Makassar Straits environment interpretation using foraminifera and palynomorphs (emphasise clastic facies)

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Palynova
June 2011

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Makassar Straits environment interpretation using foraminifera and palynomorphs

1) Effects of 'Throughflow'
2) Sequence model
3) Microfossils and depositional environments
4) Logging techniques and eco-taxonomic groupings for foraminifera
5) Characterisation of depositional environments
   - Shelf environments
   - Slope environments
   - Carbonate dissolution issues
   - Delta front and delta plain, Mahakam Delta
6) Palynology and environments
   - Coastal plain and mangroves
   - Mangroves in temporal perspective
   - Upper coastal plain and lacustrine deposits
   - Coals

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1. Effects of 'Throughflow'

The sills between the Sulu Sea and the Pacific prevent deep cold Antarctic bottom water from entering the Makassar Straits. This prevents deep water foraminiferal associations associated with deep cold Antarctic water from entering the Straits, and consequently it is not possible to interpret water depths in deeper parts of the Straits using depth-related foraminifera (1500m- 2500m) in the manner used by micropalaeontologists in Pacific-type ocean-margin successions.

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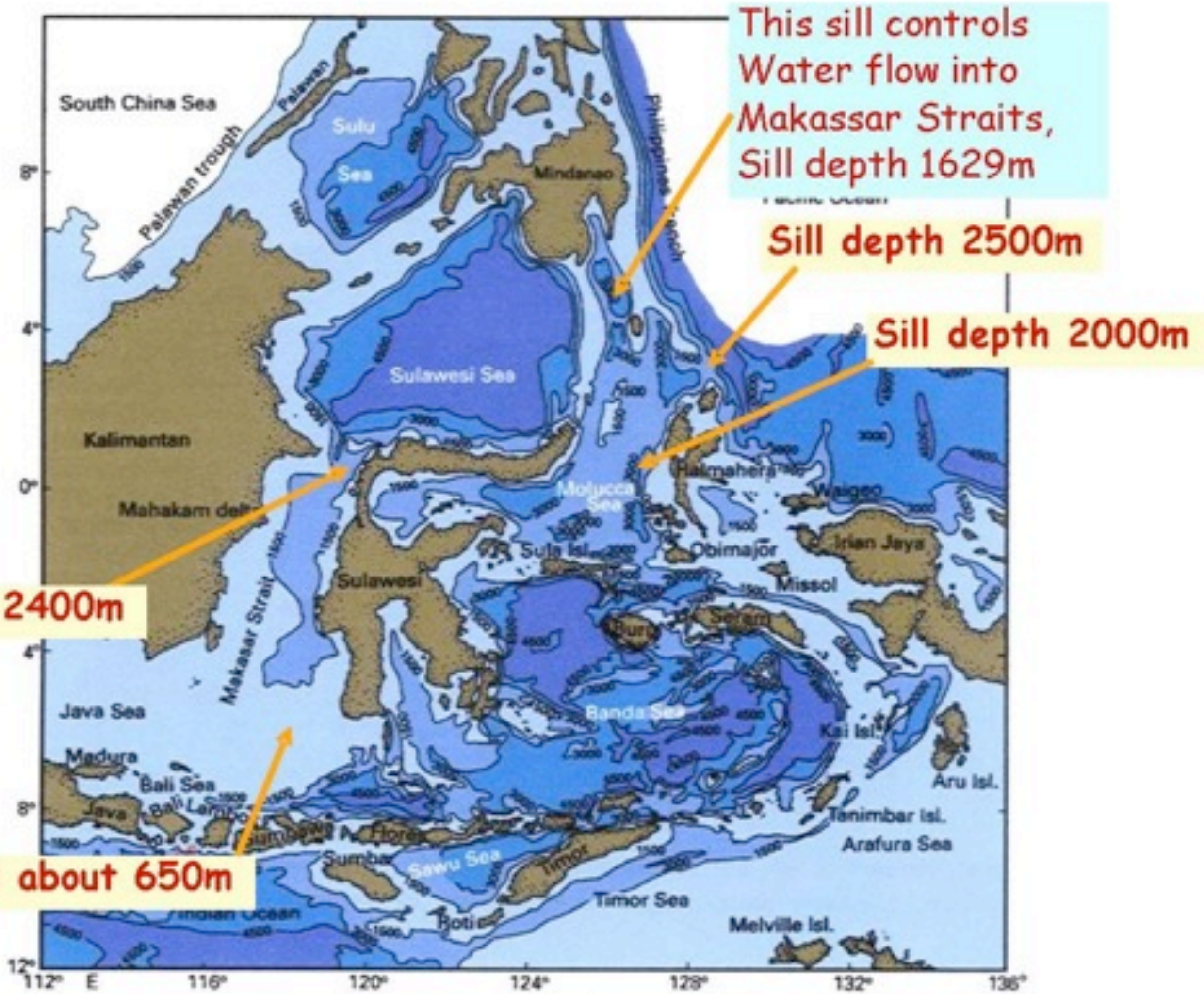
Note:
The water masses in Makassar Strait are derived from the Pacific, and controlled by the Mindanao sill, the Mangkalihat sill has no effect.



Subsea Topography in Areas of Indonesian Throughflow

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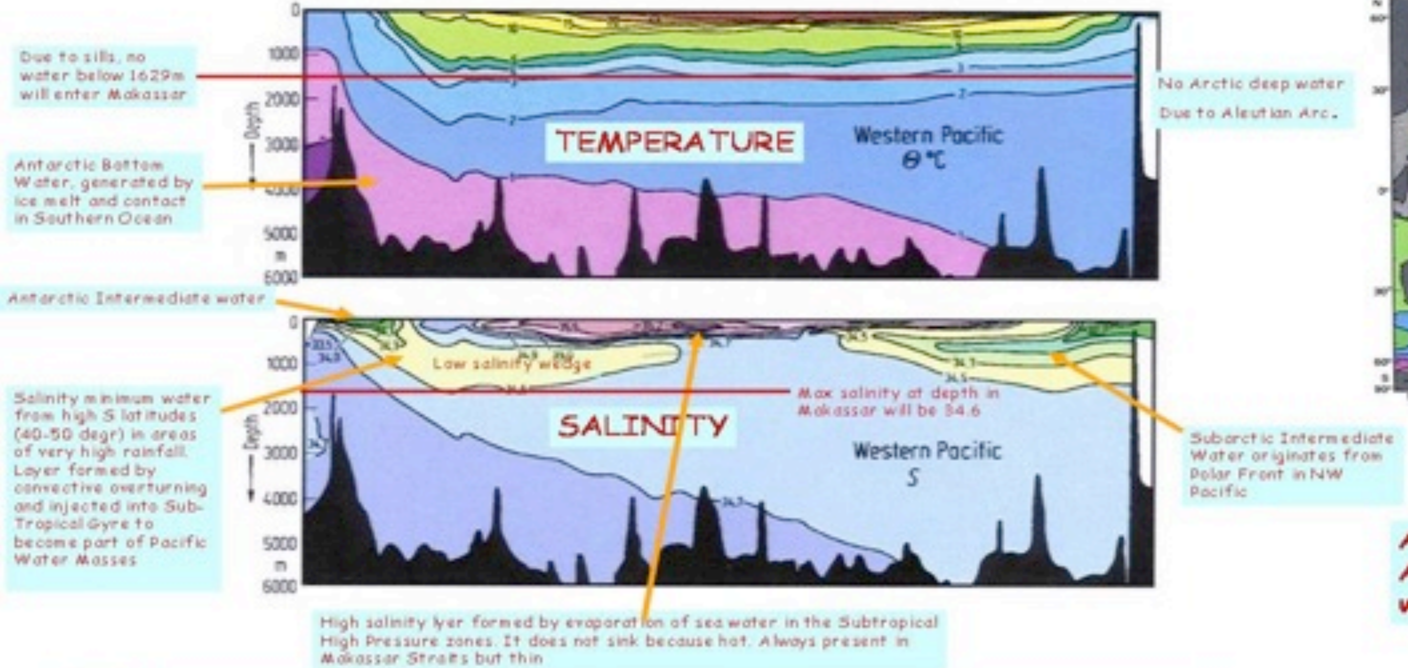

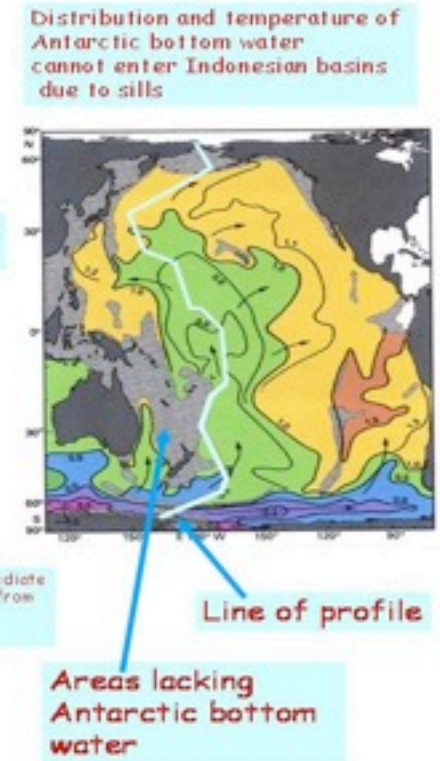

NOTES:
1) High and low salinity water masses are formed in the Pacific, but transported into Makassar by Indonesian Throughflow, without significant mixing from one layer to another
2) Polar-derived water layers retain their integrity over wide areas, so low salinity layer in Makassar Straits is derived from Antarctic Intermediate and Subarctic Intermediate water masses

Pacific Water Masses
N-S Profile Through Pacific

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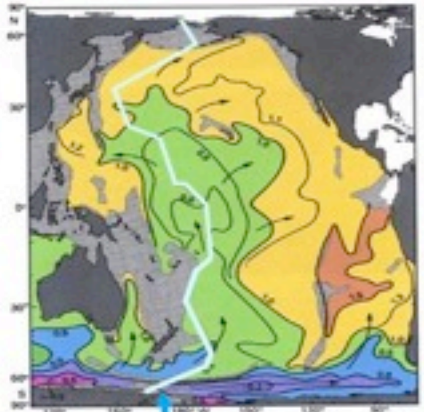
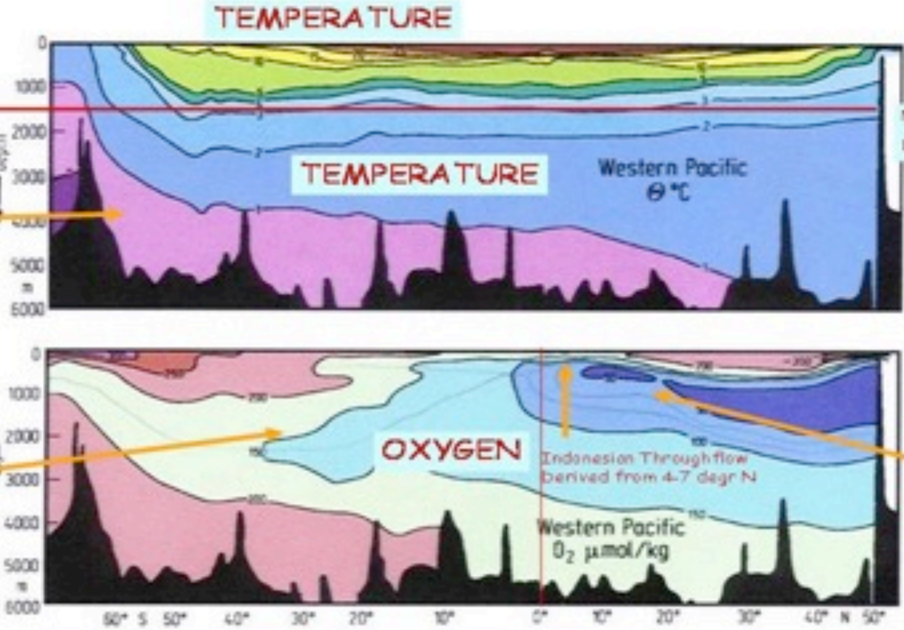
Distribution and temperature of
Antarctic bottom water
cannot enter Indonesian basins
due to sills



Line of profile



An oxygen-deficient layer is characteristic of each of the oceans, due to upwelling around their margins induced from surface winds, such as the Trades.
These are reflected in the fossil record by blooms of certain groups of foraminifera. Such blooms are not seen in Makassar since there is no upwelling, and no oxygen-minimum layer.

Pacific Water Masses
N-S Profile Through Pacific

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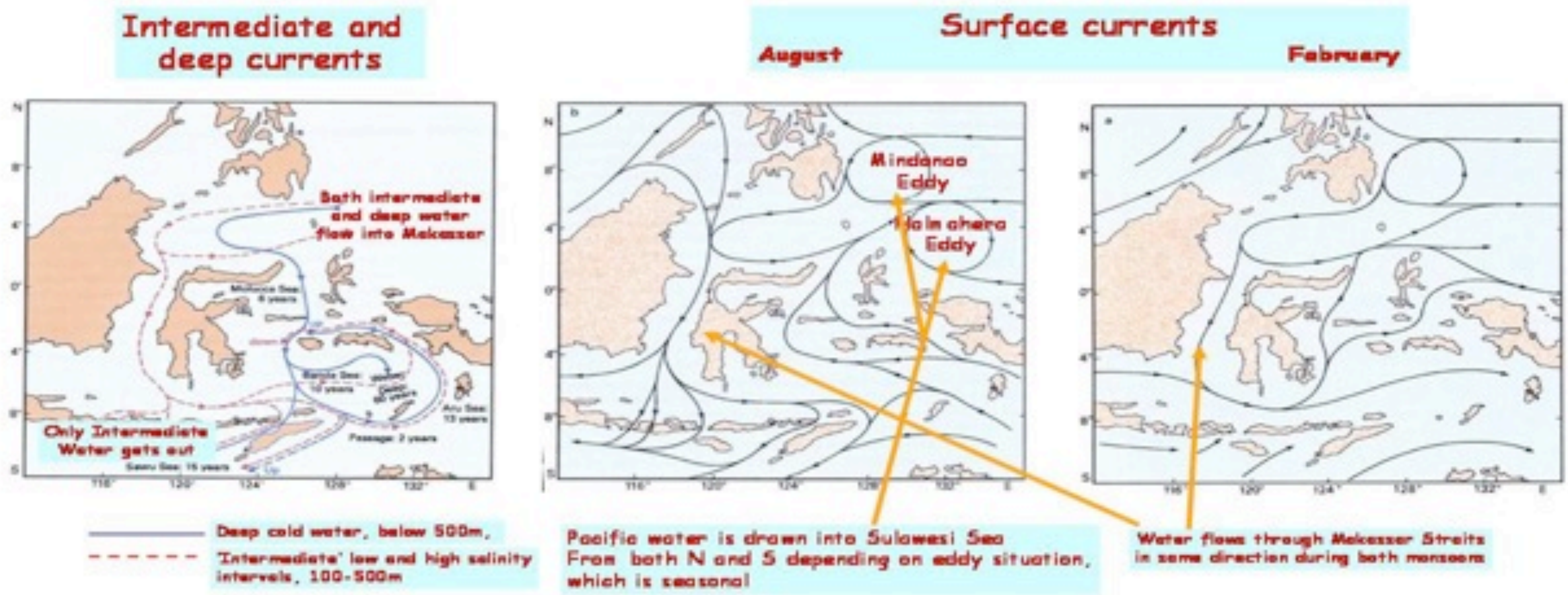

