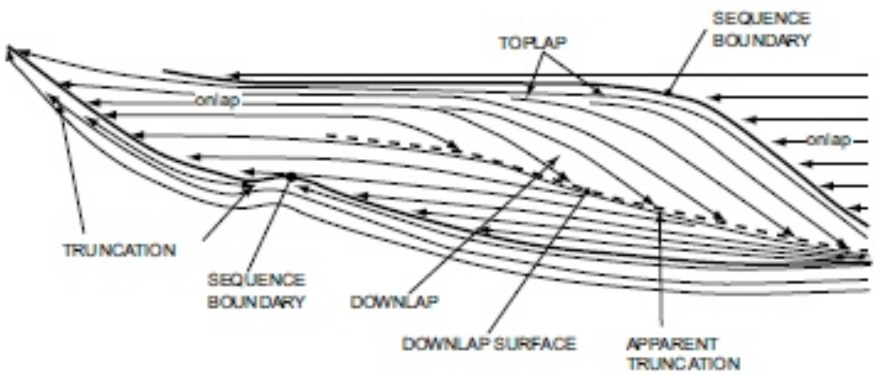


Type-1 sequence boundary (SB1) forms when relative sea-level falls below the shelf break of the preceding sequence

Type-2 sequence boundary (SB2) forms when relative sea-level falls to somewhere between the old shoreline and the shelf break.

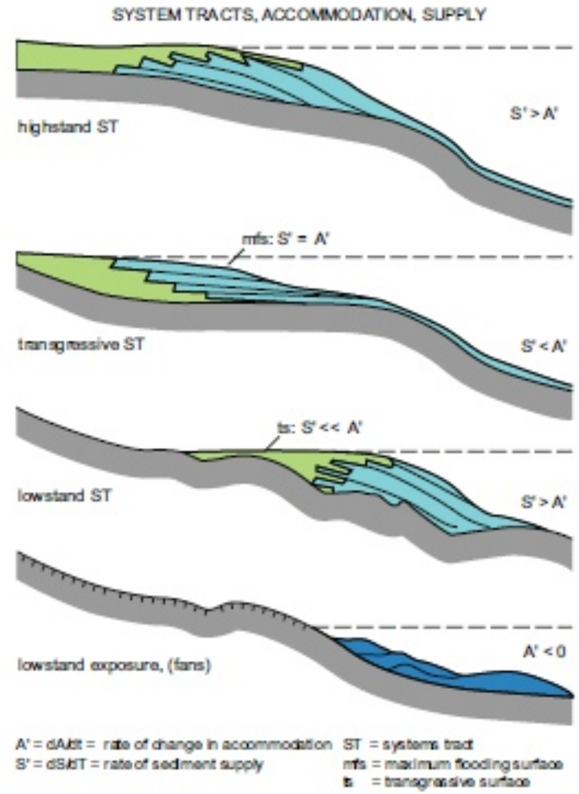
Systems tracts in sequence stratigraphy were originally defined by lap-out patterns at the base and top, internal bedding, stacking patterns and position within a sequence (Posamentier et al., 1988)

All these criteria are based on geometry



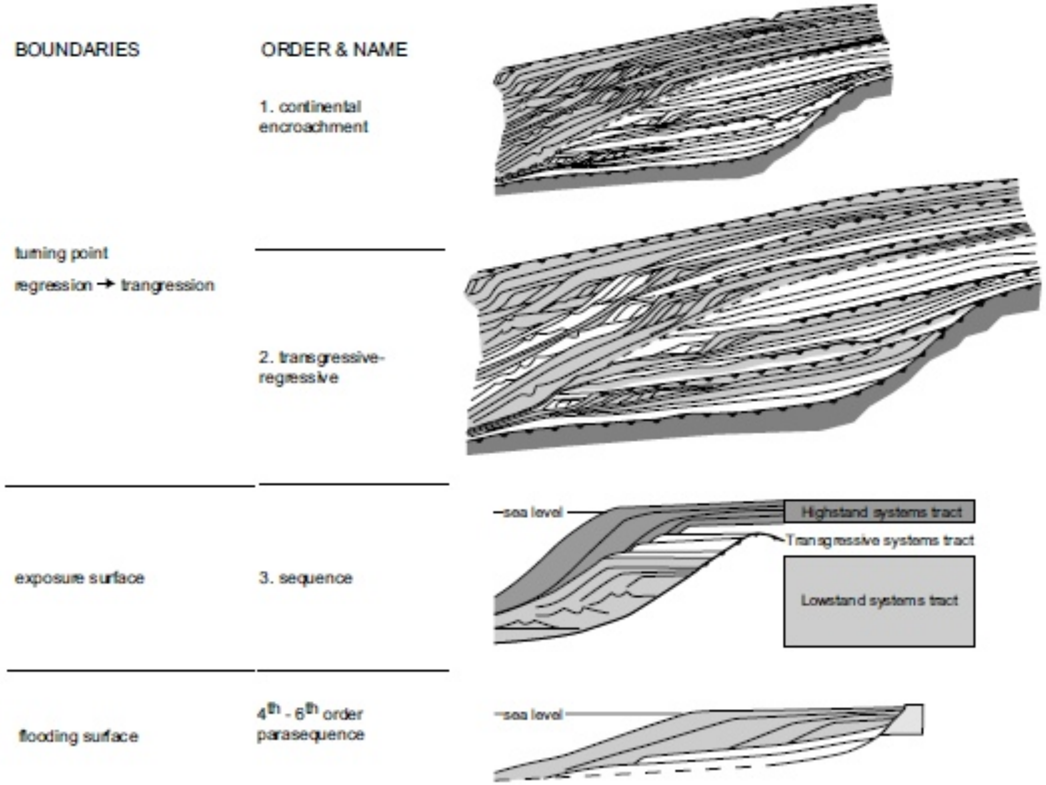
The geometry of systems tracts leads to characteristic stratal patterns in seismic profiles and large outcrops

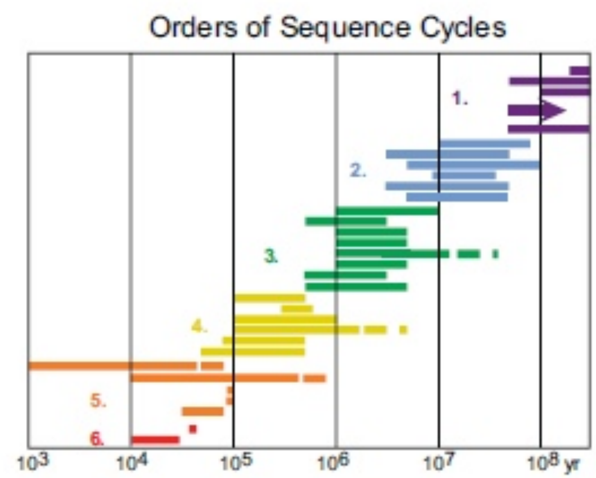
Systems tracts in siliciclastics are generated by the interplay of the rate of change in accommodation, A’, and the rate of change in sediment supply, S’.



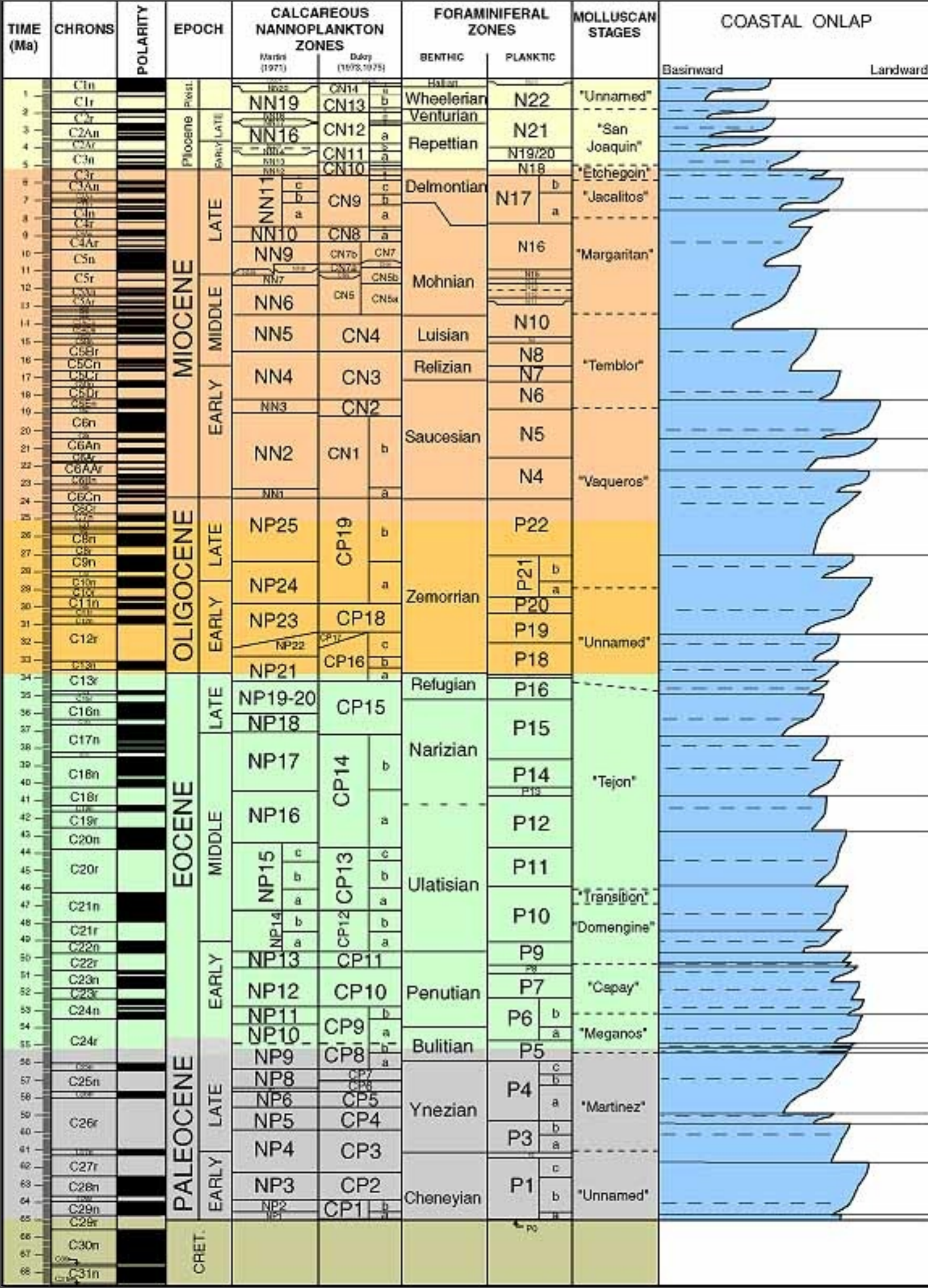
Accommodation space or accommodation is the sum of the rates of subsidence, sediment compaction, structural deformation, and eustasy

The assumption of standard sequence stratigraphy that the sequence pattern is dominated by sea-level related changes in accommodation should not be acepted a priori (Schlager, 2005)





Parasequence, or P sequence , shows the succession: highstand tract - sequence boundary – transgressive tract - highstand tract. The sequence boundary is a type-3 boundary, i.e. a flooding surface that overlies marine deposits without demonstrable evidence of terrestrial exposure or forced regression (Schlager, 2005)



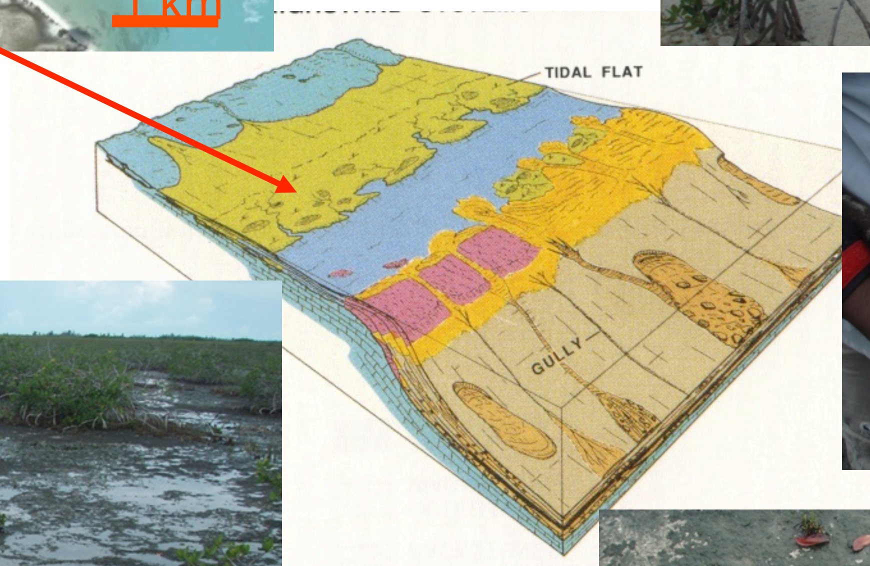
Integrated timescale

Coastal onlap/sequence stratigraphy

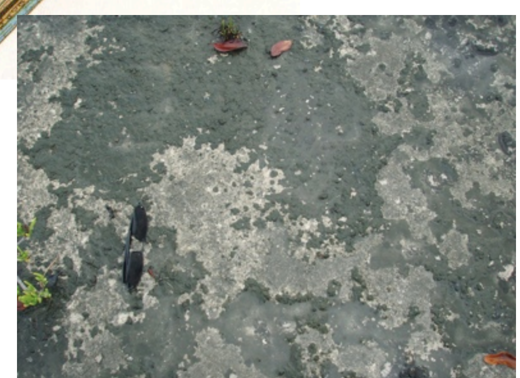
Provided a constant subsidence rate (stable margin ~ stable tectonic setting) the succession of depositional sequences can be interpreted as reflecting eustatic (global) sea level changes.