The Indonesian Throughflow

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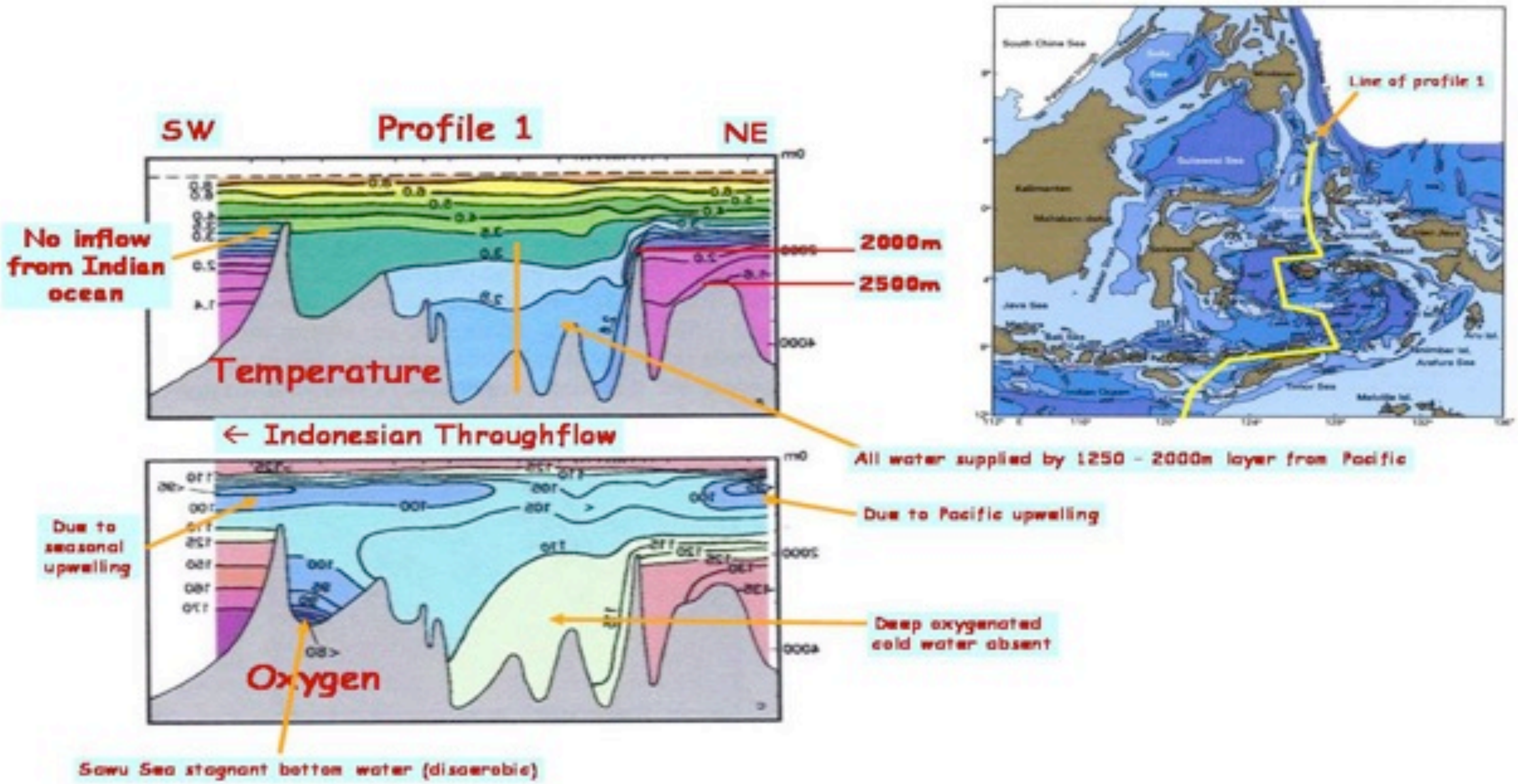
Temperature and oxygen profiles Across Banda Sea are a good proxy for Sulawesi Sea and Makassar Strait



Temperature and Oxygen Profiles
Across Banda Sea

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Mixed upper layer
Temp, ox and salinity homogenous above sharp salinity increase. T>25 degr; S<34.4pMil; Ox > 4m/L

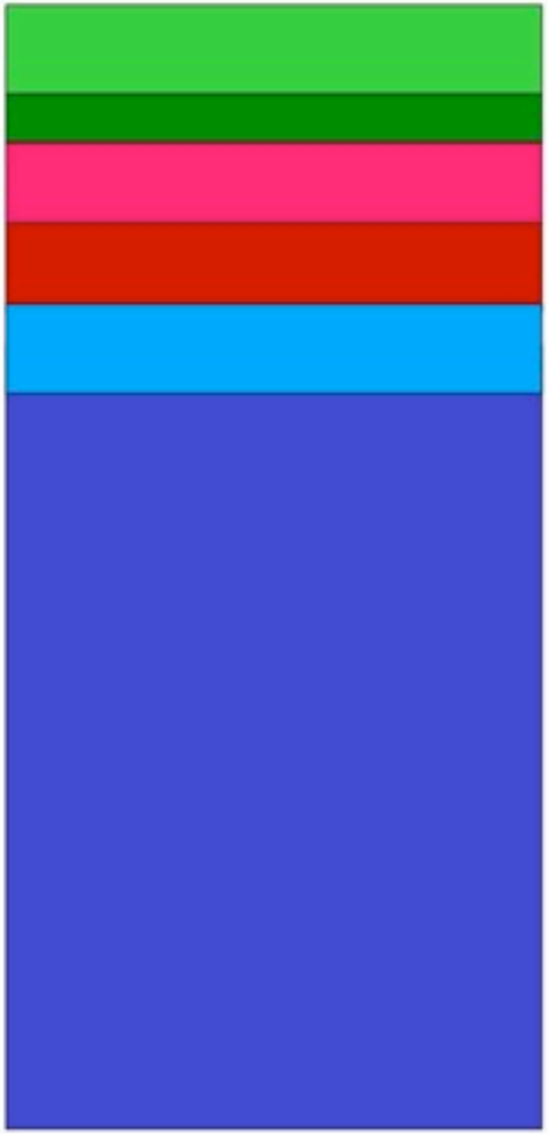
Barrier layer
Steep gradient toward higher salinities

High salinity layer
Relatively high salinities, higher than in any other layer, S>34.6pMl/L

Intermediate layer
Salinity about 35.6pMil, Ox about 3ml/L, temp gradient decreasing down to 12 degr

Low salinity layer
Salinity falls sharply to below 35.5pMil, steep temp gradient in upper part, less in lower part, decr to 8 degr at base

Sulawesi Sea deep water
Deep cold water, less than 8 degr, to 3.6 at base



Makassar Strait Water Masses

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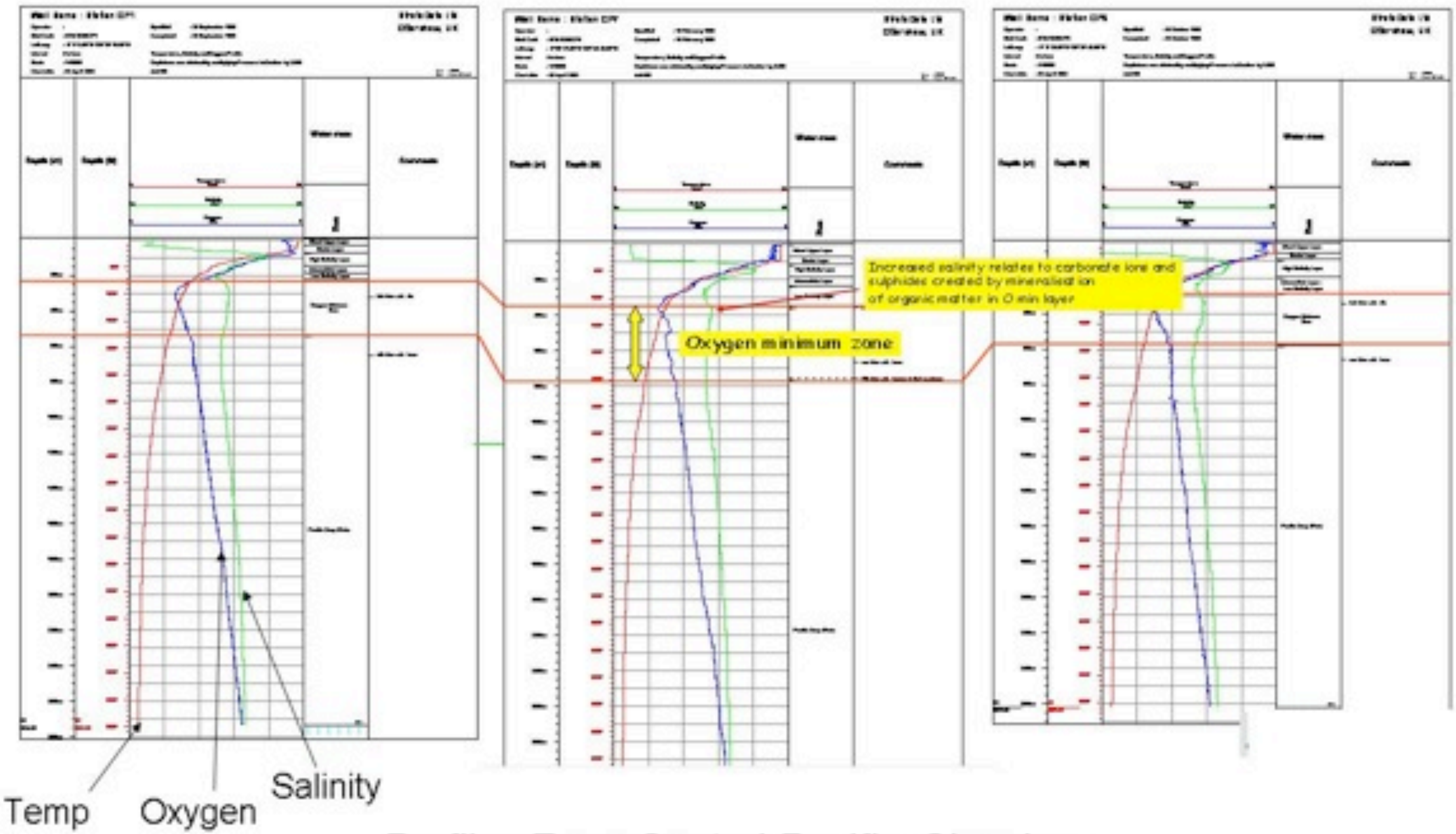

Profiles From Central Pacific, Showing Well Developed Oxygen Minimum Zone

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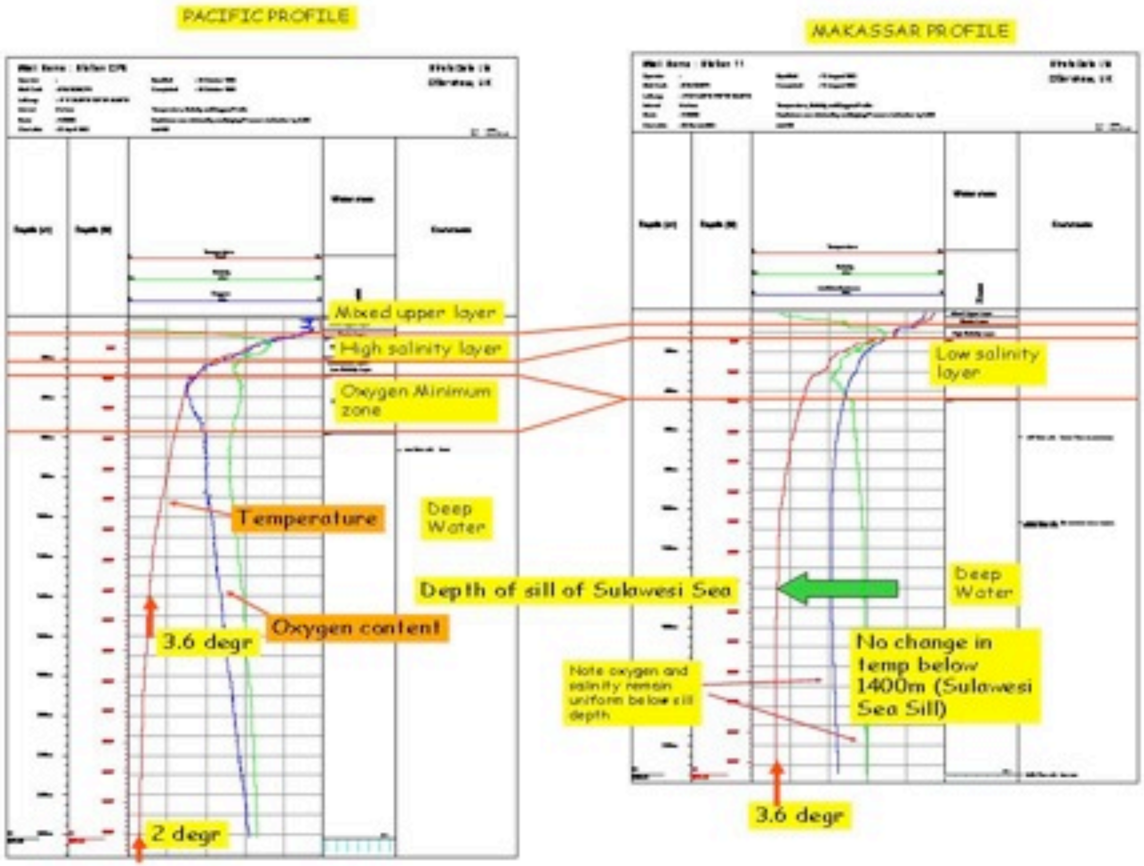
Comparison of Central Pacific water mass Profile and typical Profile from Makassar Strait

Note:
There are two major differences between Makassar Strait water masses and open ocean Pacific water masses:

1) There is no oxygen minimum zone within the Makassar Straits

2) Pacific 'Deep Water' gets increasingly cold with depth due to replenishment from cold Antarctic surface waters.
Due to the Sulawesi Sea sill at 1400m, Pacific water below this depth cannot circulate via the Indonesia throughflow, and so water colder than 3.6 degr cannot enter Makassar Straits. Makassar water temps below 1400m are therefore uniform at 3.6 degr, regardless of water depth.



Comparison of Central Pacific
Water Mass Profile Makassar Strait

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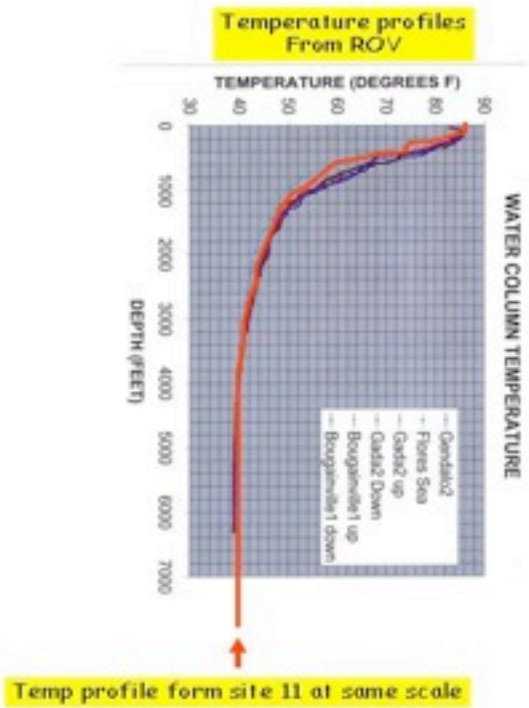
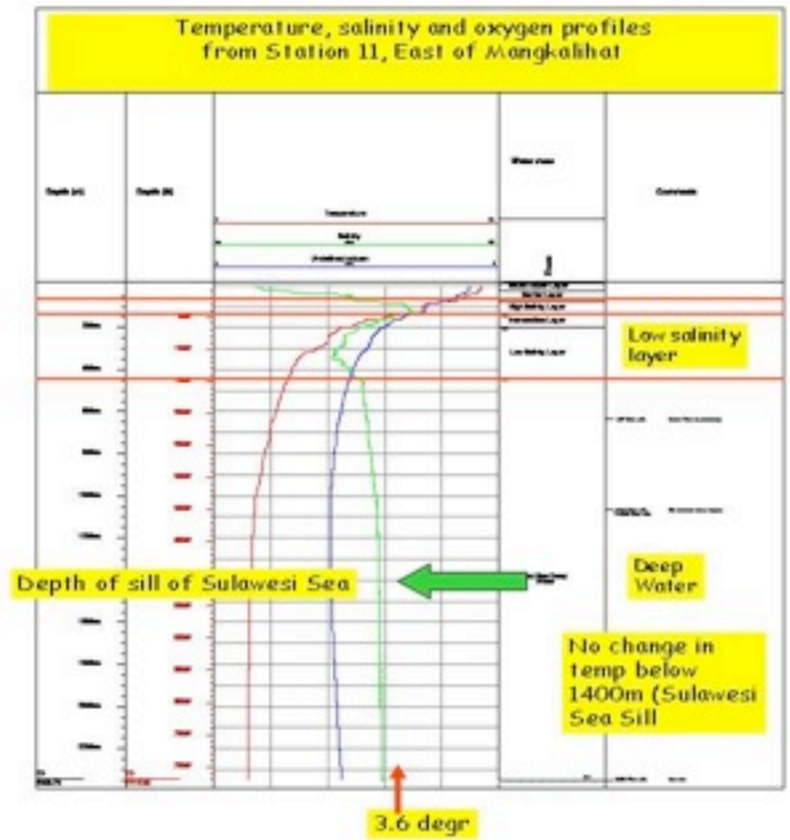

Temperature profiles
From ROV
TEMPERATURE (DEGREES F)
30 40 50 60 70 80 90
WATER COLUMN TEMPERATURE
DEPTH (FEET)
0 1000 2000 3000 4000 5000 6000 7000
Flores Sea
Bougainville1 up
Bougainville1 down
Temp profile form site 11 at same scale


Temperature, salinity and oxygen profiles
from Station 11, East of Mangkalihat
Low salinity
layer
Depth of sill of Sulawesi Sea
Deep
Water
No change in
temp below
1400m (Sulawesi
Sea Sill
3.6 degr

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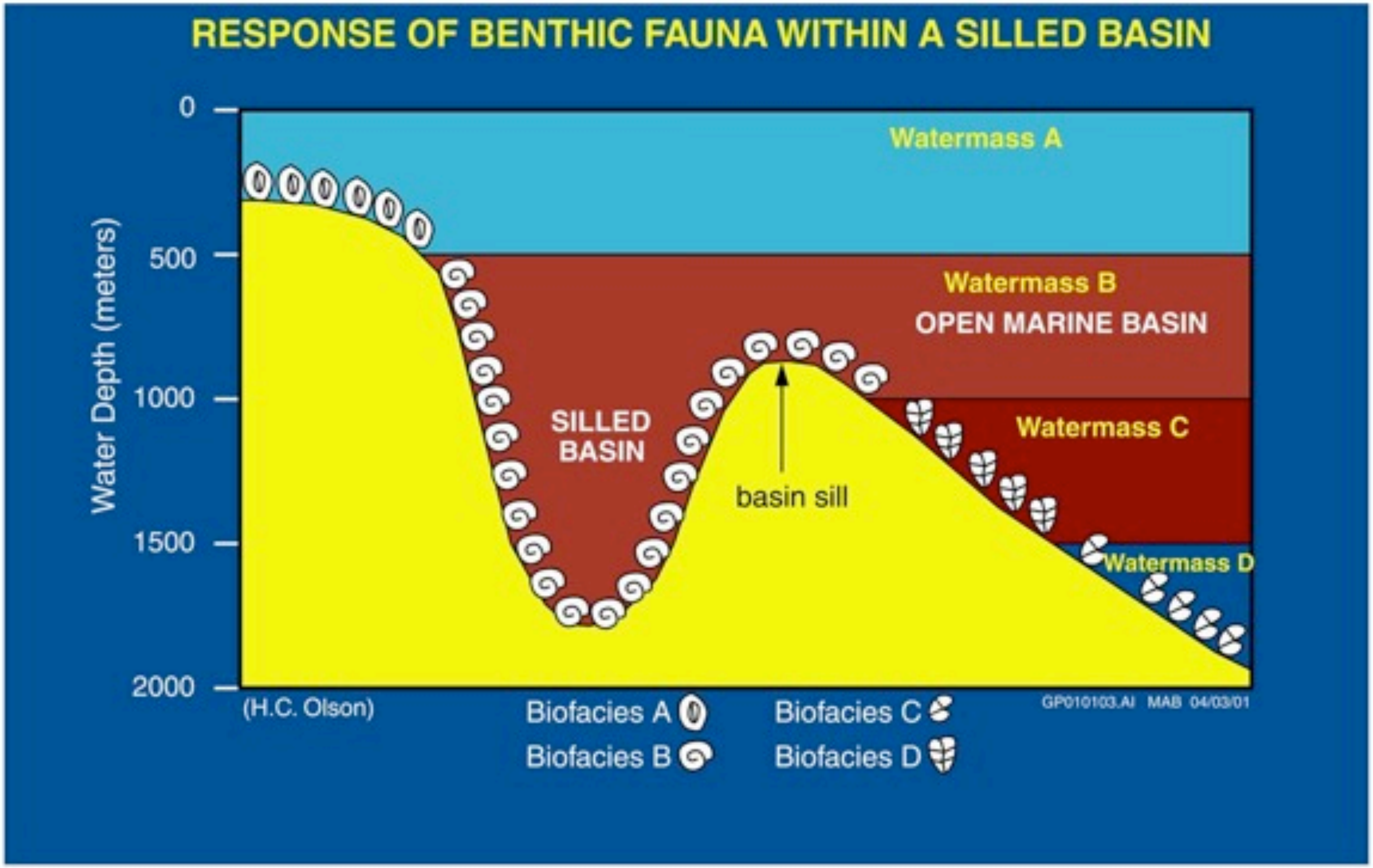
RESPONSE OF BENTHIC FAUNA WITHIN A SILLED BASIN
Water Depth (meters)
0
500
1000
1500
2000
Watermass A
Watermass B
OPEN MARINE BASIN
Watermass C
Watermass D
SILLED BASIN
basin sill
(H.C. Olson)
Biofacies A
Biofacies B
Biofacies C
Biofacies D
GP010103.AI MAB 04/03/01

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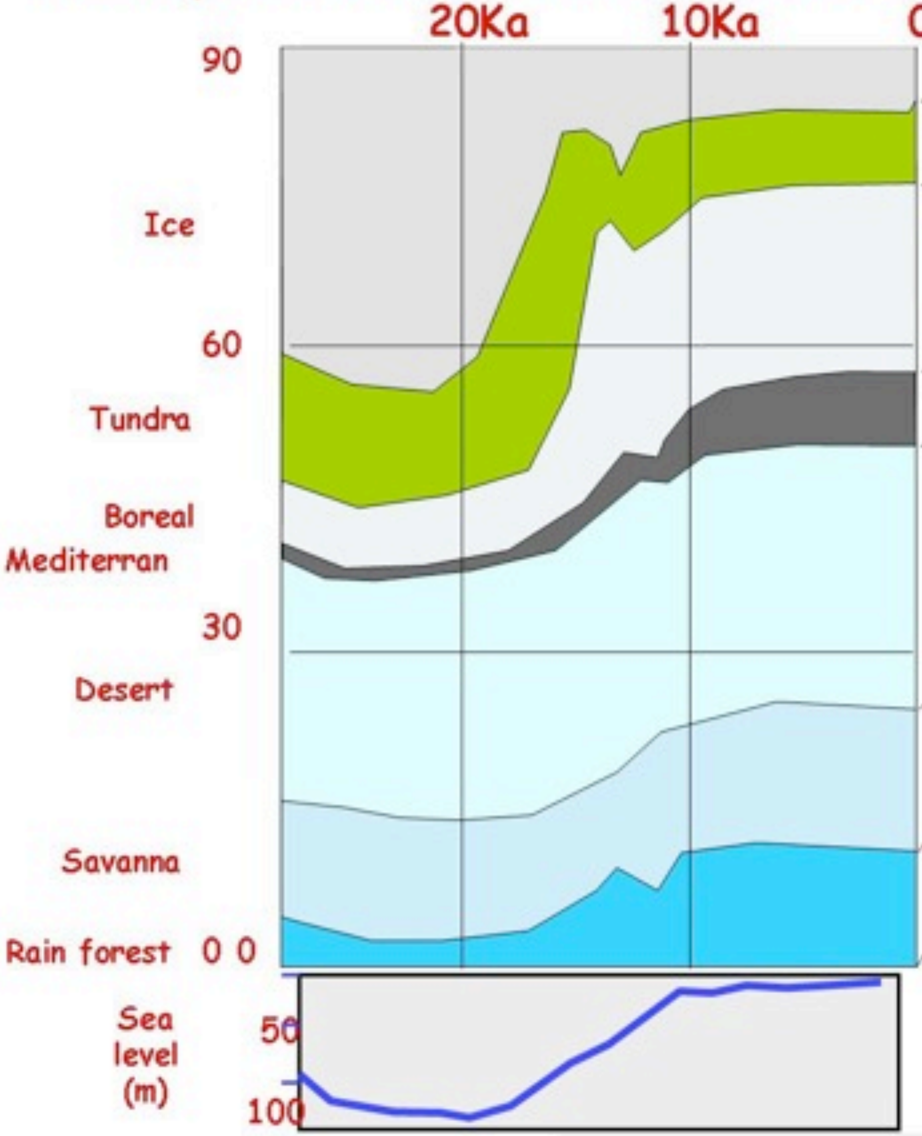
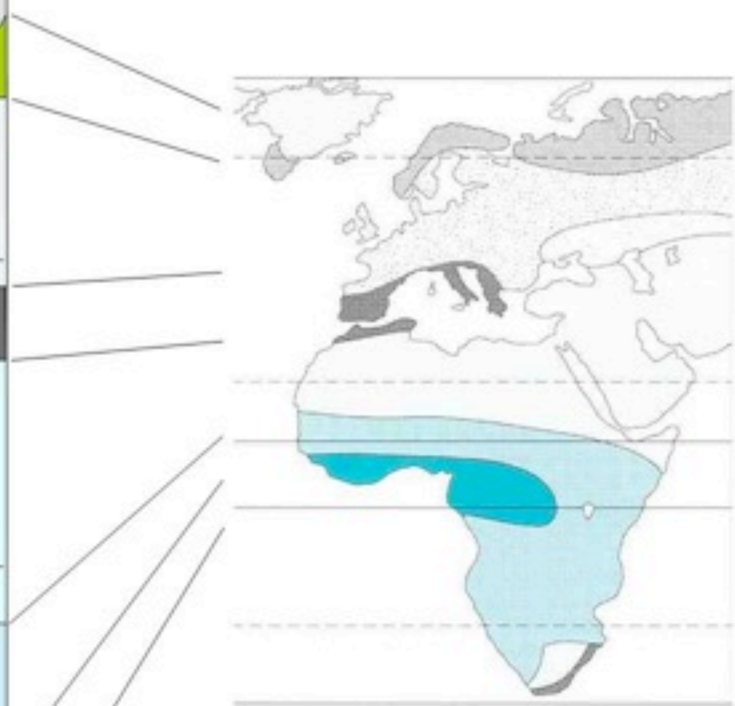
Sea level change and climate change – background

Correspondence of sea level and climate change since last glaciation



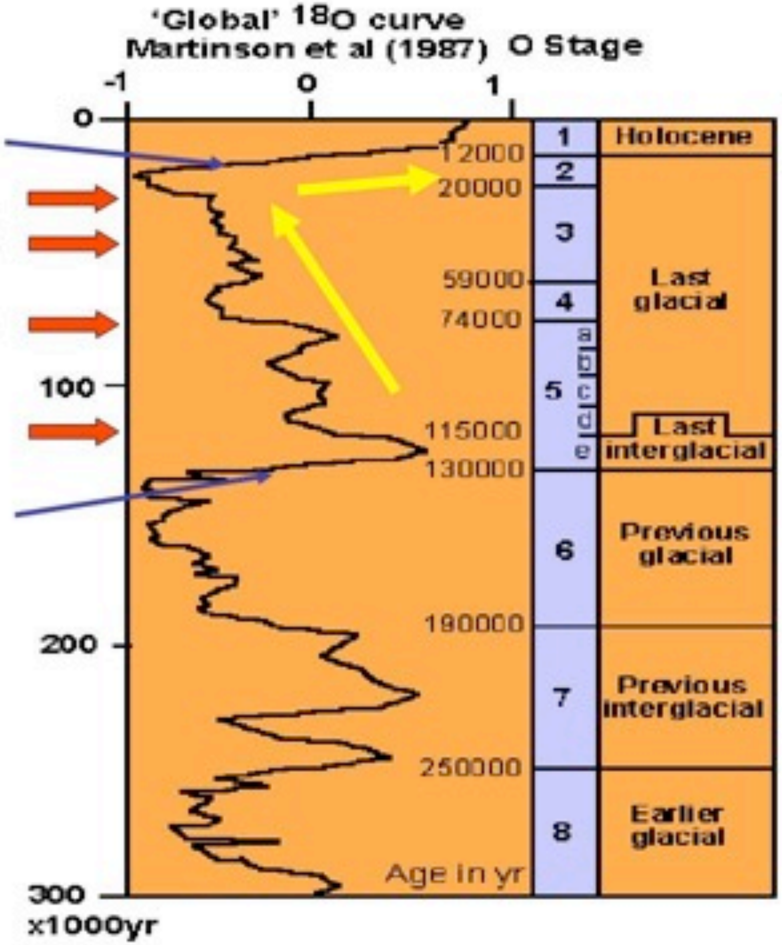


Sea level rise and fall

Termination

Sb?
Sb?
Sb?
Sb?