Proxy for a global sea-level curve

Tropical carbonate systems



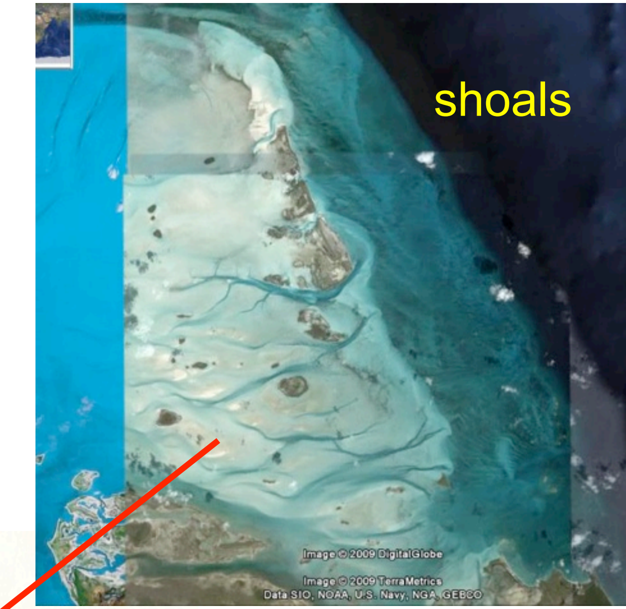
algal marsh



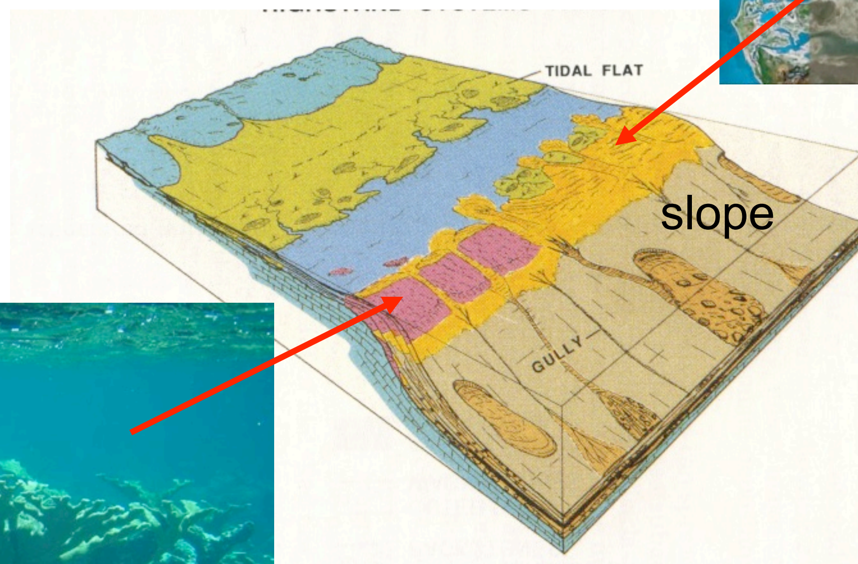
mud cracks and algal (cyanobacteria) mats

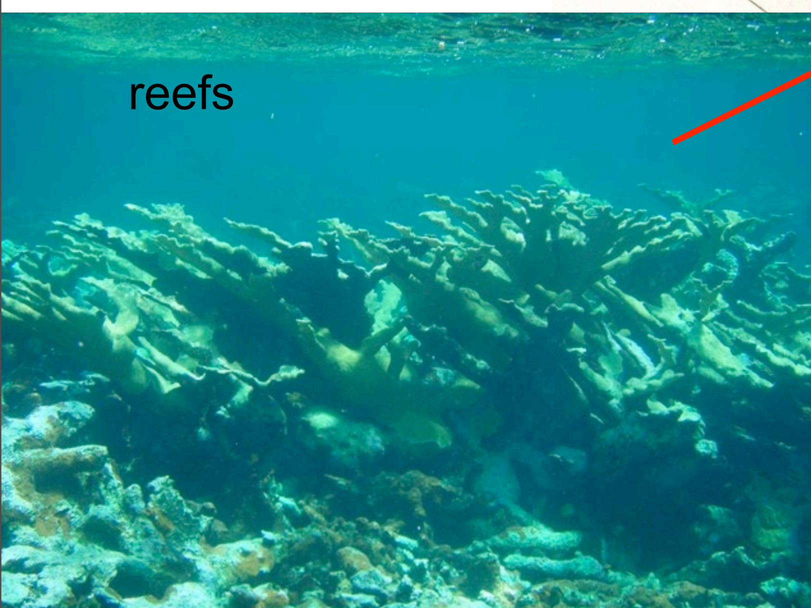
Production of sediment within the system

Most sediment feeding the systems
is produced in the photic zone
at the platform top



wave-resistant,
elevated margins



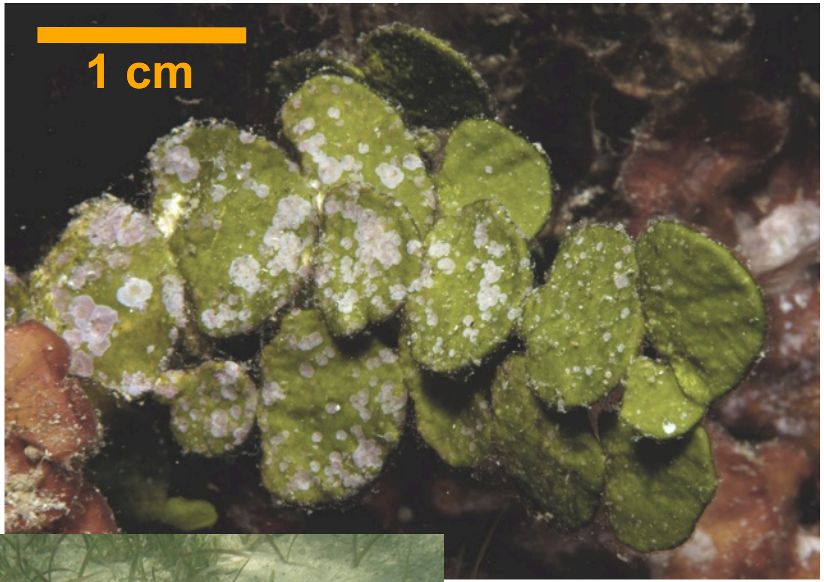


Sediment producers

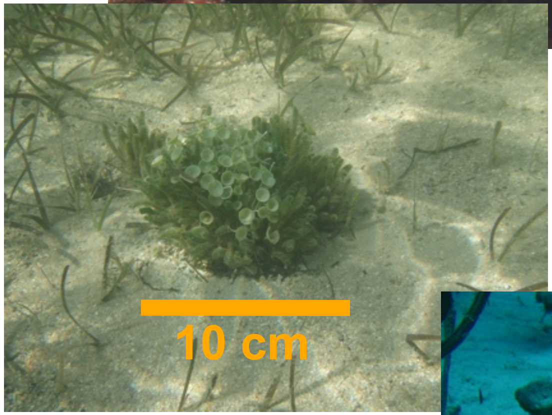
Skeletal particles

Corals (zooxanthellate corals)