Termination



Very rapid sea level rise

Irregular but gradual sea level fall

Can be viewed in terms of transgressive and 'falling stage' systems tracts

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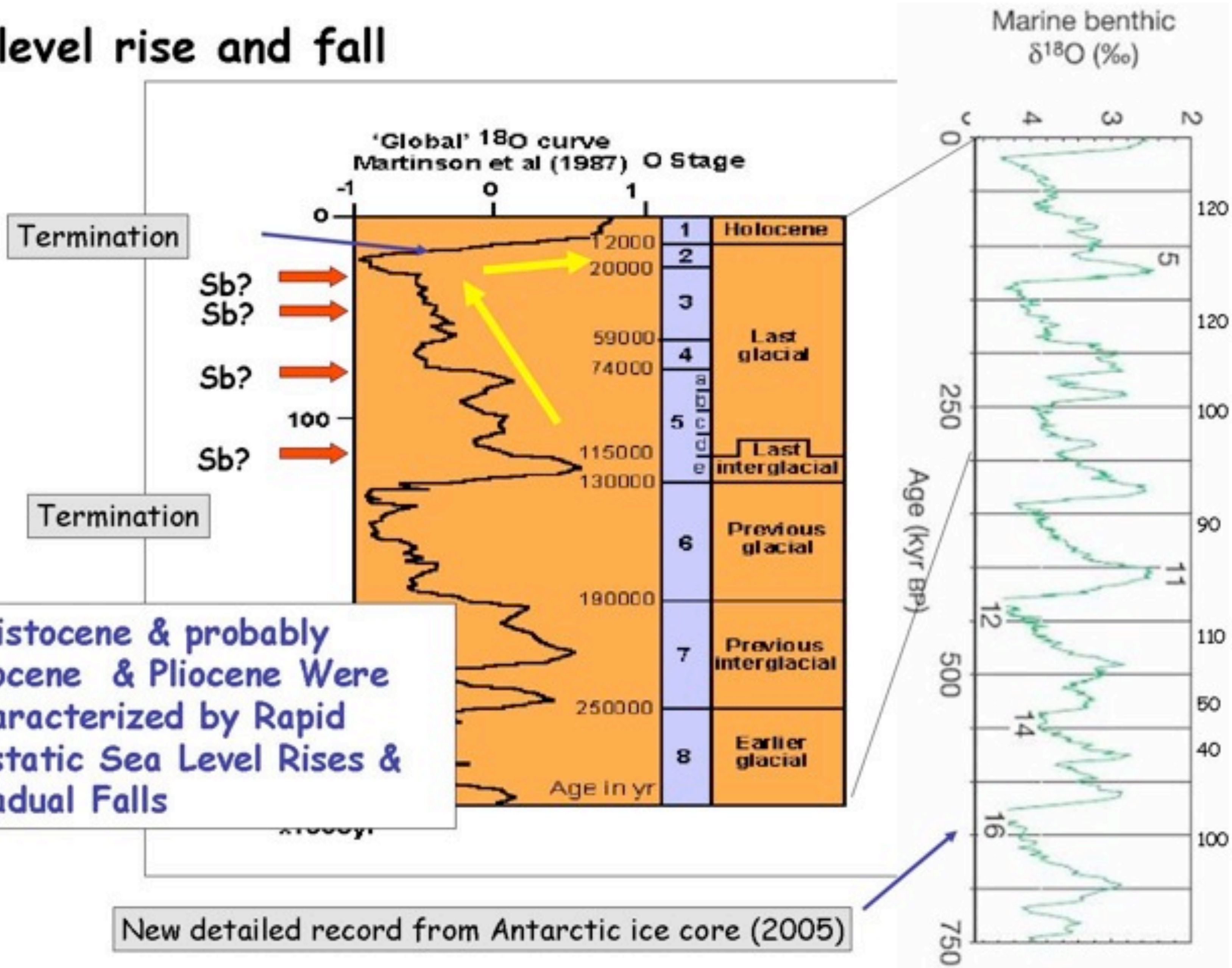
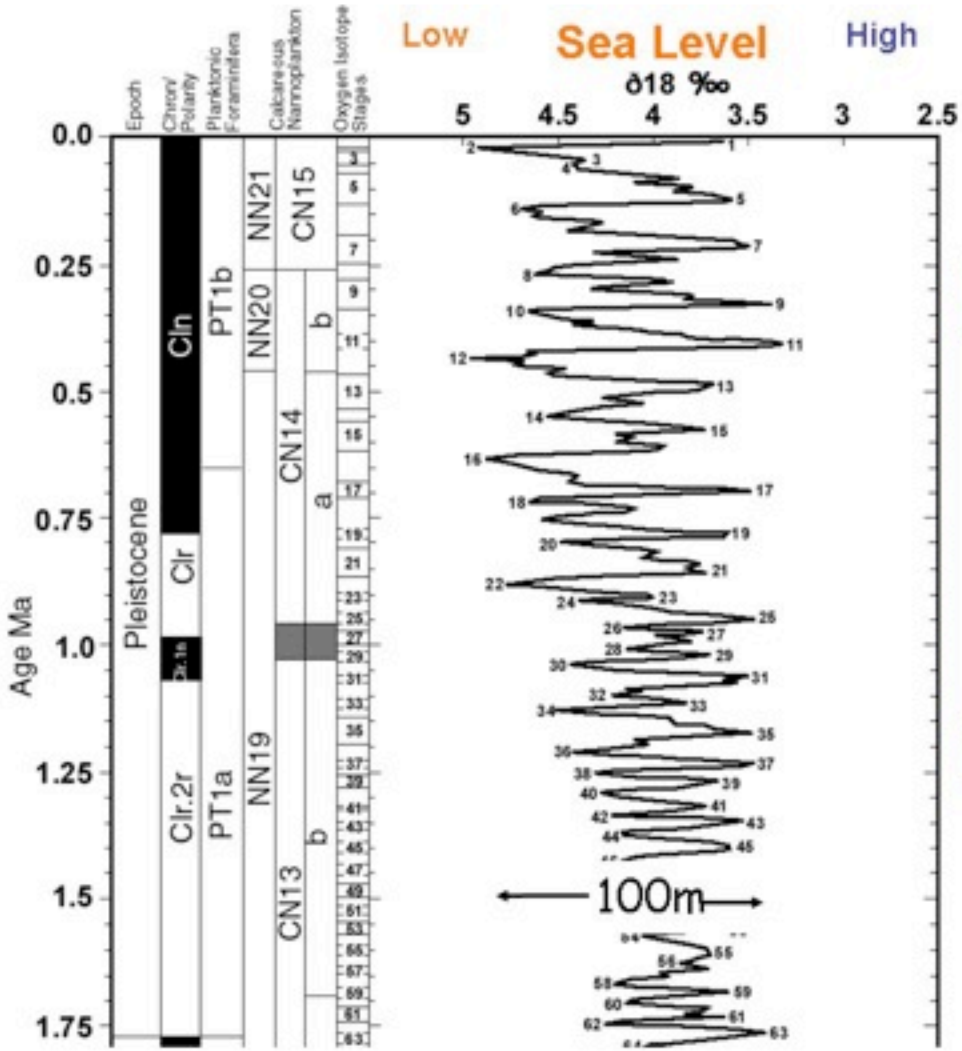
Sea level rise and fall

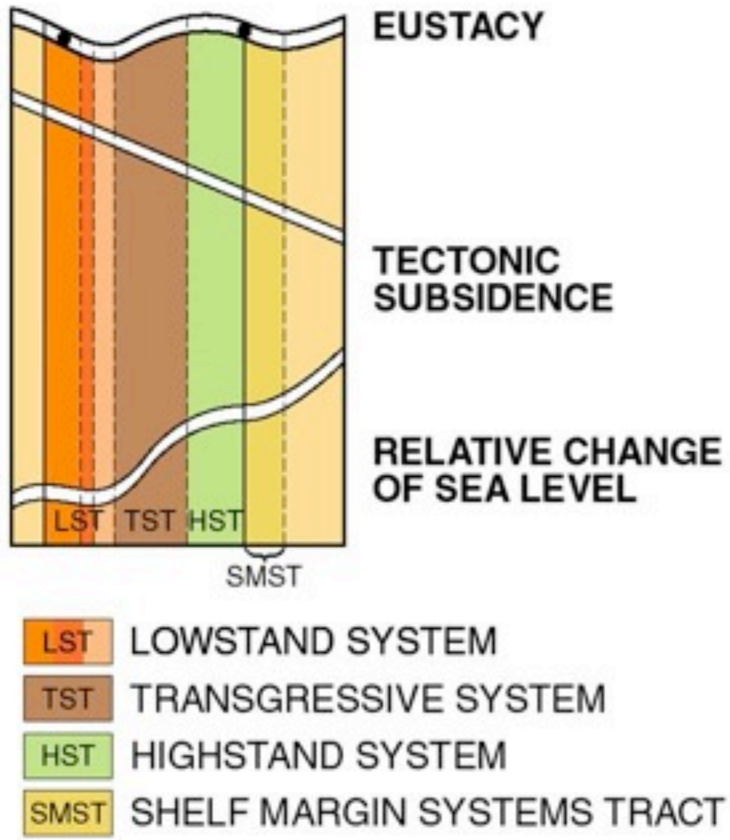


Pleistocene & probably Miocene & Pliocene Were Characterized by Rapid Eustatic Sea Level Rises & Gradual Falls

New detailed record from Antarctic ice core (2005)

"Slug" Model is based (in part) on approx. Sinuous Model for Eustatic Sea-Level Fluctuations





(from Vail et al and Van Wagoner et al, 1998)

Sea level rise and fall

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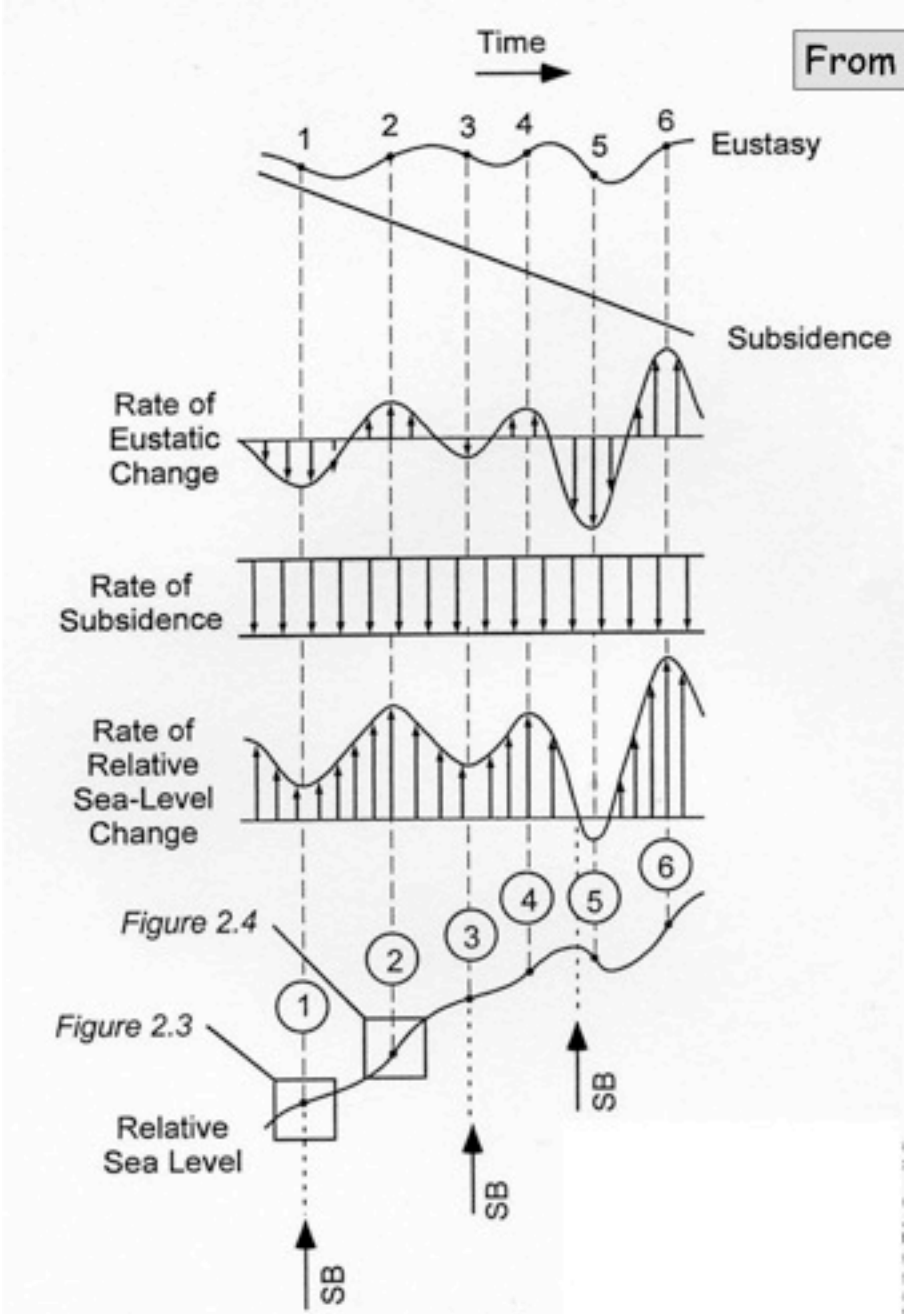
From Posementier and Allen 1999



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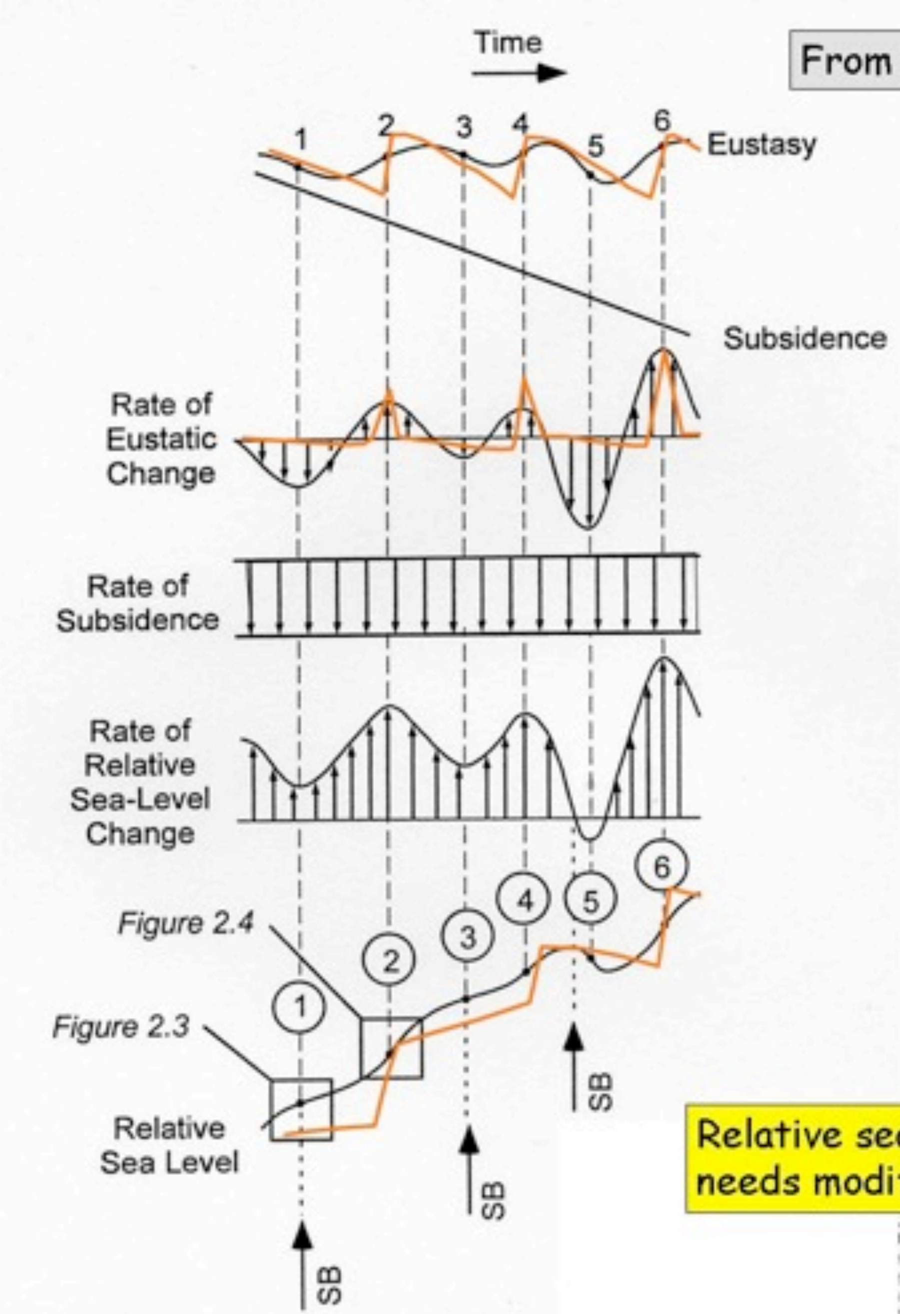

From Posementier and Allen 1999

Relative sea level model needs modification

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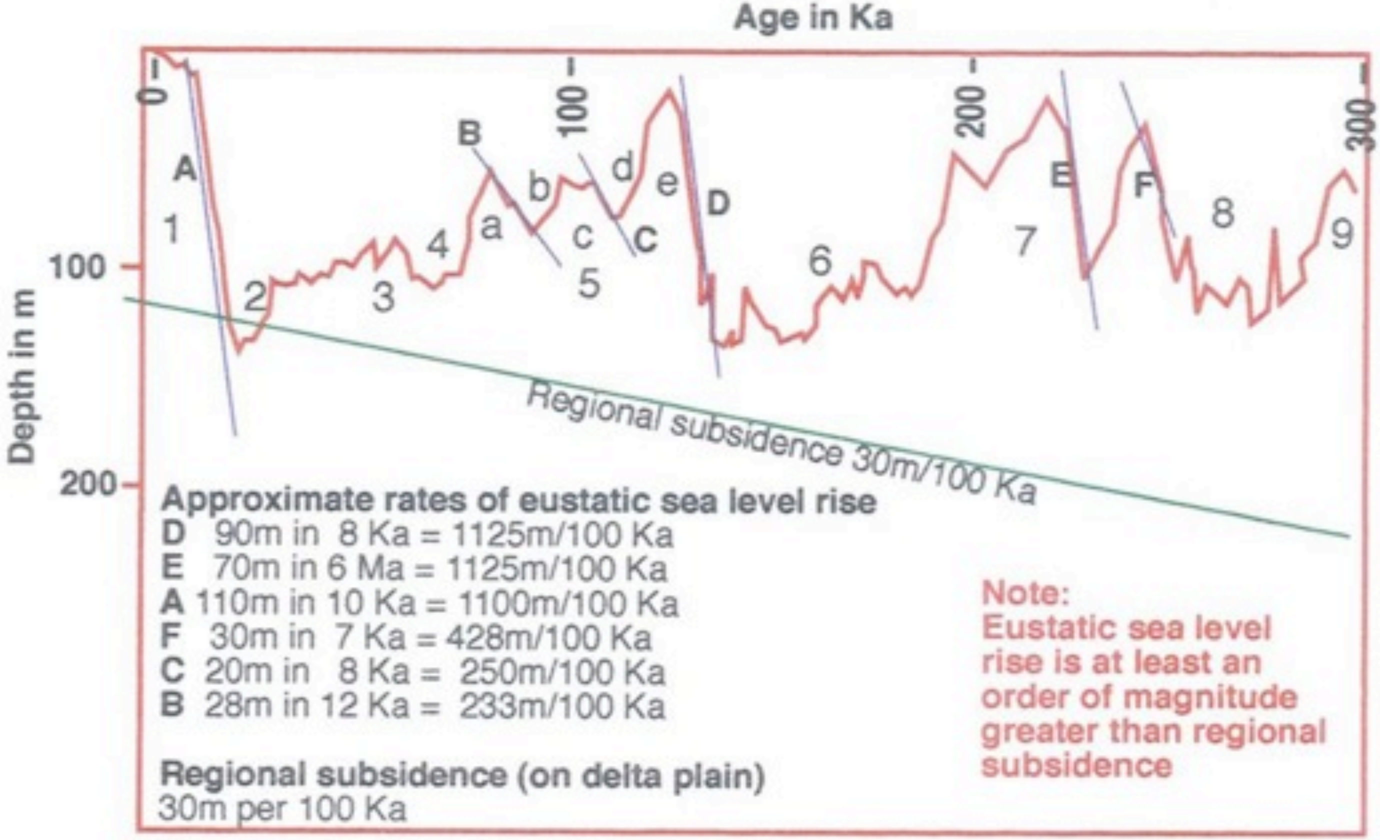
9.a Sequence biostratigraphy



Comparison of creation of accomodation space through regional subsidence, and sea level rise

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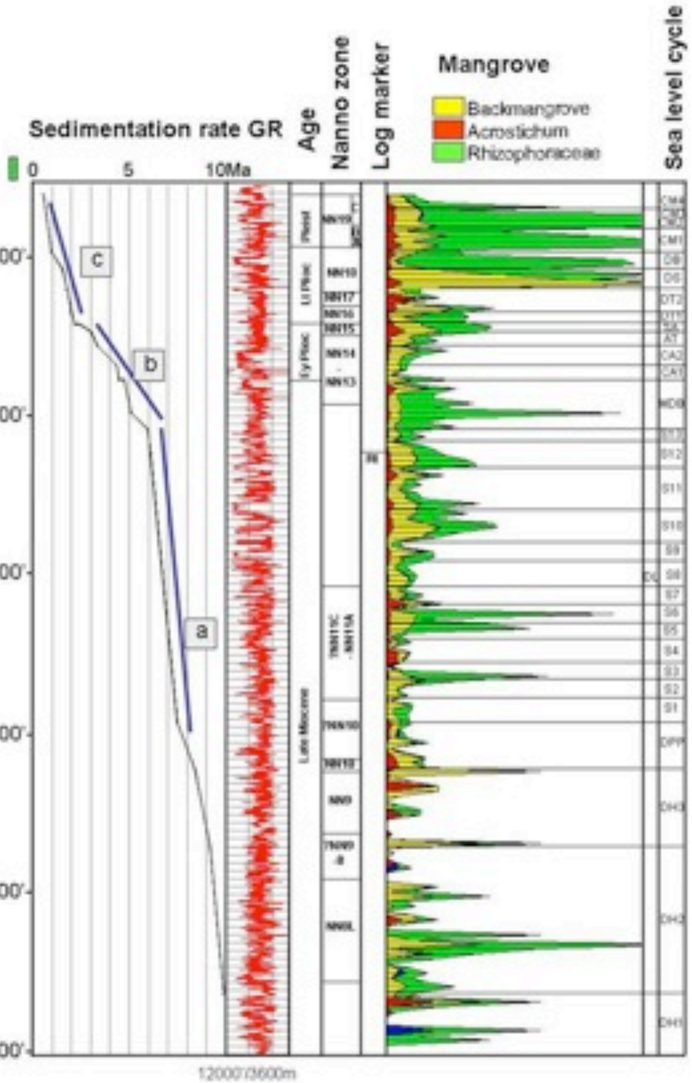
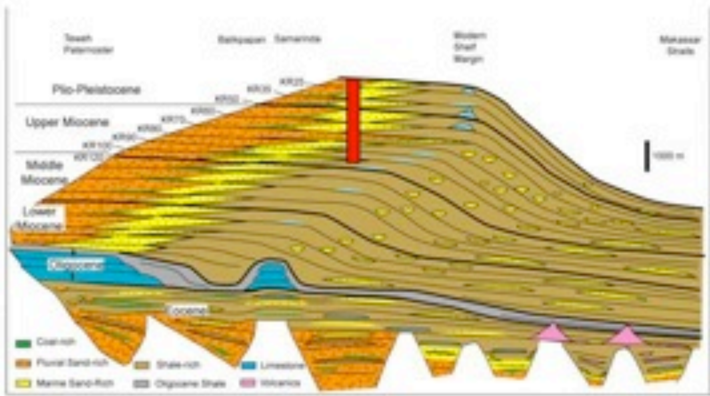
Sea level change and the palynological record

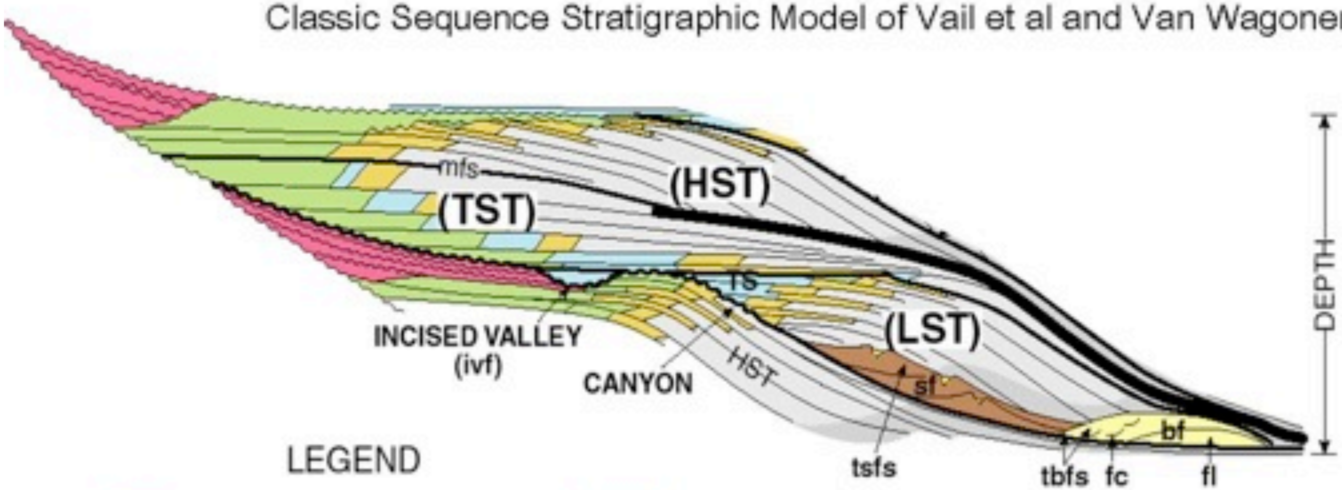
Attaka well, Mahakam Delta (Morley and Morley 2010)



Mangrove pollen acmes approximately reflect frequency and extent of rapid sea level rises over Late Miocene to Pleist



Classic Sequence Stratigraphic Model of Vail et al and Van Wagoner et al. (1988)



LEGEND

- Alluvial
- Coastal Plain
- Estuarine/Fluvia
- Shoreface/Deltaic Sands
- Marine Silt,
- Marine
- Deep-Water Sands

Modified from
Vail et al (1988)
Van Wagoner et al (1988)

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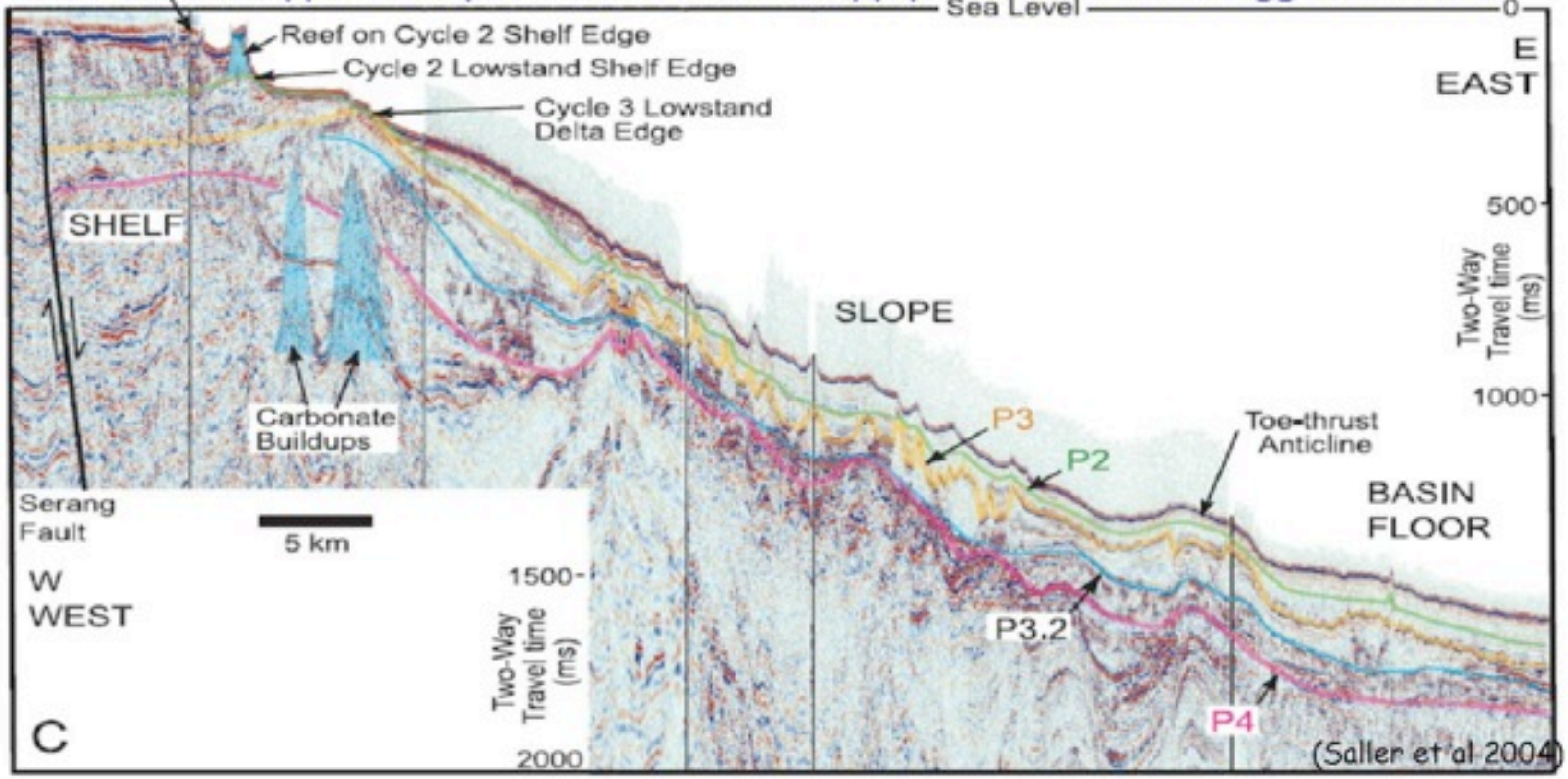
Kutei Basin typical sequence, sediment supply = subsidence, aggradational