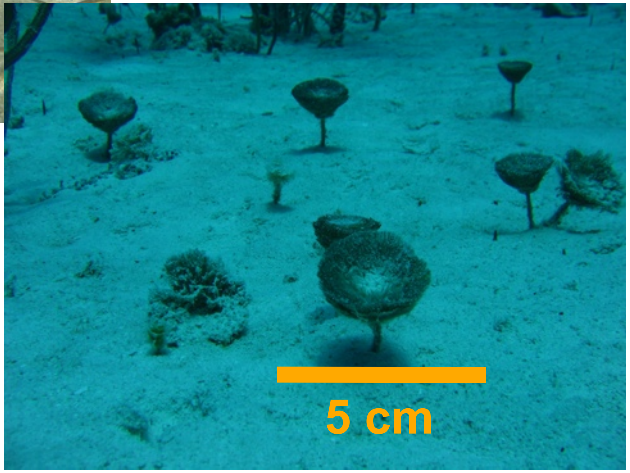
Green algae



Halimedaleans



Dasycladaleans



Udoteaceans

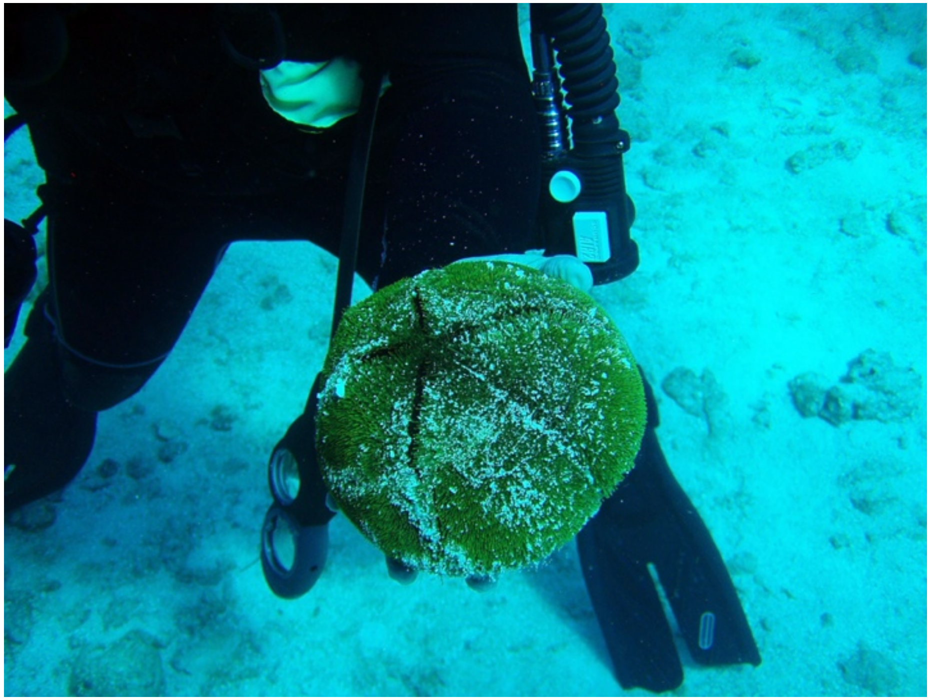
molluscs

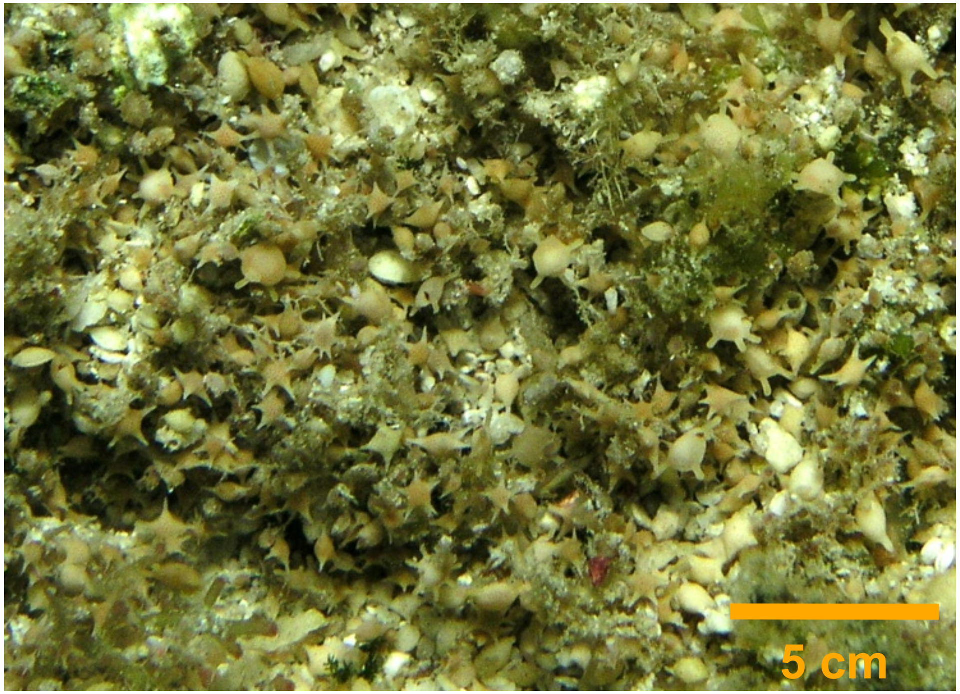
Other important carbonate producers

gastropods

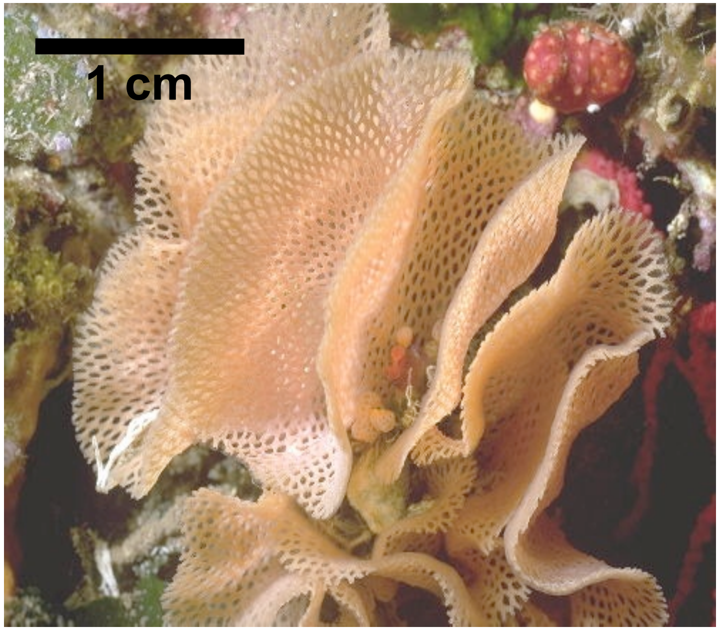
bivalves

echinoids

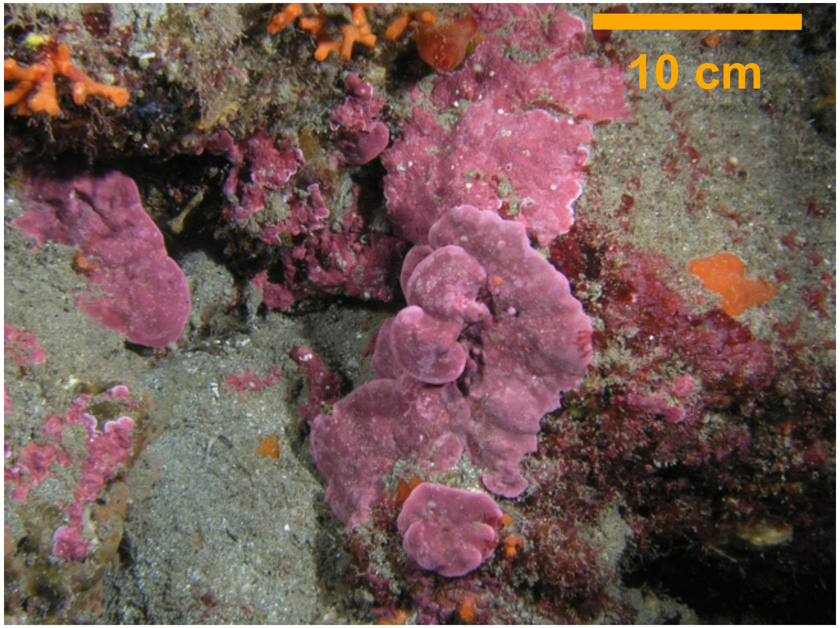




Benthic foraminifers



Bryozoans



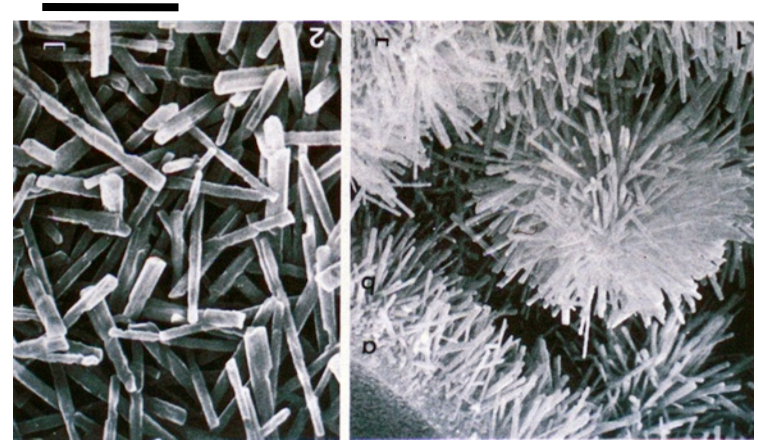
Coralline red algae

Micrite/micritic mud

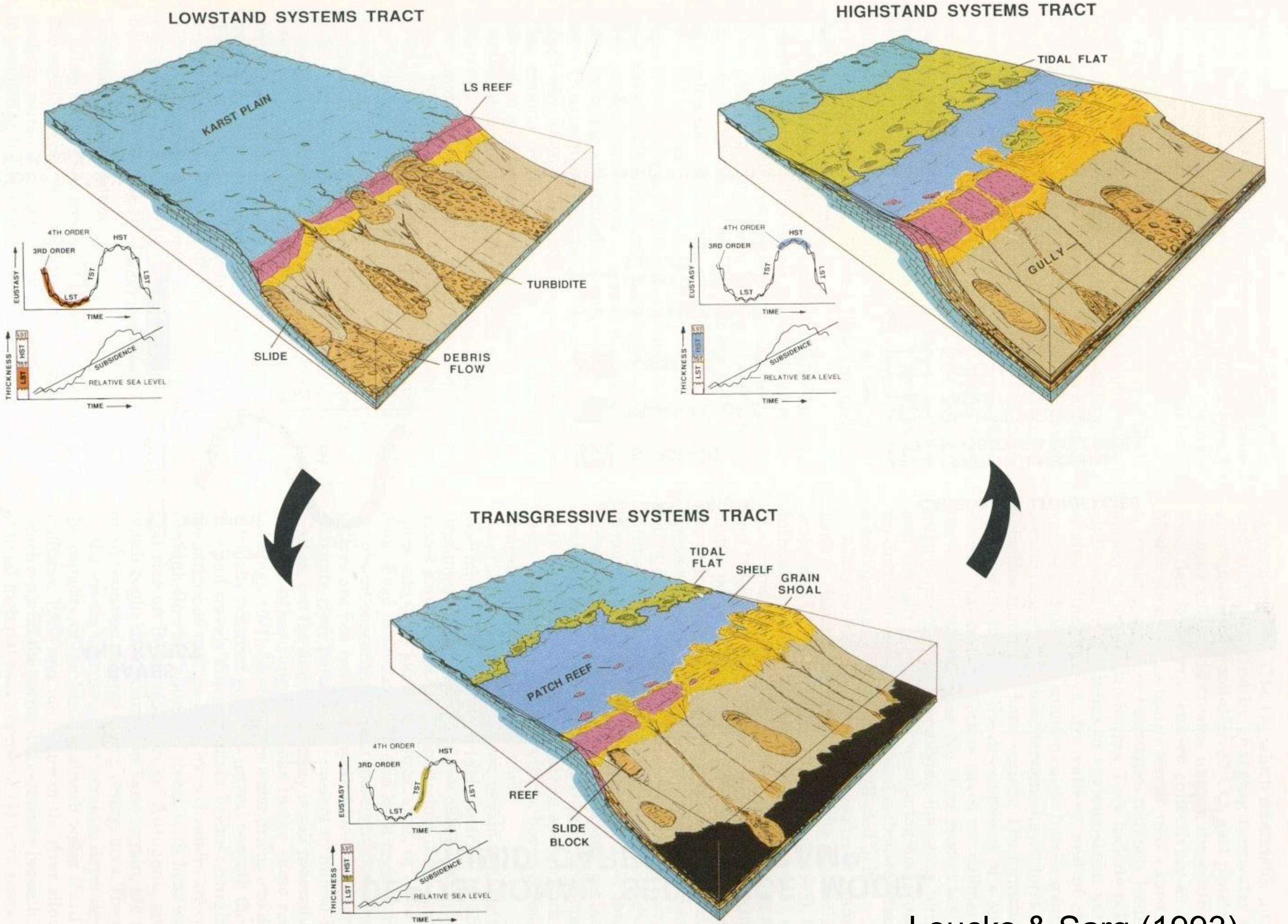
Early submarine cements

Calcareous green algae produce aragonitic mud

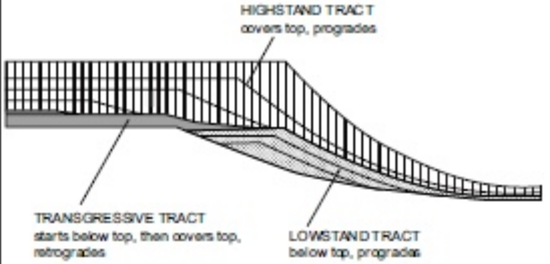
5 micron

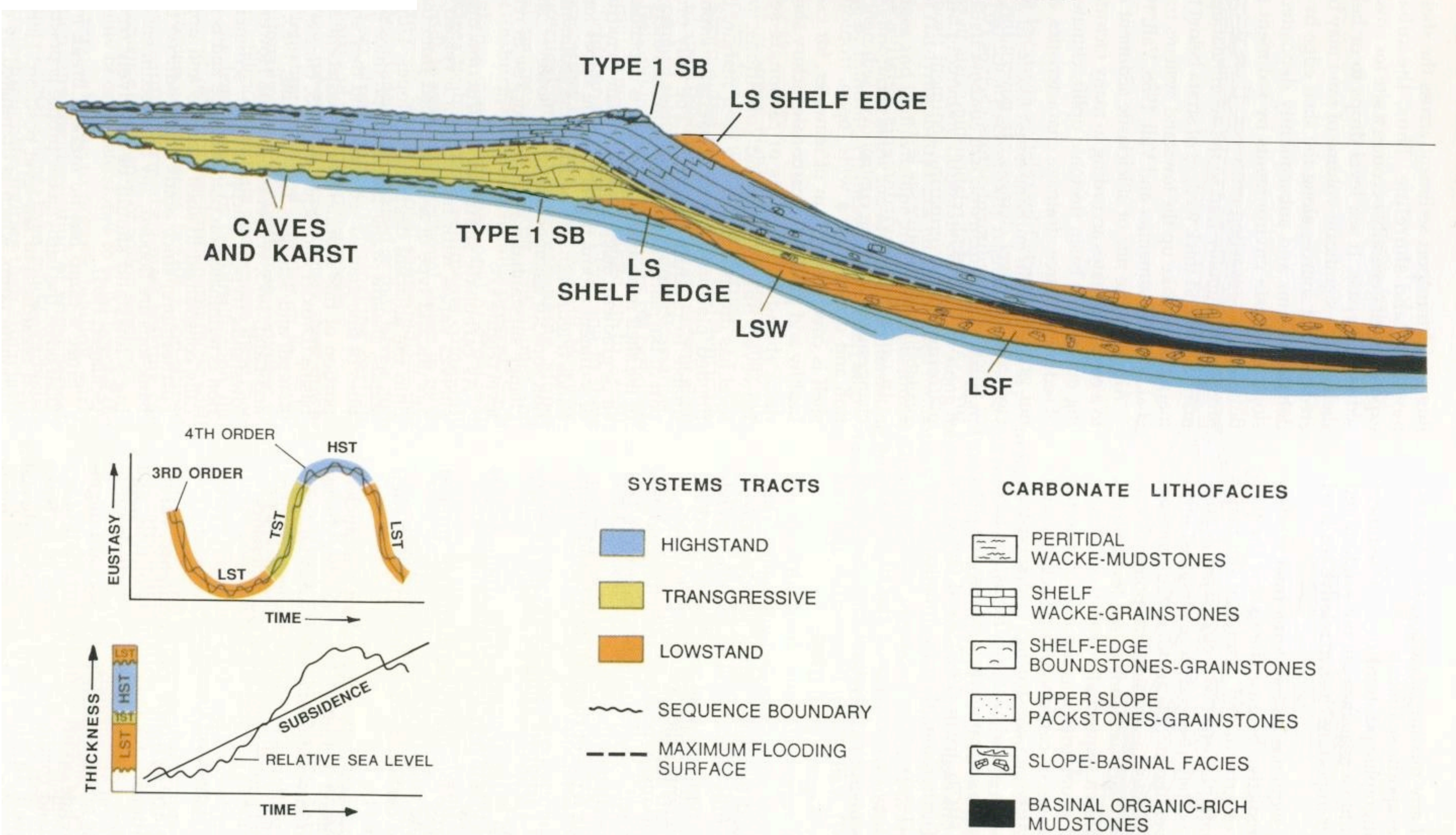


SEM

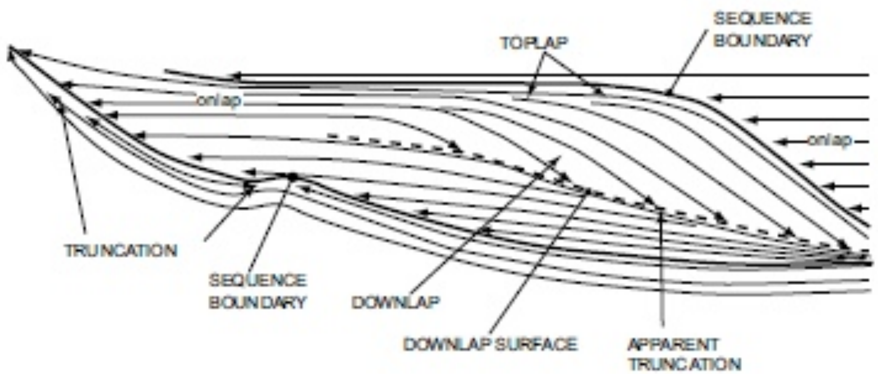


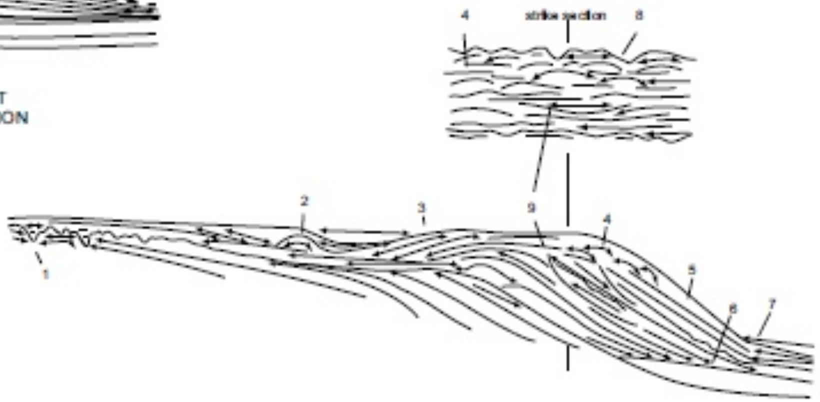
Loucks & Sarg (1993)


HIGHSTAND TRACT
covers top, progrades
TRANSGRESSIVE TRACT
starts below top, then covers top,
retrogrades
LOWSTAND TRACT
below top, progrades


DEPOSITIONAL SEQUENCE MODEL
HUMID CARBONATE RIMMED SHELF
TYPE 1 SB
LS SHELF EDGE
CAVES
AND KARST
TYPE 1 SB
LS
SHELF EDGE
LSW
LSF
4TH ORDER
HST
3RD ORDER
EUSTASY
TST
LST
LST
TIME
THICKNESS
LST
HST
TST
LST
SUBSIDENCE
RELATIVE SEA LEVEL
TIME
SYSTEMS TRACTS
HIGHSTAND
TRANSGRESSIVE
LOWSTAND
SEQUENCE BOUNDARY
MAXIMUM FLOODING
SURFACE
CARBONATE LITHOFACIES
PERITIDAL
WACKE-MUDSTONES
SHELF
WACKE-GRAINSTONES
SHELF-EDGE
BOUNDSTONES-GRAINSTONES
UPPER SLOPE
PACKSTONES-GRAINSTONES
SLOPE-BASINAL FACIES
BASINAL ORGANIC-RICH
MUDSTONES

Siliciclastic vs. Carbonate lapout patterns





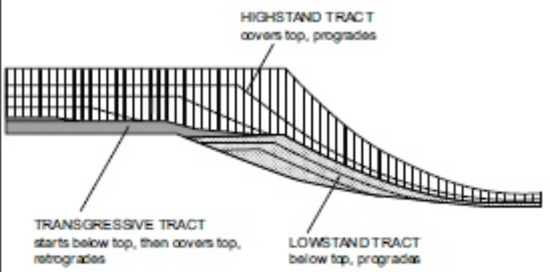
carbonates

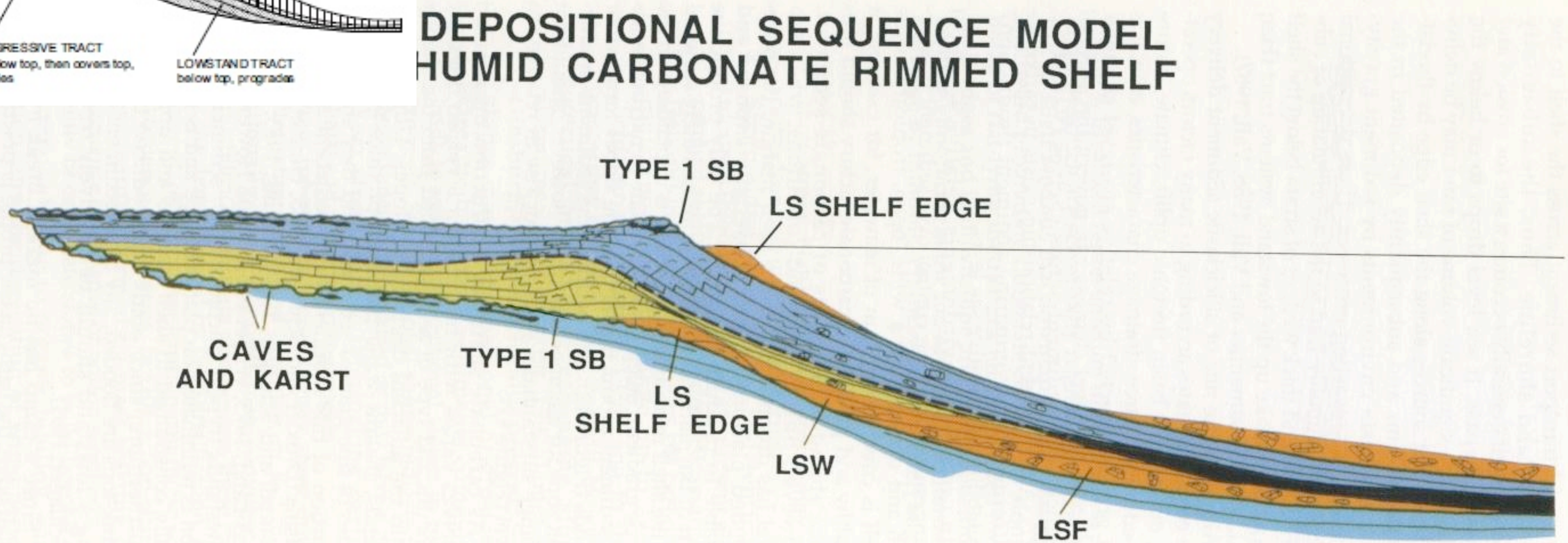
- more complex lapout patterns

- horizontal tops rather than seaward dipping shelf profiles

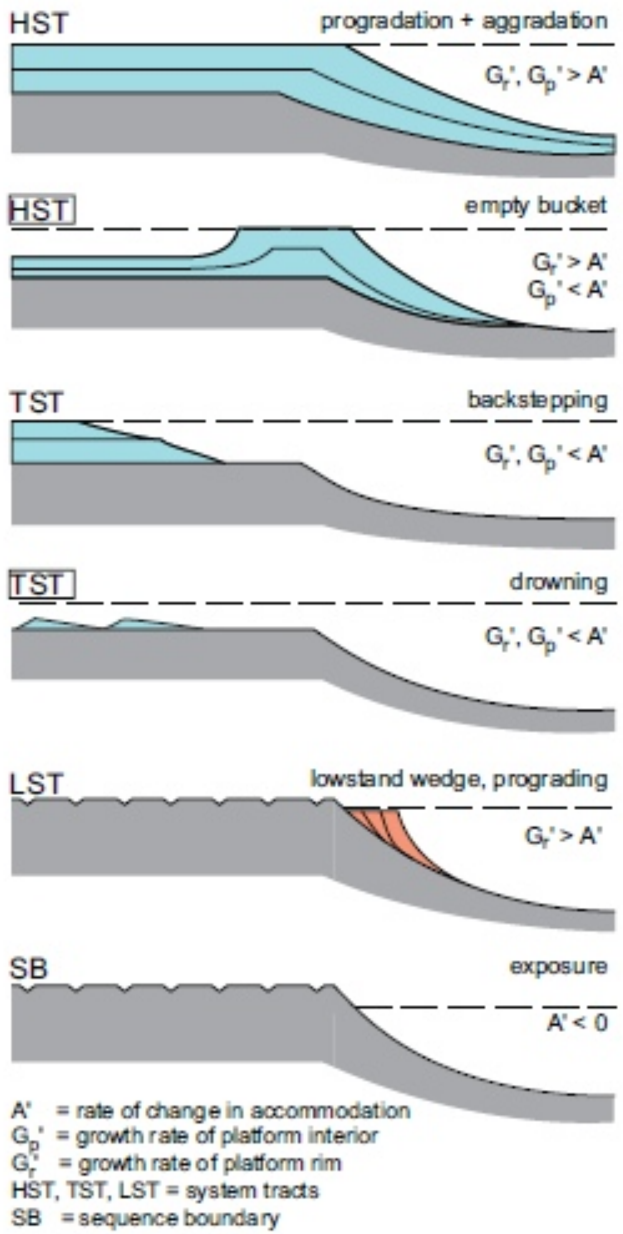
- wave-resistant structures in the depositional environment. These structures are independent of shoreline position.

- may show a reversed dip from the rim into the lagoon





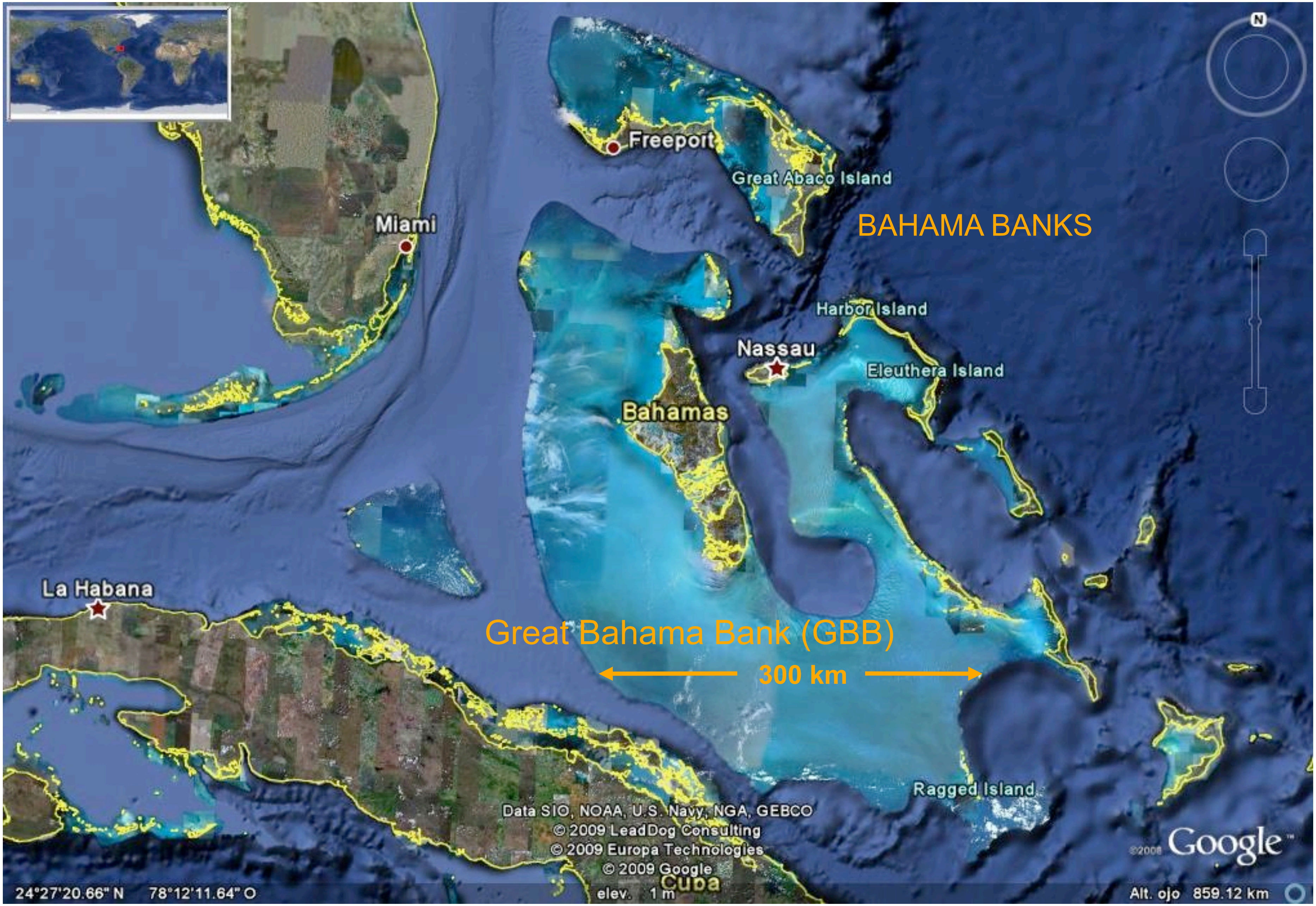
carbonates develop karst surfaces where mechanical denudation is minimal and chemical denudation is relatively slow

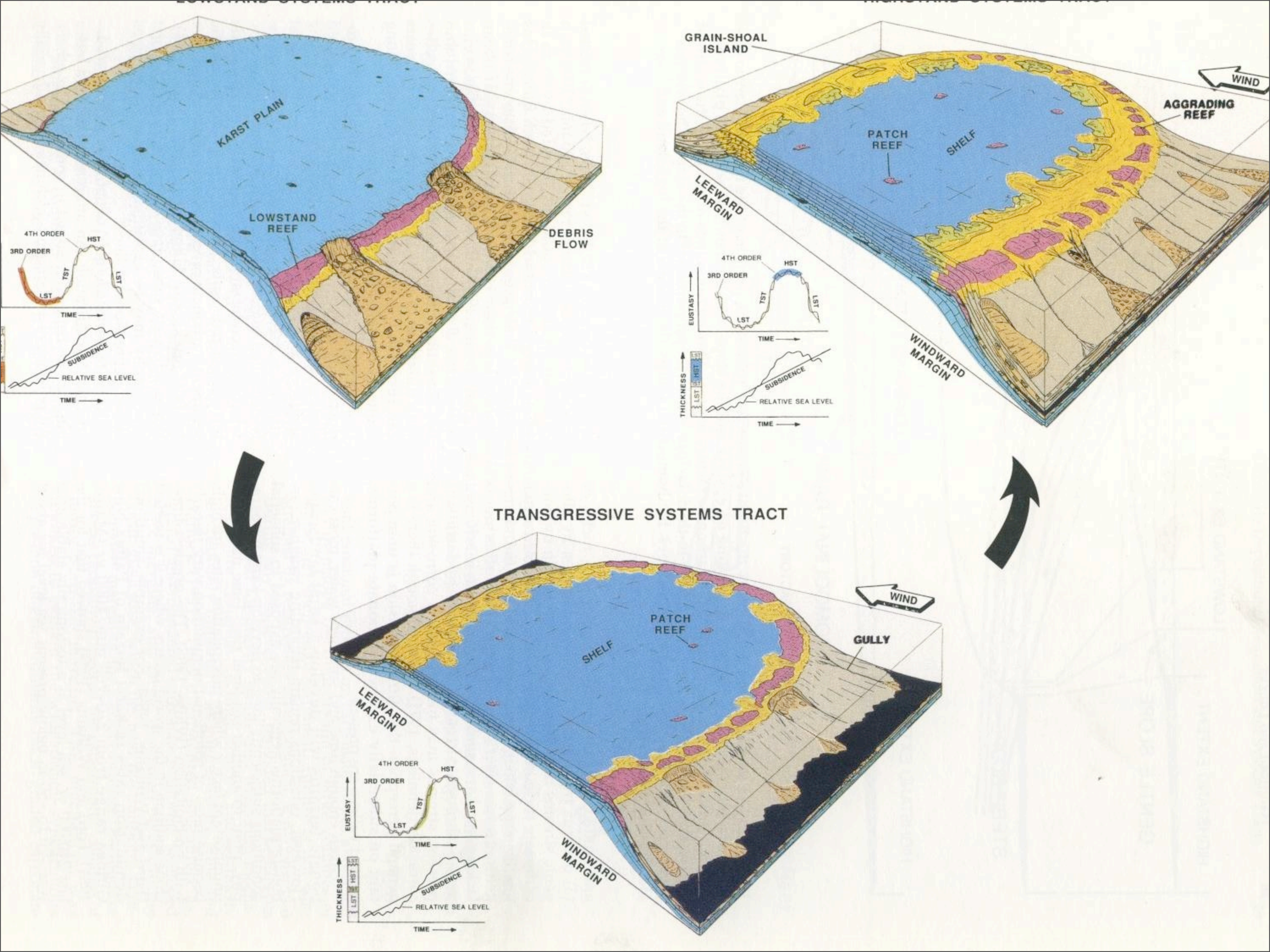


Large amounts of particulate material from clay- to granule size are shed down the slope and into the basin because accommodation on the very shallow platforms is limited and the factory normally produces far more than can be stored on the platform top.