24 Linked Lowstand Delta to Basin-Floor Fan Deposition, Offshore Indonesia

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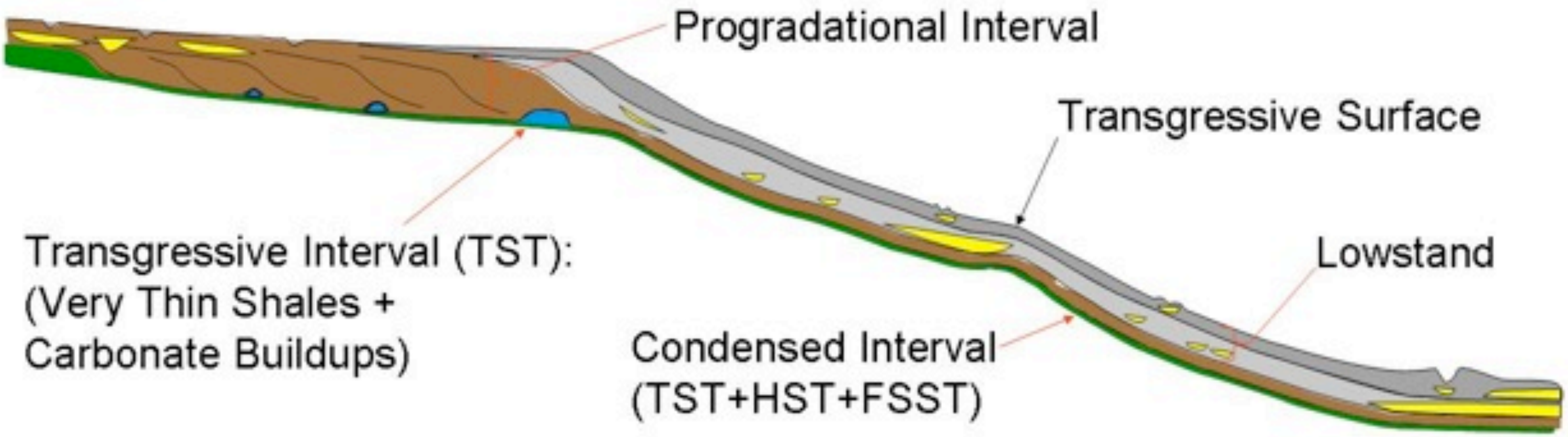

Differences with the classic “Vail et al” sequence stratigraphic model include

- Stratal Patterns are dominated by Progradation on the Shelf.
- No Onlapping Packages on the Slope

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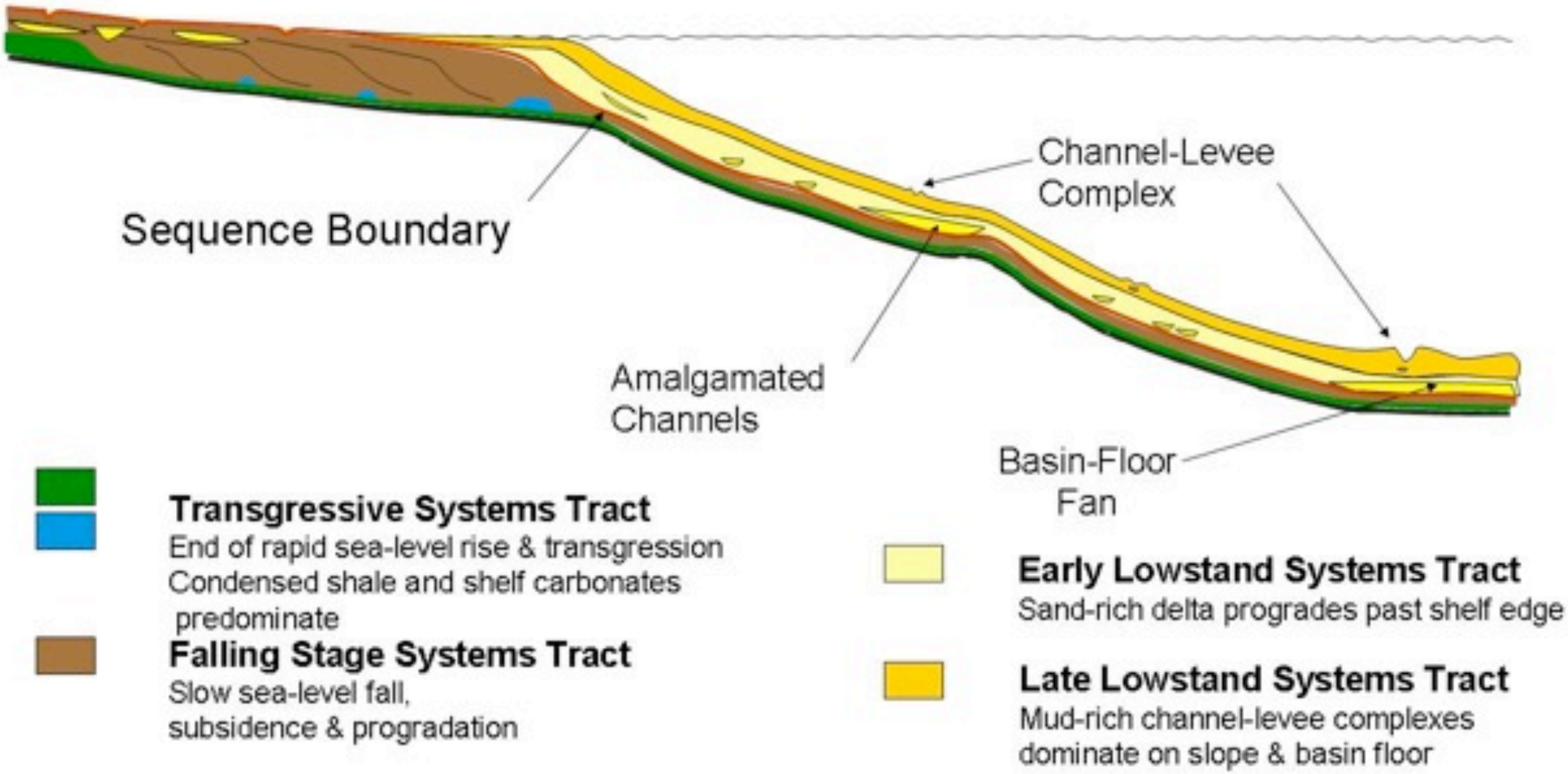
Classic Sequence Framework



- Kutei Basin Strata can be put into a Classic Sequence Stratigraphic Framework,
- However, It is awkward because Sequence Boundaries are Difficult to Recognize ***on the shelf, and Correlate from Shelf to Basin***
- Sequence Boundaries Must Pass through Prograding Clinoforms

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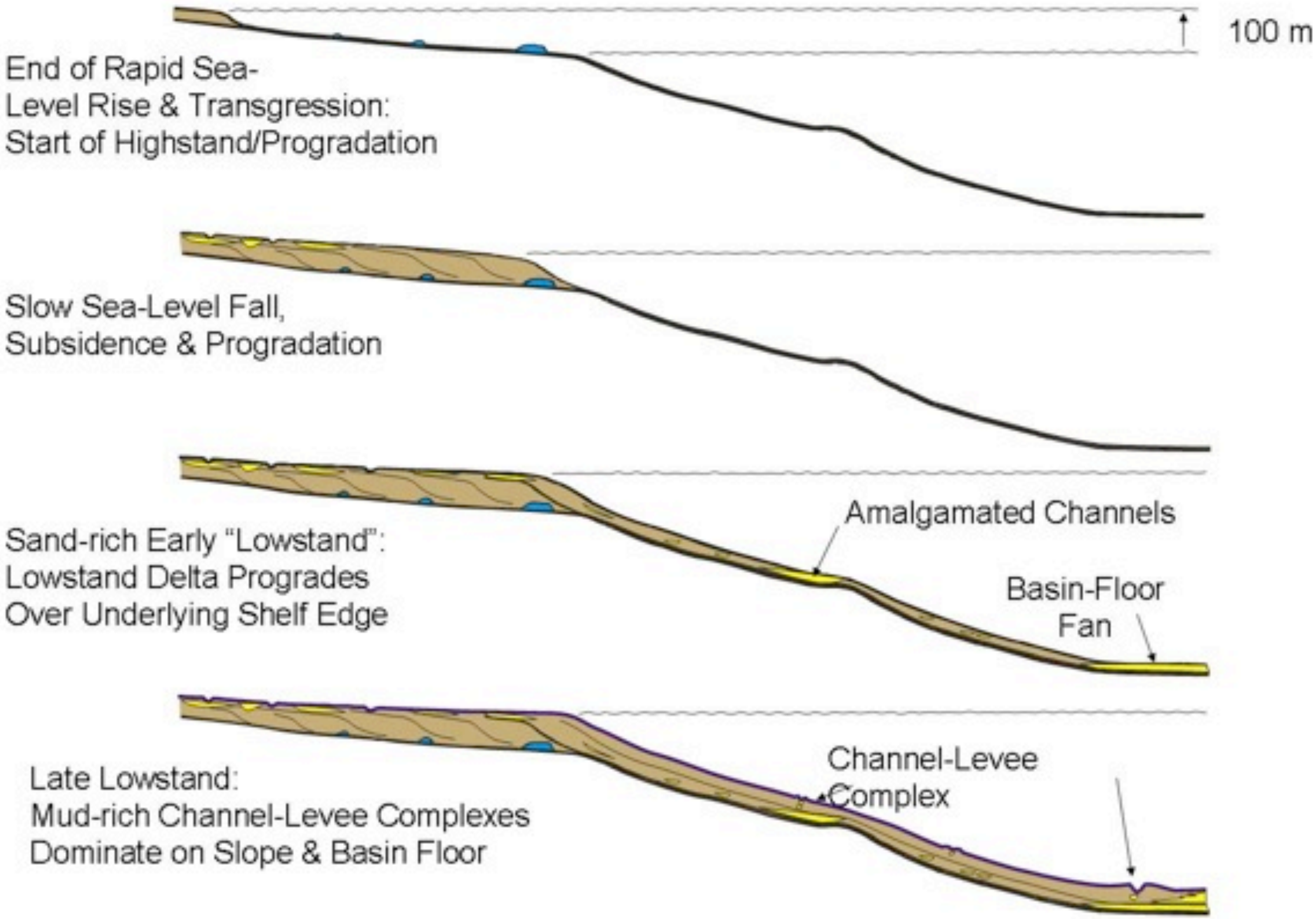

100 m
End of Rapid Sea-
Level Rise & Transgression:
Start of Highstand/Progradation
Slow Sea-Level Fall,
Subsidence & Progradation
Sand-rich Early "Lowstand":
Lowstand Delta Progrades
Over Underlying Shelf Edge
Amalgamated Channels
Basin-Floor
Fan
Late Lowstand:
Mud-rich Channel-Levee Complexes
Dominate on Slope & Basin Floor
Channel-Levee
Complex

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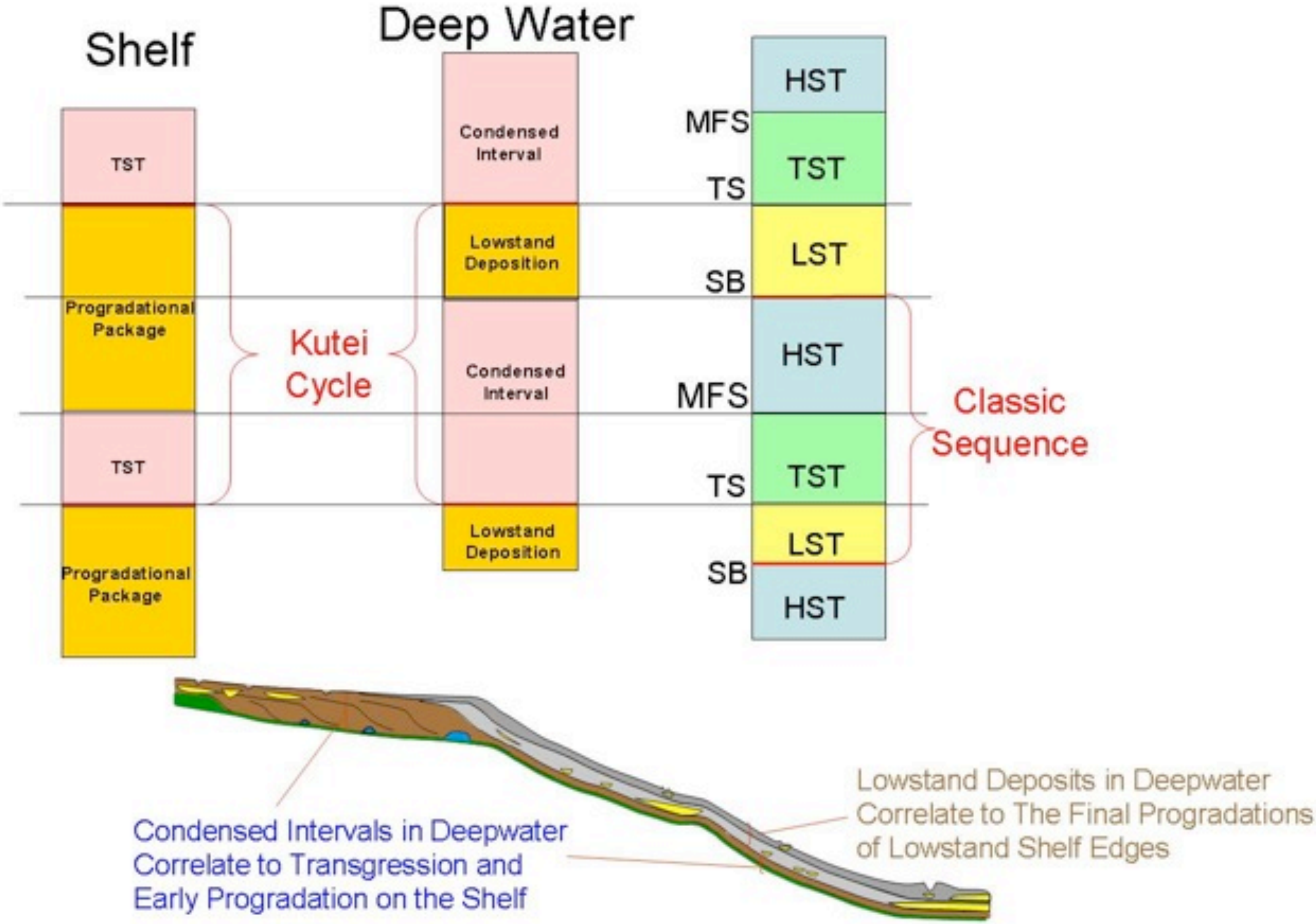
Shelf
Deep Water
TST
Progradational Package
TST
Progradational Package
Kutei Cycle
Condensed Interval
Lowstand Deposition
Condensed Interval
Lowstand Deposition
HST
MFS
TST
TS
LST
SB
HST
MFS
Classic Sequence
TST
TS
LST
SB
HST
Condensed Intervals in Deepwater Correlate to Transgression and Early Progradation on the Shelf
Lowstand Deposits in Deepwater Correlate to The Final Progradations of Lowstand Shelf Edges