Growth (production) vs. accomodation

Detached platforms




KARST PLAIN
LOWSTAND REEF
DEBRIS FLOW
4TH ORDER
3RD ORDER
HST
TST
LST
LST
TIME
SUBSIDENCE
RELATIVE SEA LEVEL
TIME
GRAIN-SHOAL ISLAND
WIND
AGGRADING REEF
PATCH REEF
SHELF
LEEWARD MARGIN
WINDWARD MARGIN
4TH ORDER
HST
3RD ORDER
EUSTASY
TST
LST
LST
TIME
THICKNESS
LST
HST
TST
LST
SUBSIDENCE
RELATIVE SEA LEVEL
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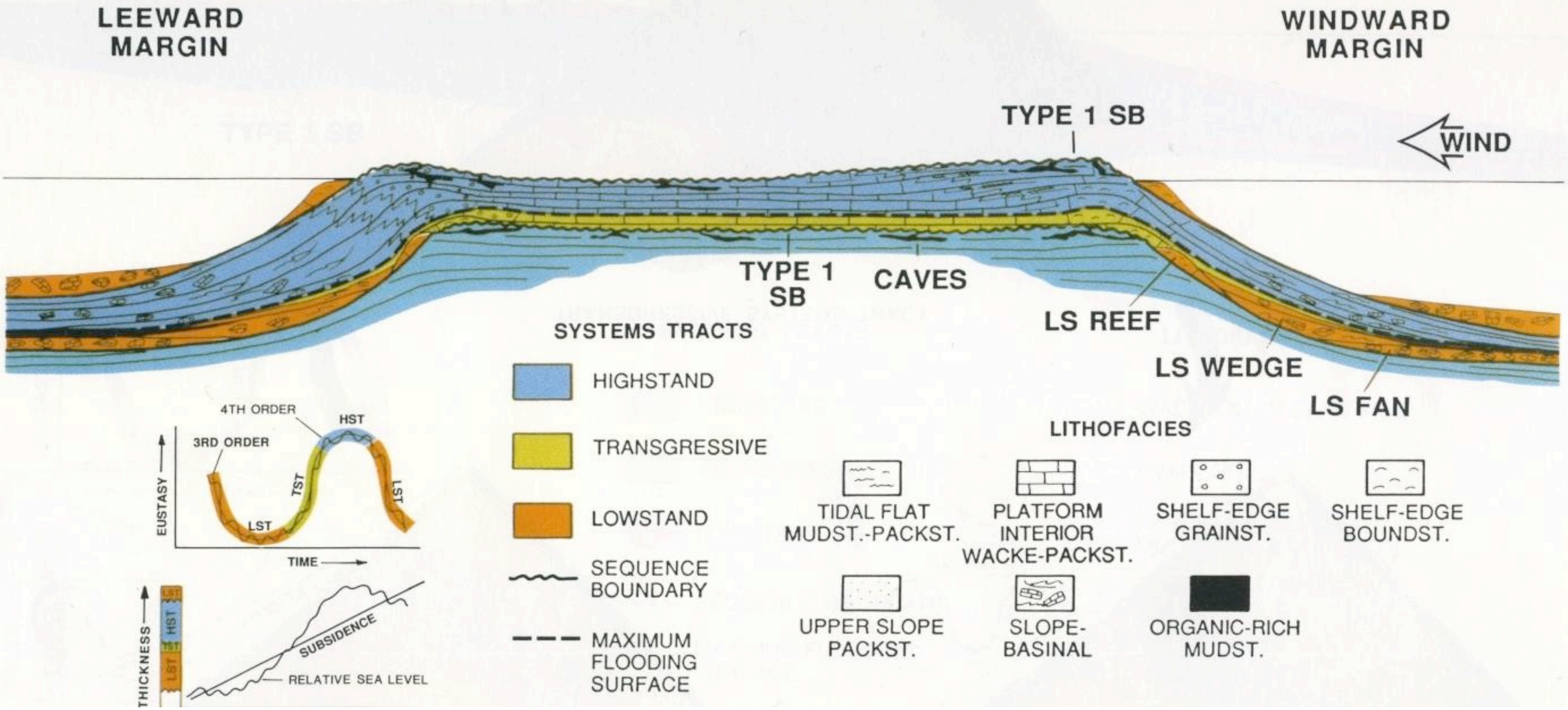
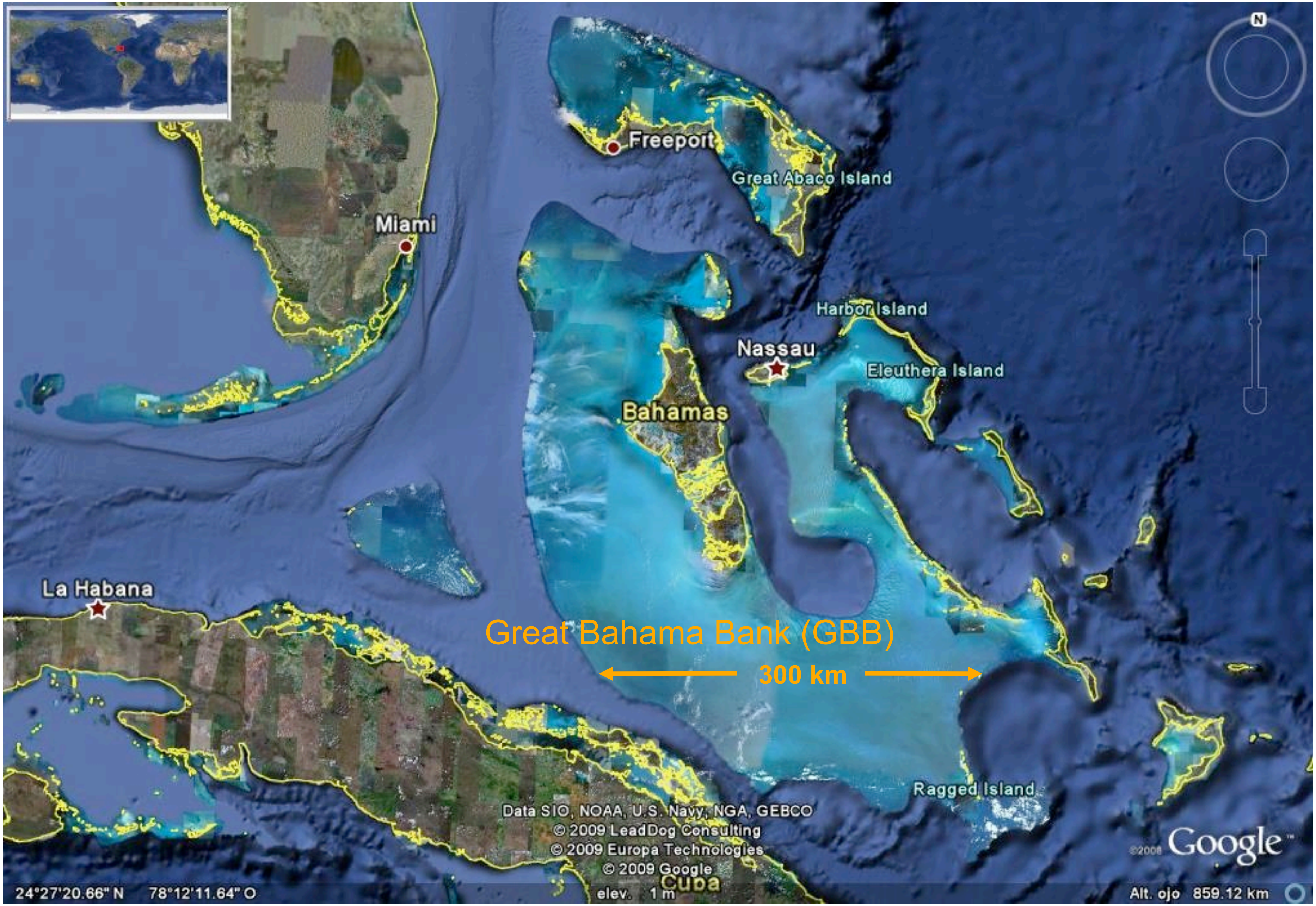
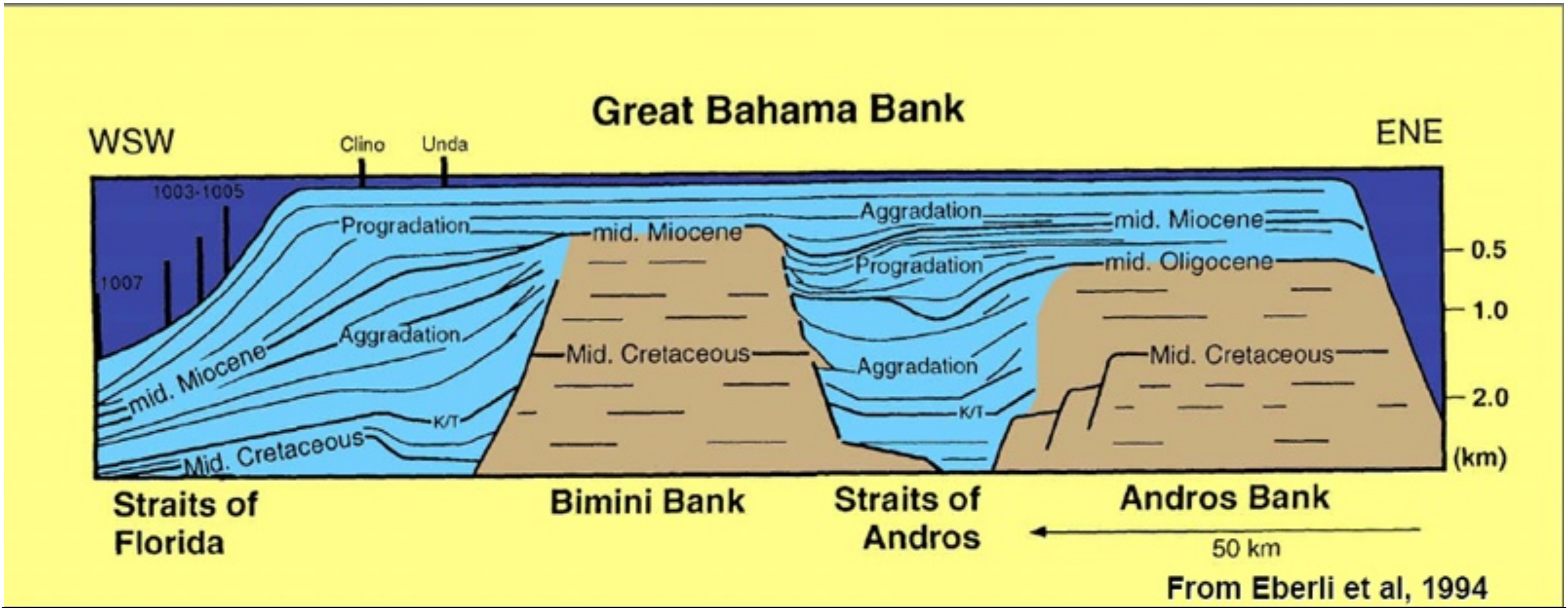
TRANSGRESSIVE SYSTEMS TRACT
WIND
PATCH REEF
SHELF
GULLY
LEEWARD MARGIN
WINDWARD MARGIN
4TH ORDER
HST
3RD ORDER
EUSTASY
TST
LST
LST
TIME
THICKNESS
LST
HST
TST
LST
SUBSIDENCE
RELATIVE SEA LEVEL
TIME

DEPOSITIONAL SEQUENCE MODEL
DETACHED, HUMID RIMMED PLATFORM



BAHAMA BANKS



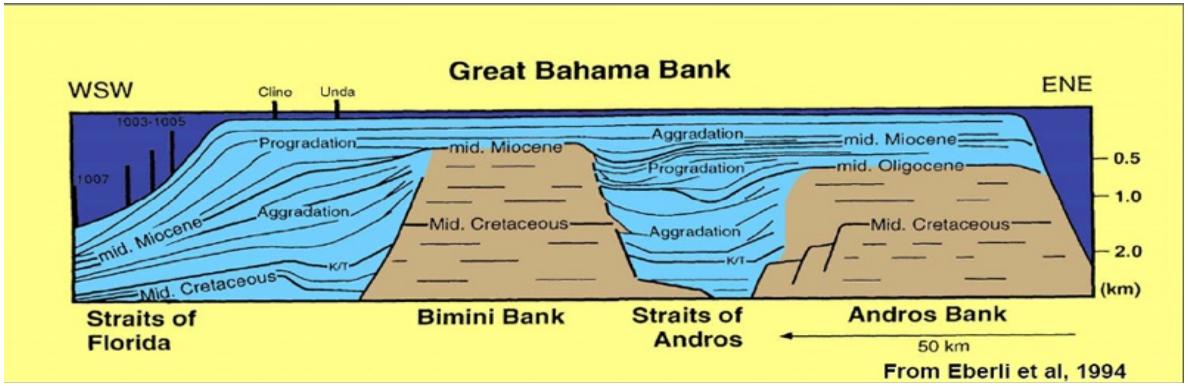


Flat-topped, steep-sided carbonate platform

< 10 m water depth at the top

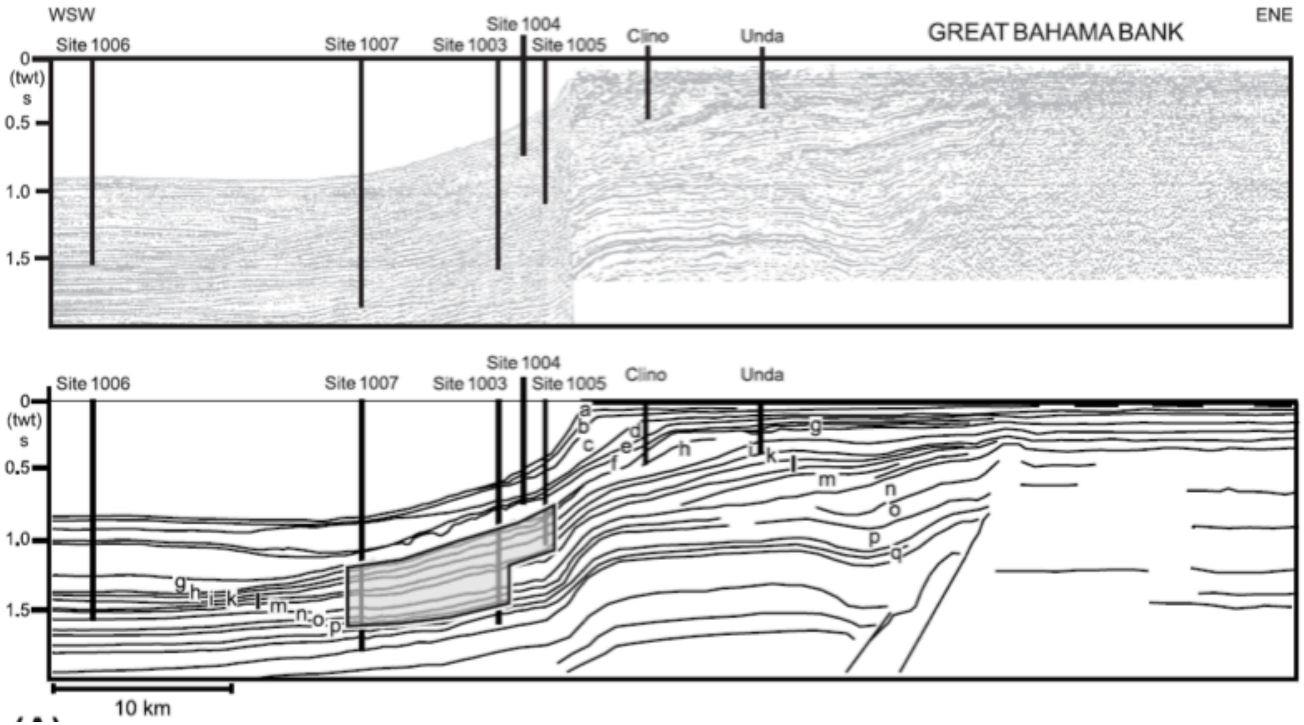
No siliciclastic input (except windblown dust)

Highstand shedding



The shallow-water top of the platform exports sand and mud to the adjacent slopes, mainly at the western margin.