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Environment interpretation

- Uniformitarianism

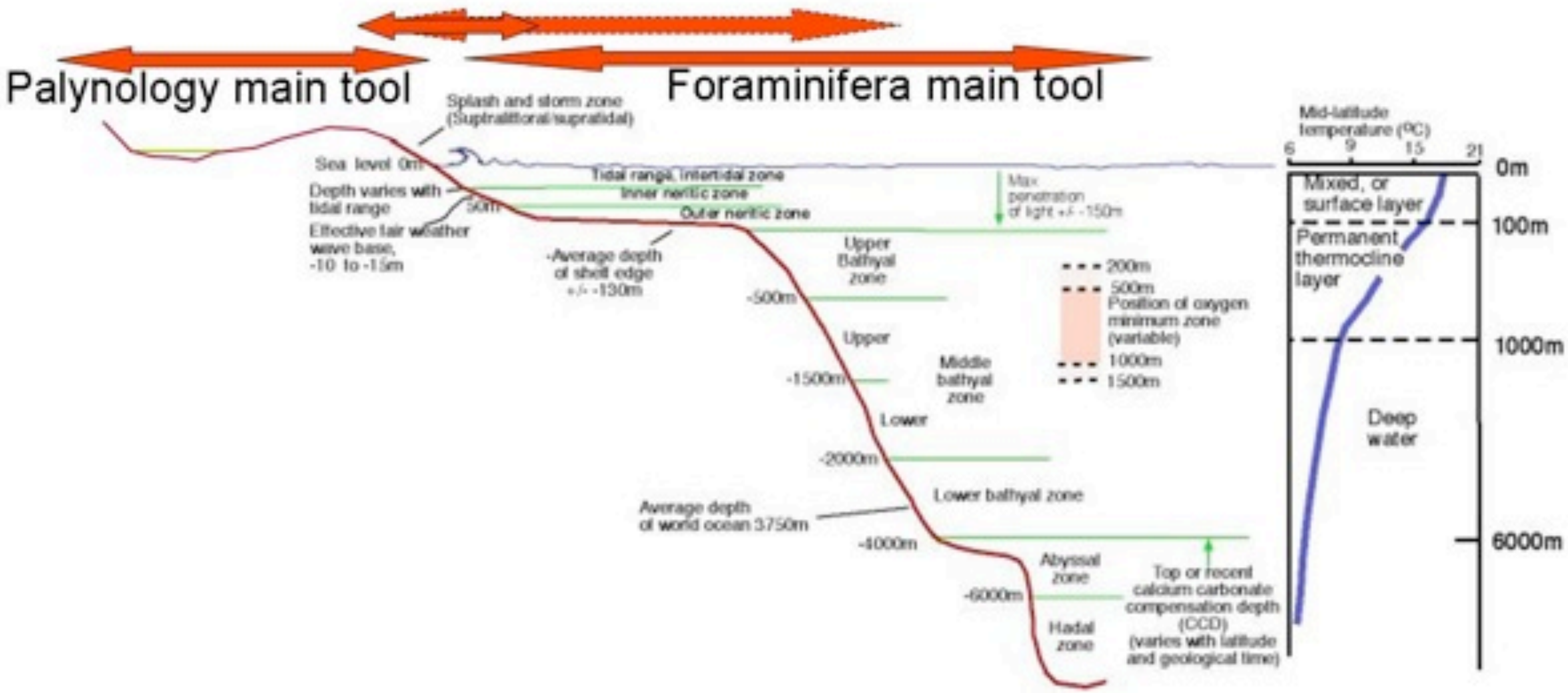
The guiding principle for nearly all paleoenvironmental reconstructions

HOWEVER:

- Modern ocean = highstand of sea level.
  - This can be resolved by using Quaternary data as analogues which cover last glacial
- Loss of information through taphonomic and diagenetic processes.

Paleoenvironmental information derived from microfossils:

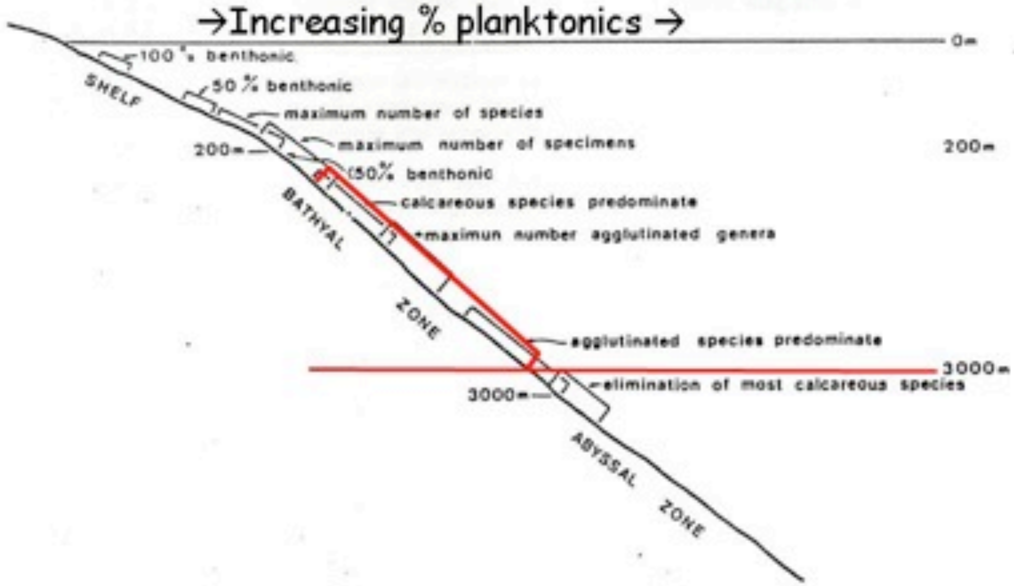
- sedimentary facies - forams, nannos, paly
- Salinity – forams, paly
- ocean temperature - forams
- Climate – paly (forams)
- water mass characteristics - forams
- Productivity – upwelling – forams (nannos)
- Water depth, and sea level change - forams, paly



6.2

Paleoenvironmental information derived from foraminifera

- Percent planktonics
- Species diversity
- Test-type ratios - planktonic/calc benthonics/agglut s
- Taxonomic approach
  - Environment requirements of specific taxa
    - Water depth-related/substrate-related etc
- Eco-taxonomic approach (mainly based on genera)



Approximate location of various benthonic foraminifera traits on the sea floor.

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6.3

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4.b Microfossil processing and logging techniques

Foraminifera

- **Sample washing and preparation**

  - take 50 gr (measured weight) of unwashed sample (sometimes light washing is necessary)

  - Wash through sieve to remove clay grade sediment and mud
  - add Hydrogen peroxide solution to disaggregate matrix
  - continue/repeat until all rock fragments are disaggregated

  Common problem, samples from deeper in well are more indurated so rock frags left in residue, and fewer forams seen in washed residue

4.b Microfossil processing and logging techniques

Foraminifera

Sample splitting method

Washed residue

Sample splitter

Split sample

Residue for logging

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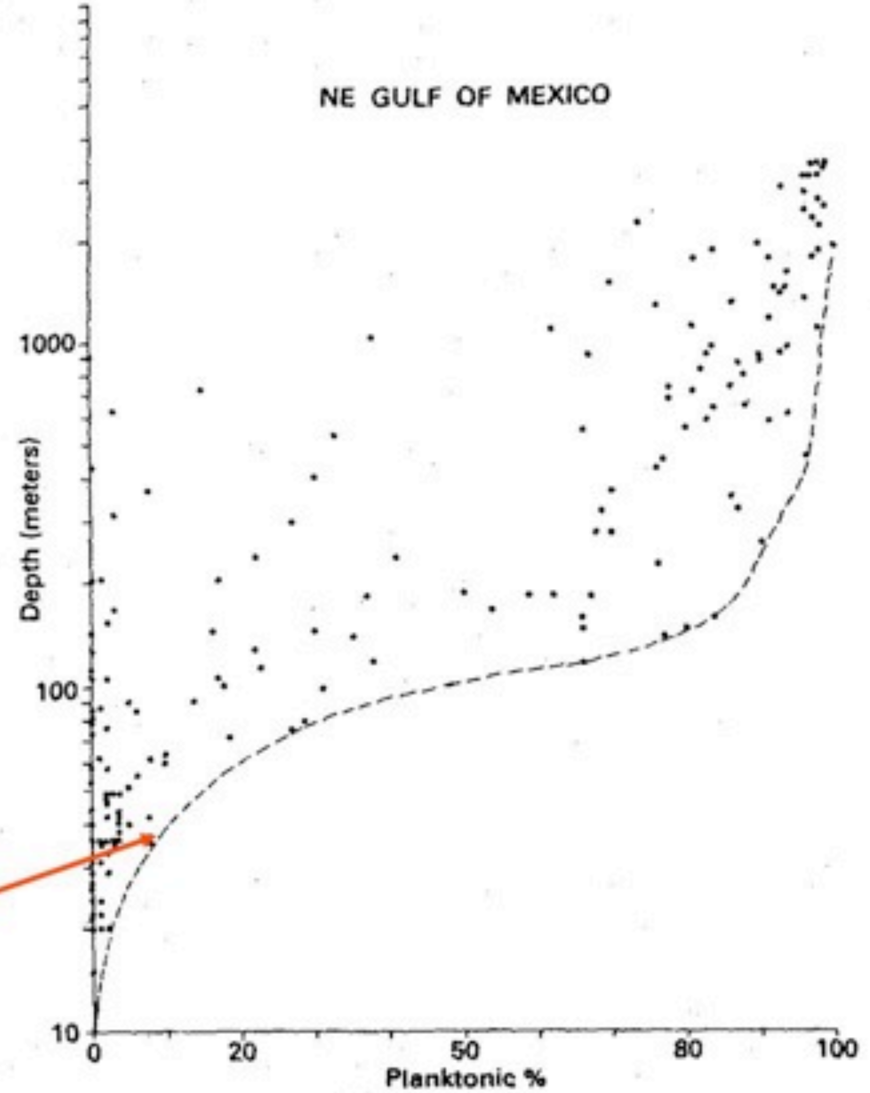
4.7

Water depth interpretation using foraminifera
Planktonic benthonic ratios

Modern Gulf of Mexico

Graph of Percent Planktonic specimens vs. Water Depth

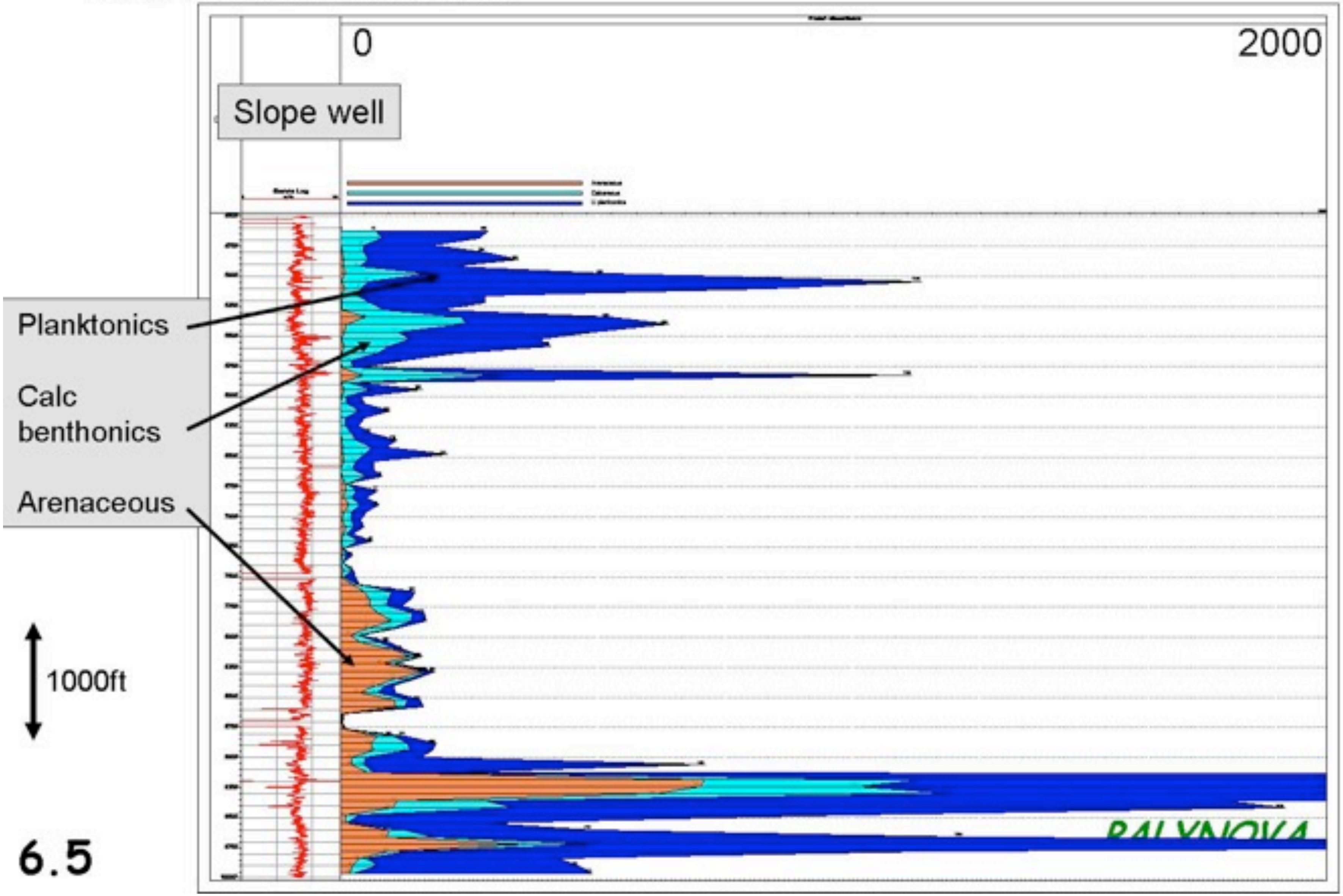


Dashed line connects minimum water depths

6.4

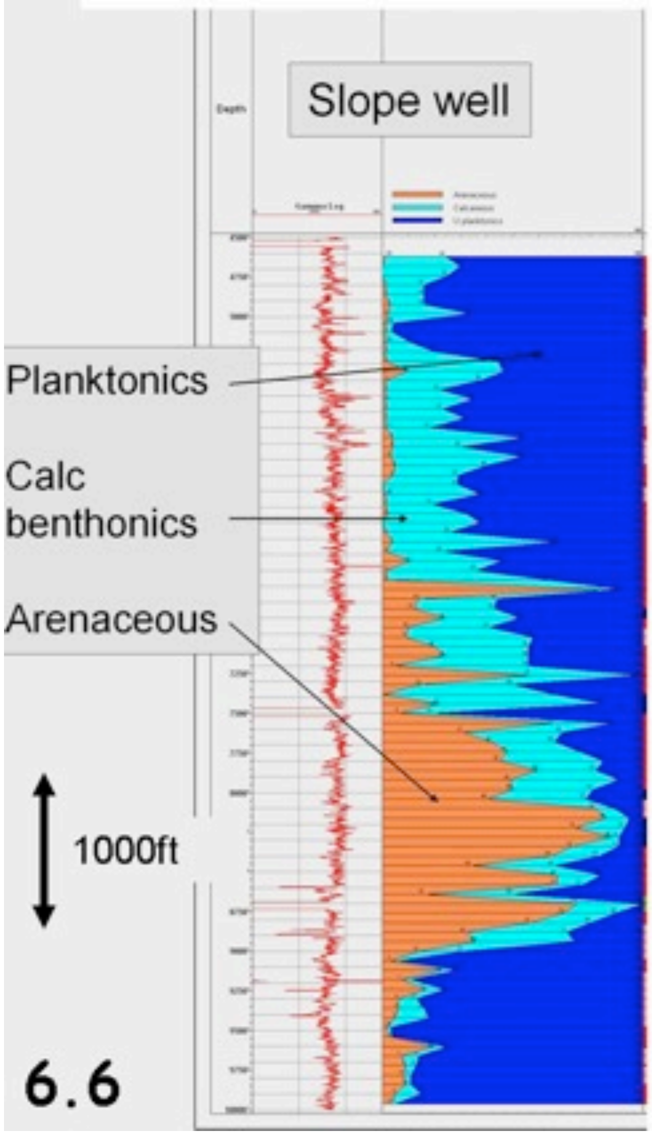
Water depth interpretation using foraminifera