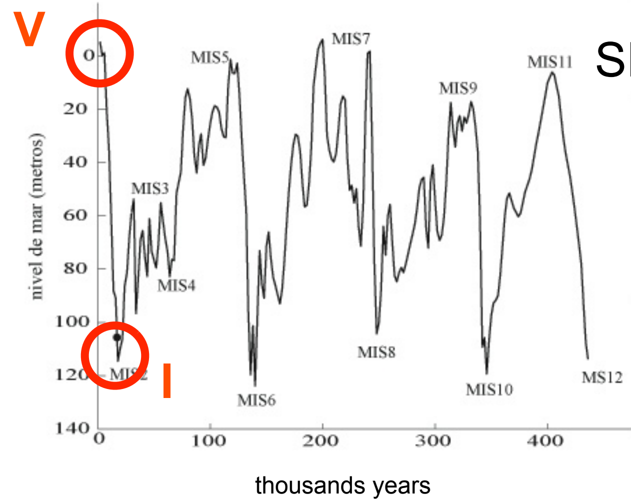
Aragonitic and high-Mg calcite composition of the particles

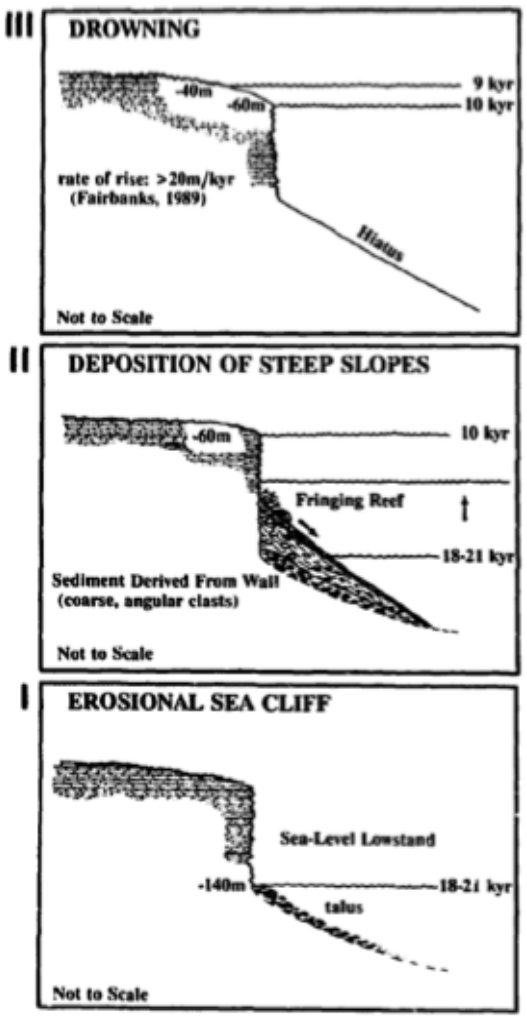


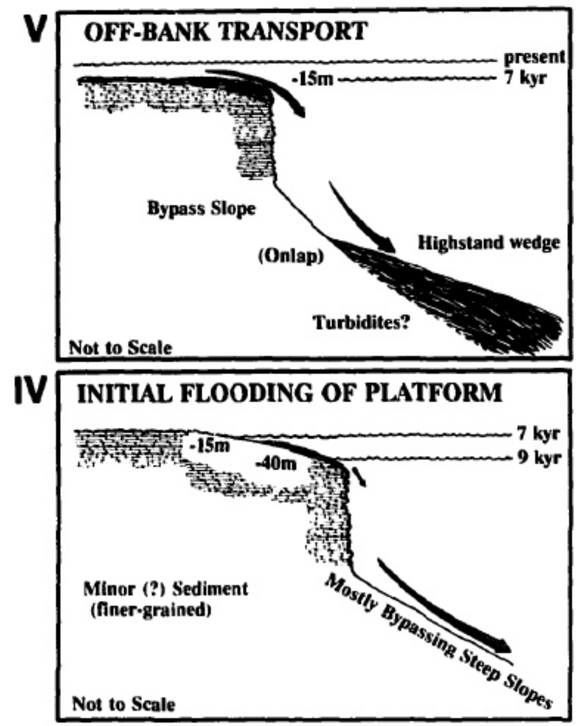
Progradation of platform margin

Record of rapid, high-amplitude
sea level changes at the Tongue of the
Ocean margin of GBB
(Grammer & Ginsburg, 1992)

SEA LEVEL





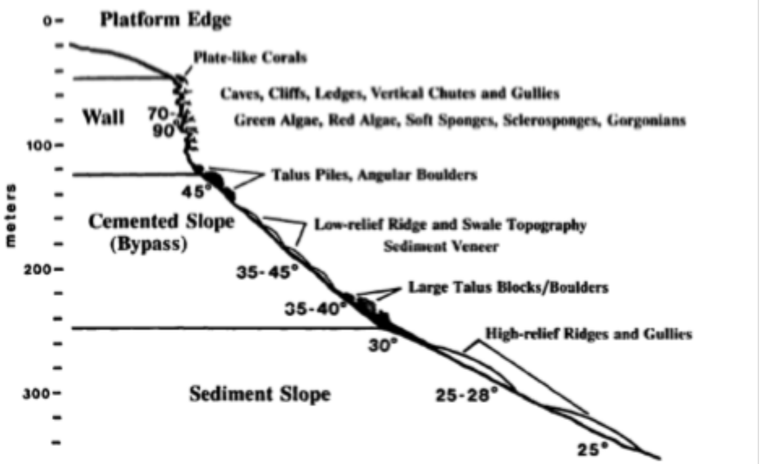


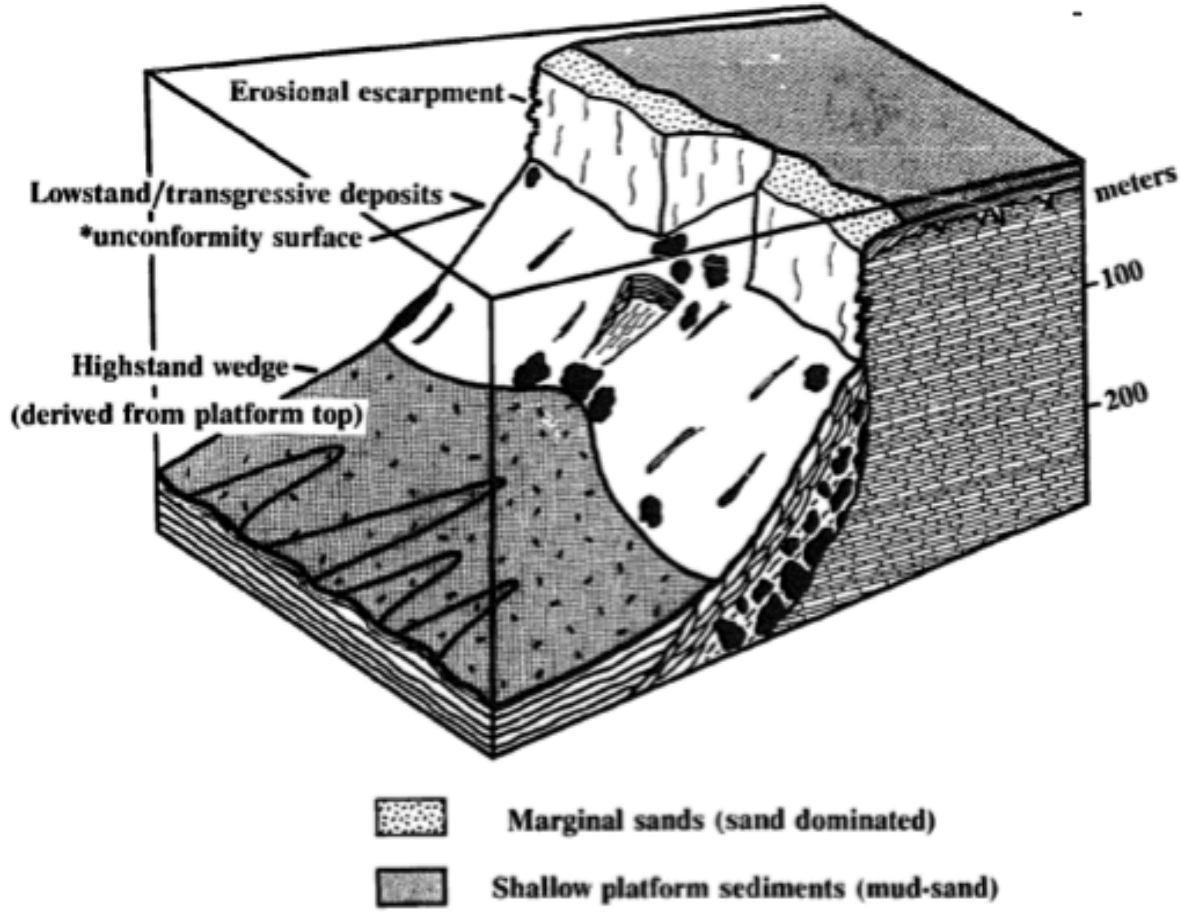
During the last 500 ka the platform has been flooded less than 10% of the time

Unconsolidated sediments younger than 6000 years

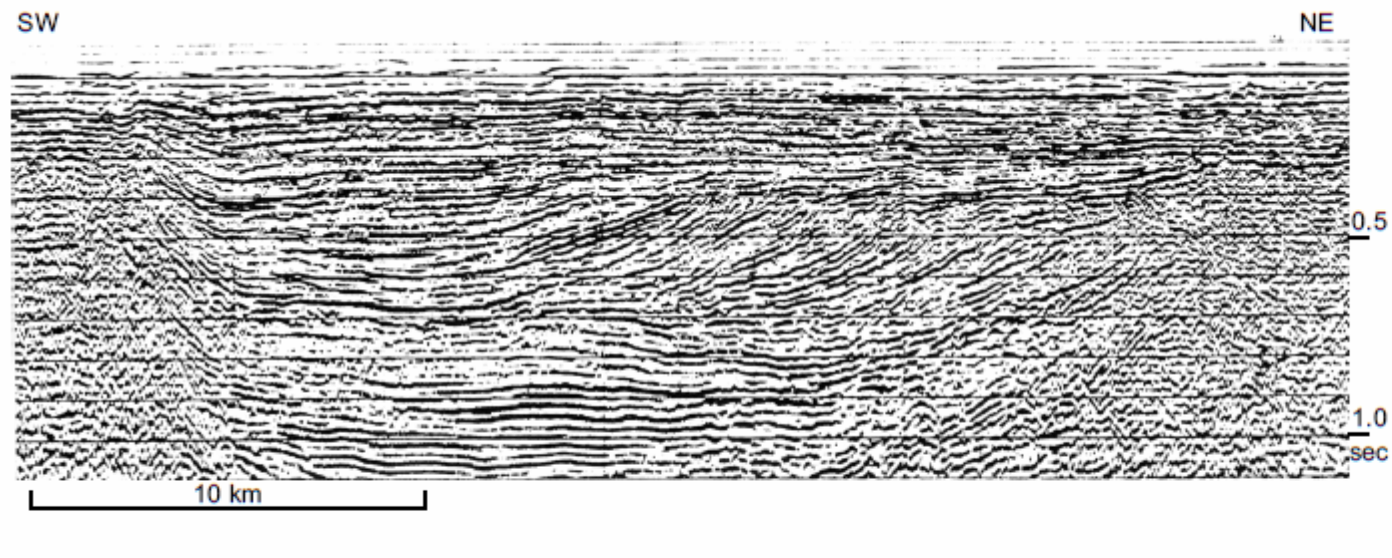
Large production and shedding only during highstands

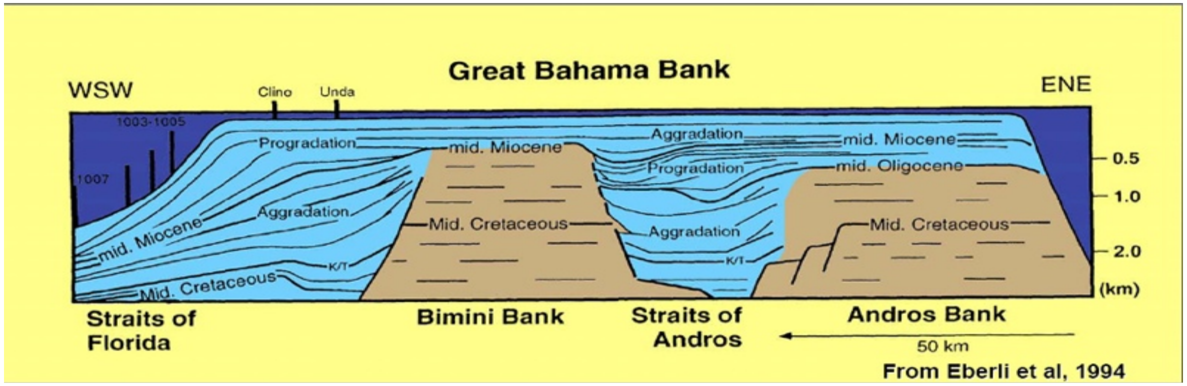
The morphology and depositional 'architechture' at the slopes are strongly conditioned by Pleistocene sealevel changes

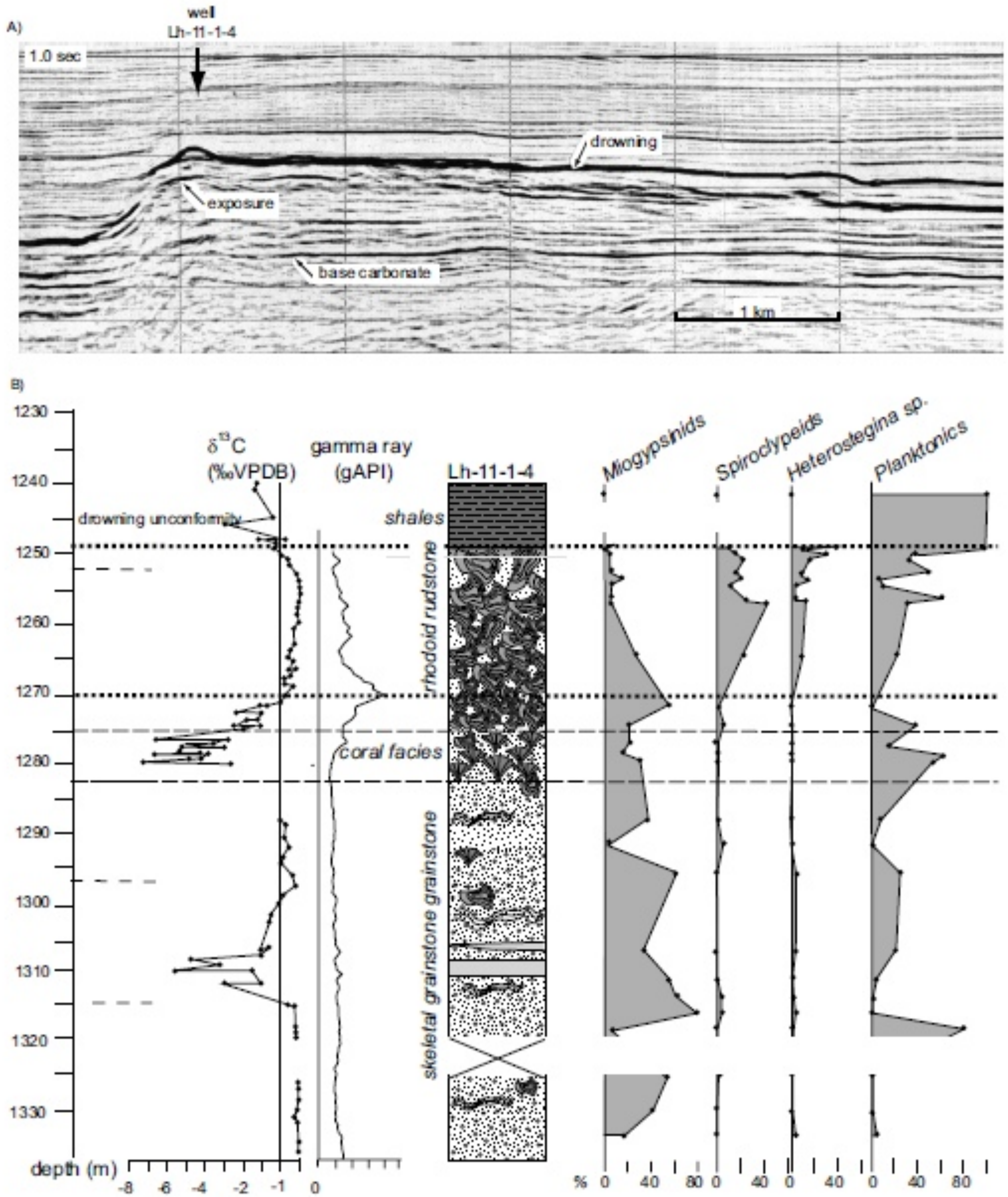




elevated rims have a strong tendency to stack vertically, putting reef on reef, sand shoal on sand shoal





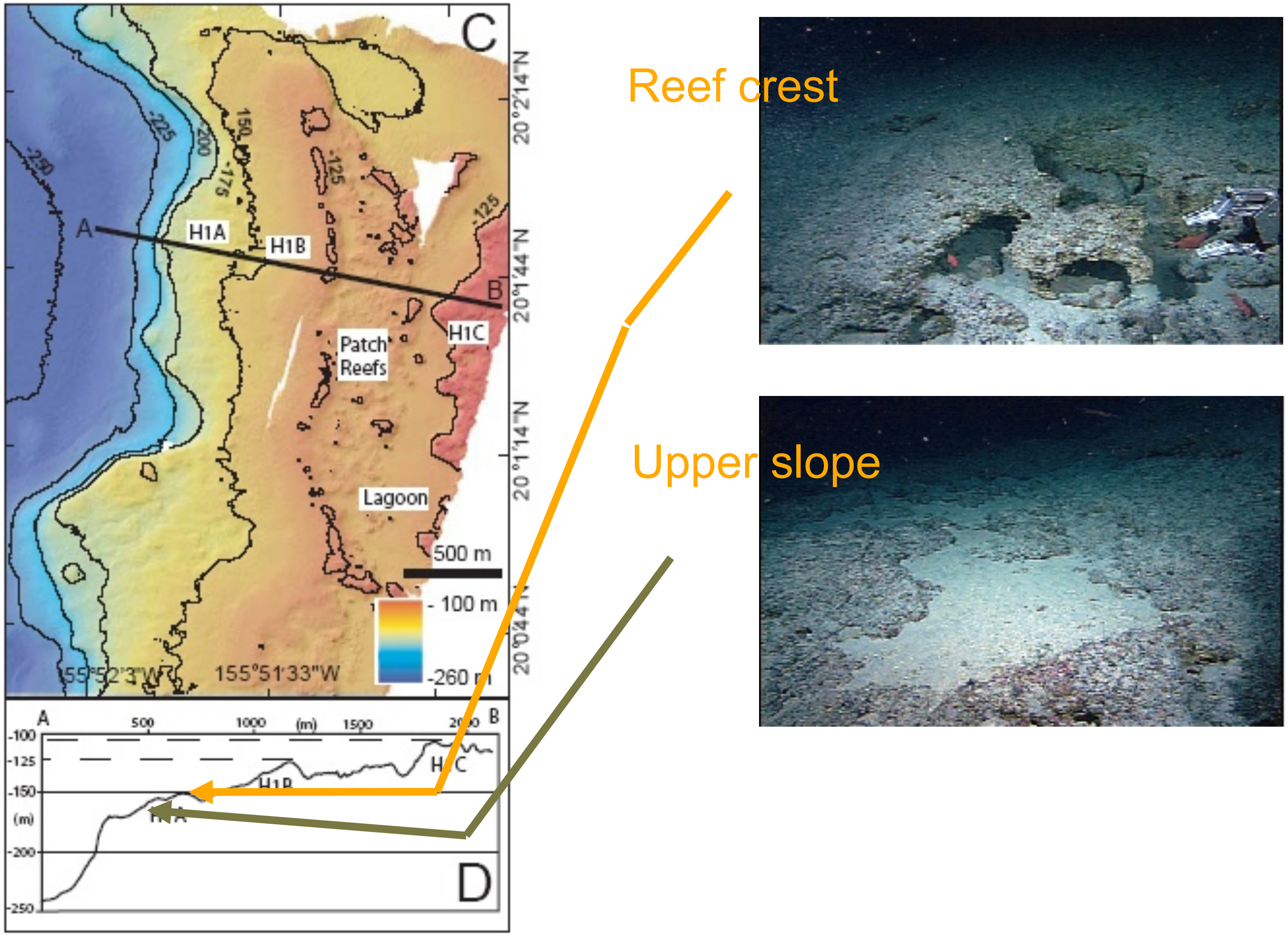


deepening of the depositional environment to below the photic zone and thus below the production zone

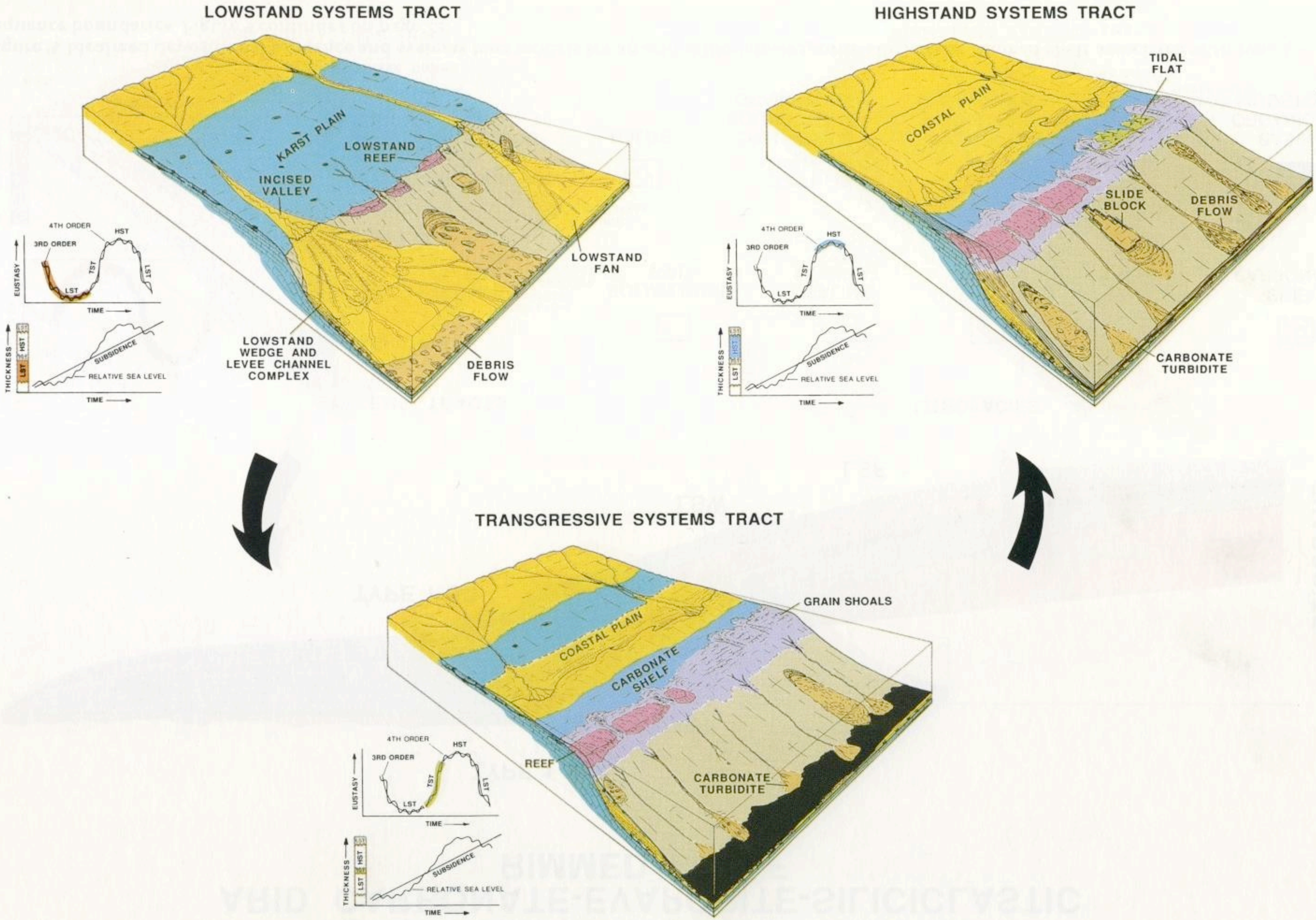
prominent seismic unconformities on record

may represent intensive and long-lasting marine erosion but triggered during a rise or highstand of relative sea level

Drowning surfaces

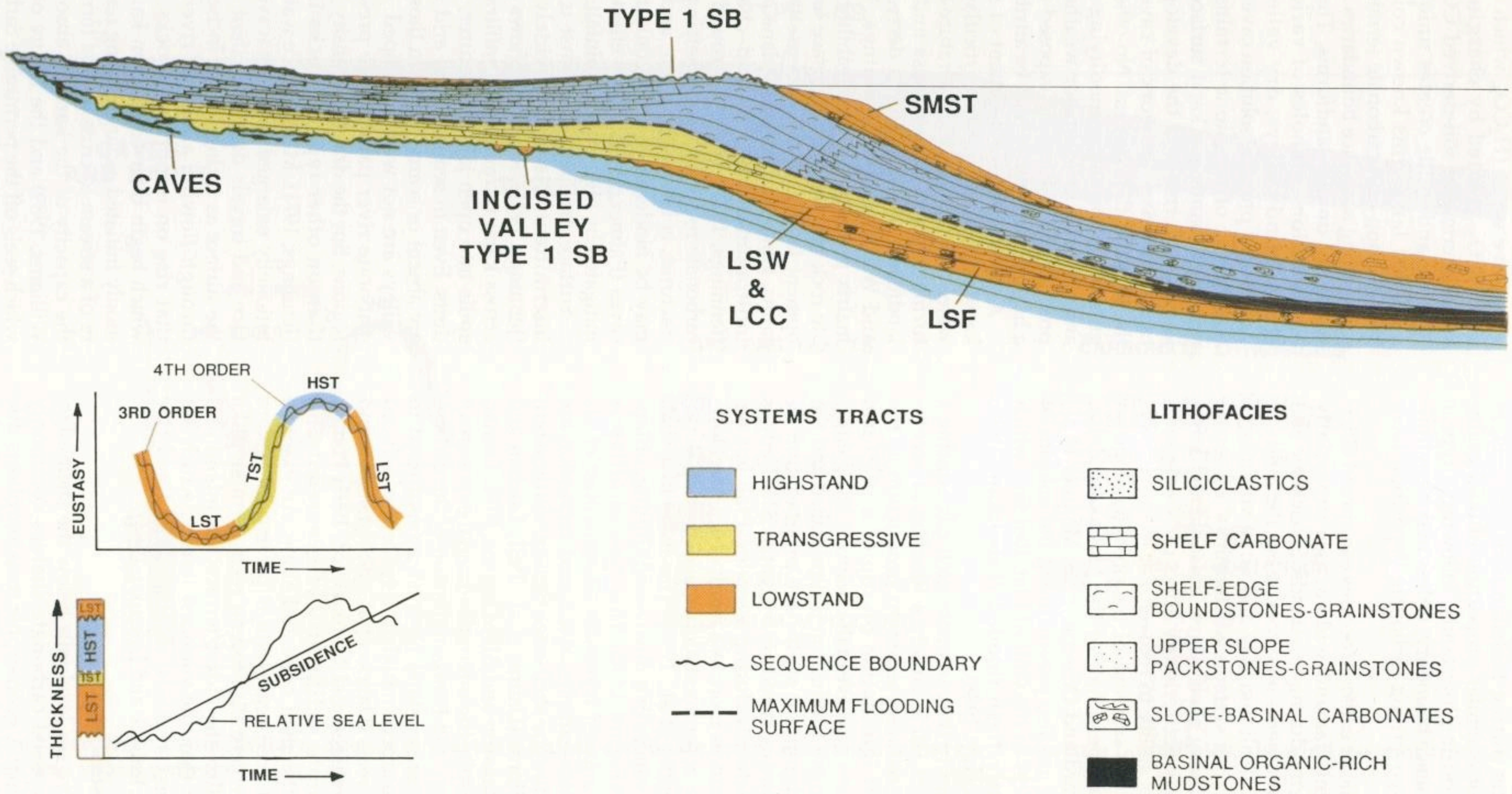


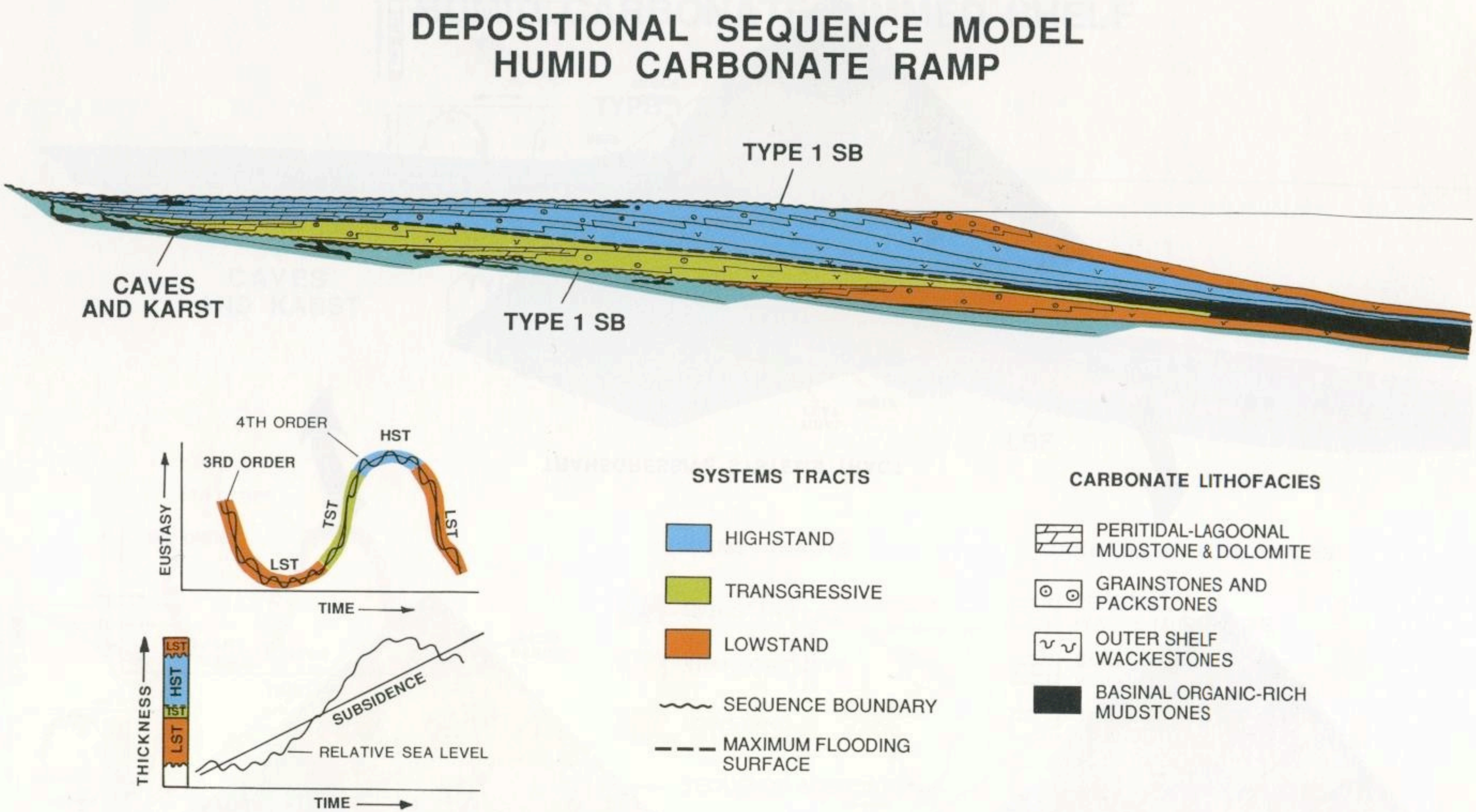
C
H1A
H1B
H1C
A
B
Patch Reefs
Lagoon
-250
-225
-200
-175
150
-125
-125
500 m
- 100 m
-260 m
155°51'33"W
20°2'14"N
20°1'44"N
20°1'14"N
20°0'44"N
Reef crest
Upper slope
500
1000
(m)
1500
-100
-125
-150
(m)
-200
-250
D



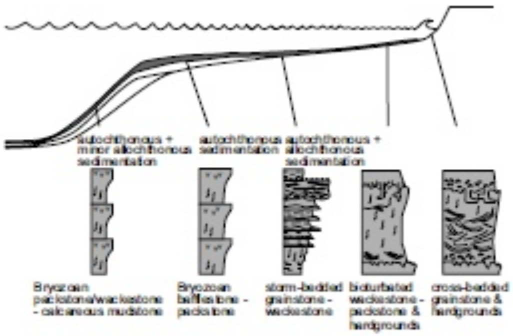
Carbonate-siliciclastic systems

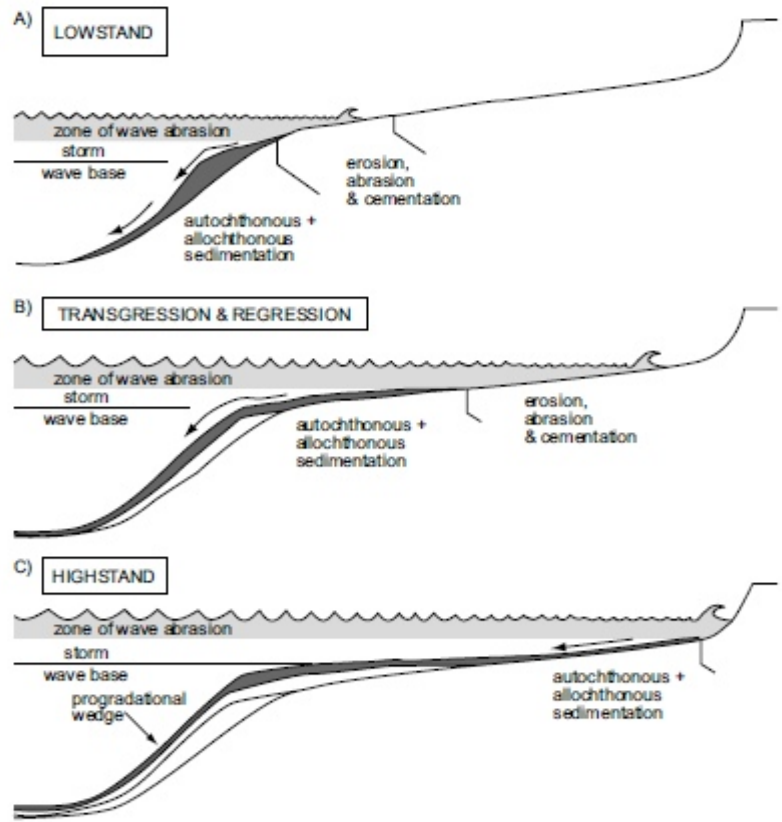
DEPOSITIONAL SEQUENCE MODEL
HUMID CARBONATE-SILICICLASTIC RIMMED SHELF




DEPOSITIONAL SEQUENCE MODEL
HUMID CARBONATE RAMP
TYPE 1 SB
CAVES AND KARST
TYPE 1 SB
4TH ORDER
HST
3RD ORDER
TST
LST
LST
EUSTASY
TIME
LST
HST
TST
LST
THICKNESS
SUBSIDENCE
RELATIVE SEA LEVEL
TIME
SYSTEMS TRACTS
HIGHSTAND
TRANSGRESSIVE
LOWSTAND
SEQUENCE BOUNDARY
MAXIMUM FLOODING SURFACE
CARBONATE LITHOFACIES
PERITIDAL-LAGOONAL MUDSTONE & DOLOMITE
GRAINSTONES AND PACKSTONES
OUTER SHELF WACKESTONES
BASINAL ORGANIC-RICH MUDSTONES

Cool-water carbonate systems





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Bosence, D.W.J. 2003. Sequence stratigraphy of carbonate depositional systems. The sedimentary record of sea-level change. The Open University, Cambridge UP.

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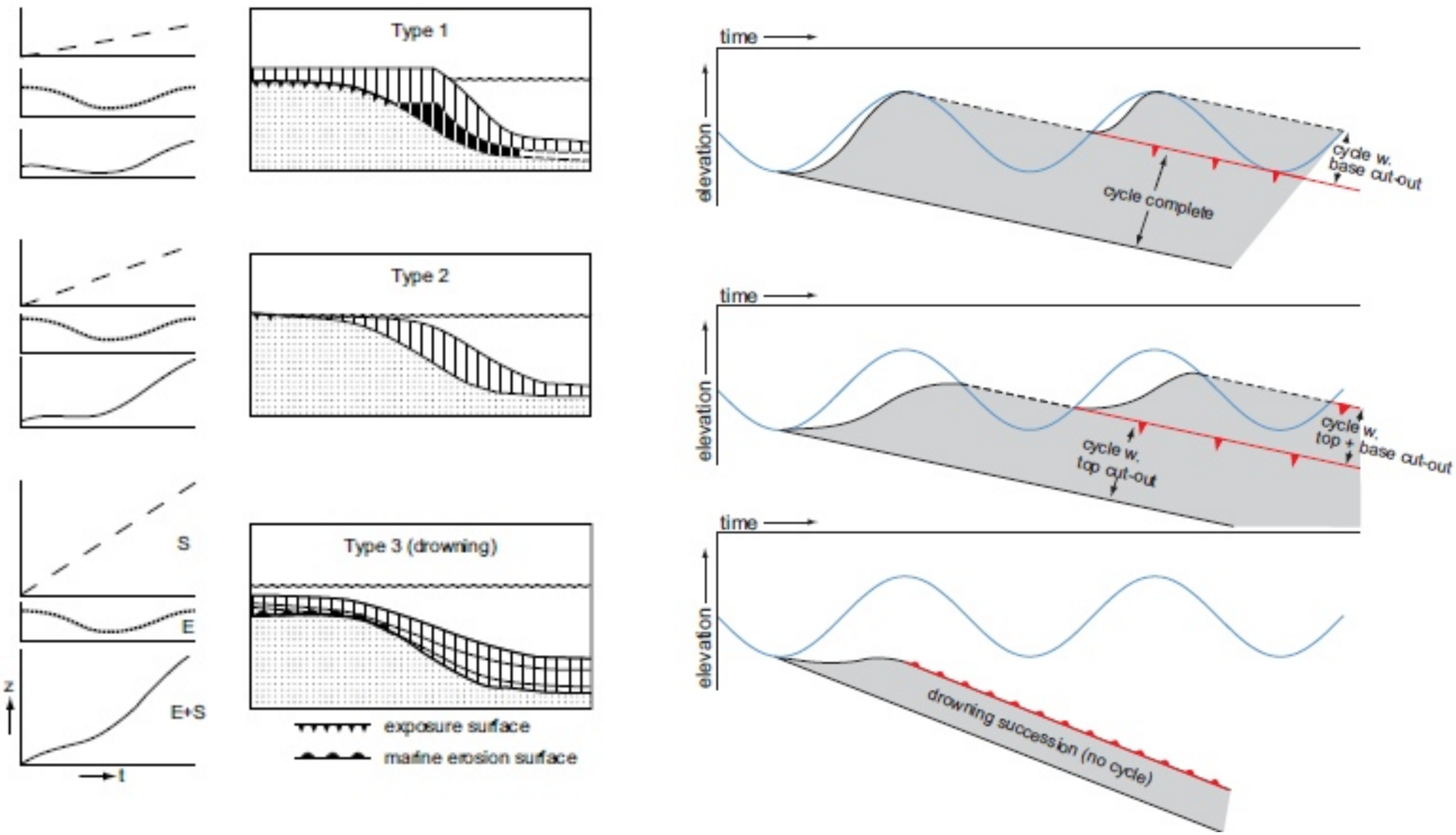

Type 1
Type 2
Type 3 (drowning)
S
E
E+S
z
t
exposure surface
marine erosion surface
time
elevation
cycle complete
cycle w. base cut-out
cycle w. top cut-out
cycle w. top + base cut-out
drowning succession (no cycle)