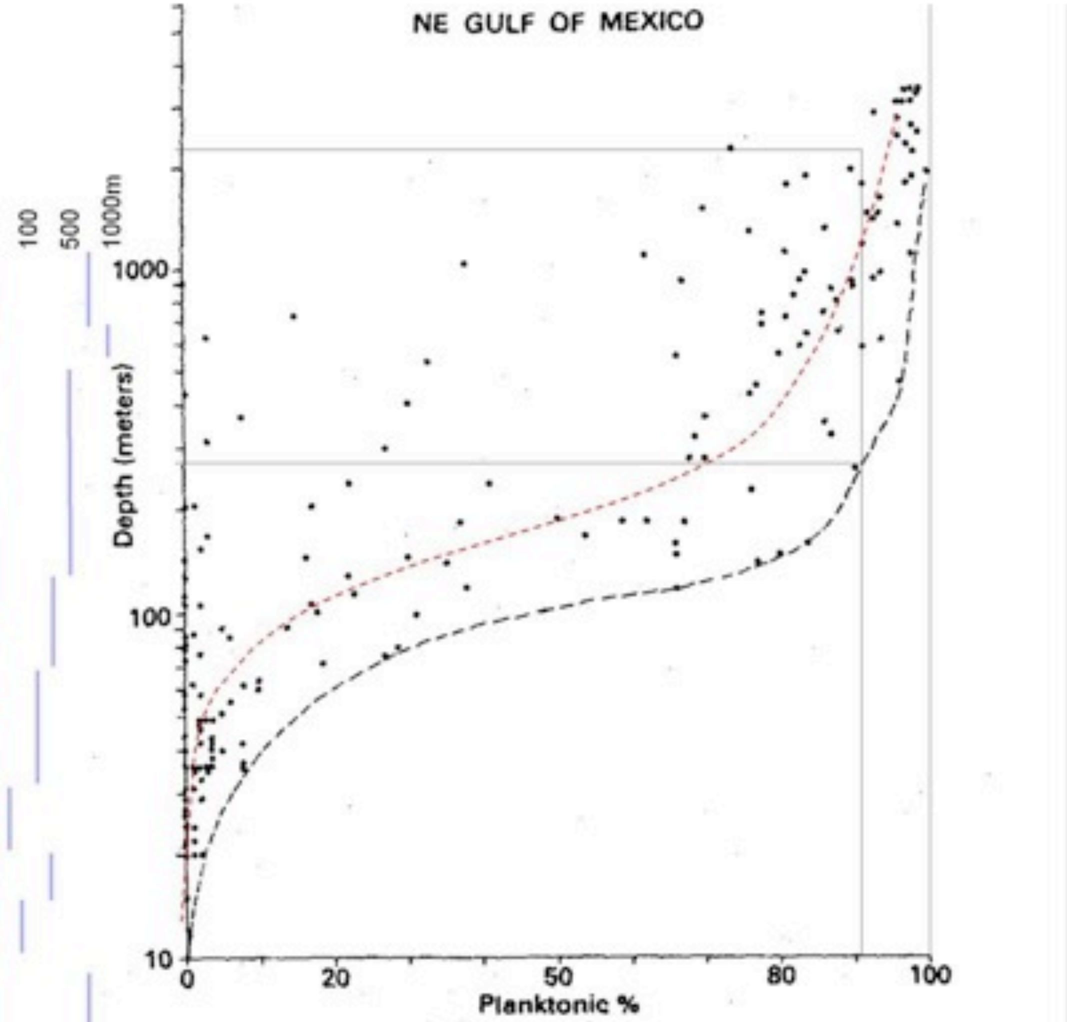
Planktonic benthonic ratios



6.5

Planktonic/benthonic and test type ratios





6.6

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Taxonomic approach (Murray 1974)

Discriminating marine depositional environments with ternary plot of benthic forams

Traditional approach to shelf environmental interpretation using ternery plots and diversity/abundance comparison

170 *Micropalaeontology in petroleum exploration*

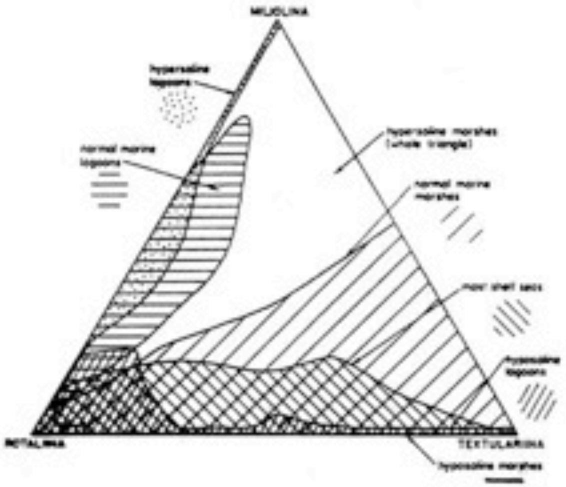

Fig. 7.8. Discrimination of marine environments by cross-plots of foraminiferal morphogroups (from Murray 1973).

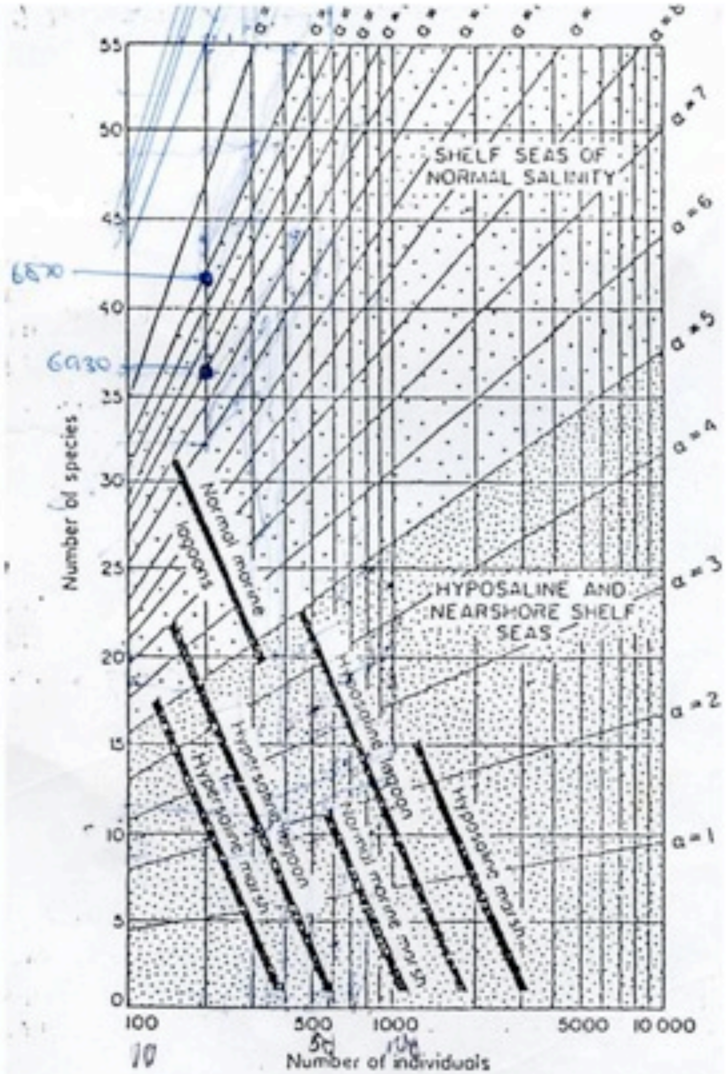

Figure 101 Summary of the range of diversity in different environments.

Mainly follows Murray 1974

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6.31

Friday, 7 October 2011

Eco-taxonomic approach (mainly based on genera)

Foraminiferal eco-taxonomic groups

- Planktonics
- Subdivide benthonic foraminifera according to main eco-taxonomic groups
  - Agglutinated simple spiral (planispiral) foraminifera –
    - diverse habitats with limited carbonate availability
  - Small rotaliids
    - shallow photic zone variable salinity
  - Miliolids
    - shelf hypersaline settings when common
  - Larger forams
    - clear water shelf settings in photic zone
  - Misc shelf group
    - diverse habitats in stenohaline settings on shelf (and poss upper slope)
  - Oxygen deficient group
    - muddy substrates poor in oxygen (mainly upper slope)
  - 'Deep/cold' group
    - prefer water depths below 150m
  - Primitive agglutinated
    - typically tubular forms – tolerate strongly restricted environments
  - Complex agglutinated
    - common in 'normal' slope settings

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3.b Eco-taxonomic groups

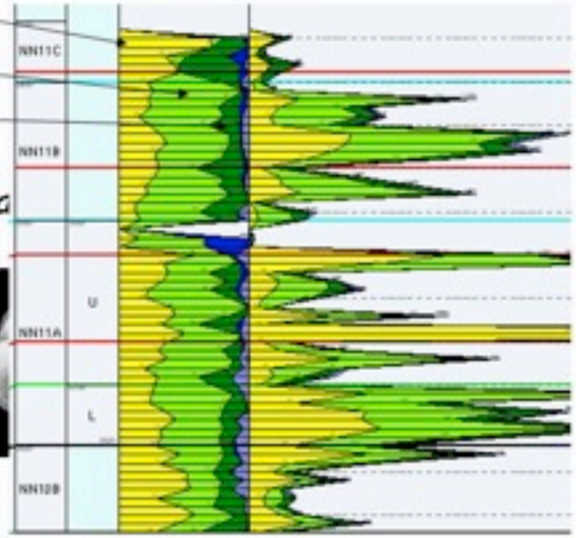
Planktonics

- ***Planktonics –***
  - *Planispiral*

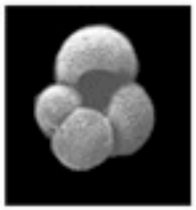
Hastigerina micra

Trochospira

Globorotalia menardii

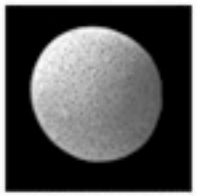


  - *Streptospiral*

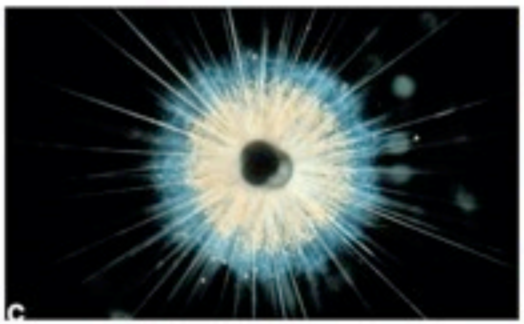


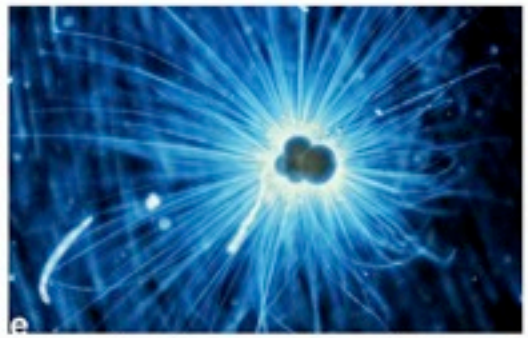
Globigerina bulloides

Final chamber envelops earlier chambers



Orbulina universa





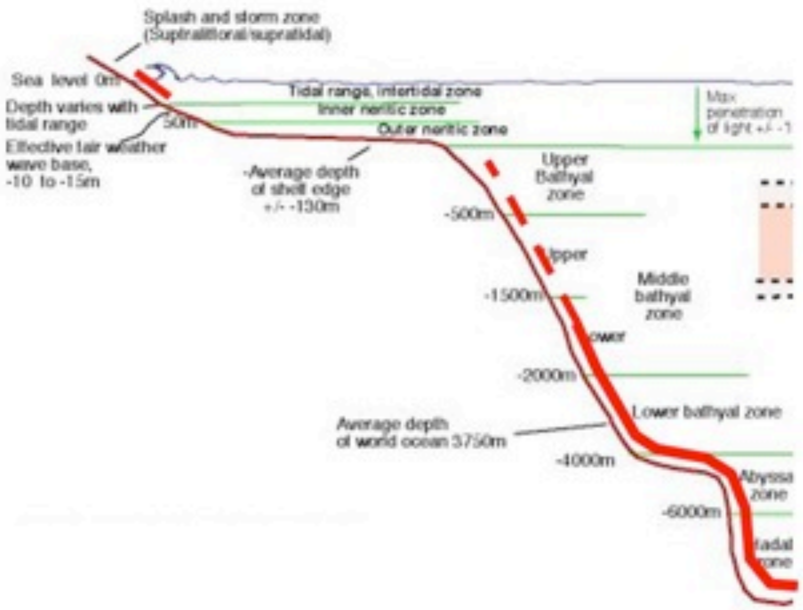
Living planktonic foraminifera showing pseudopodia

3.b Eco-taxonomic groups

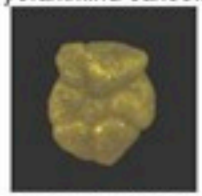
Foraminifera Agglutinated

Agglutinated simple spiral (planispiral) foraminifera –
- diverse habitats with limited carbonate avail

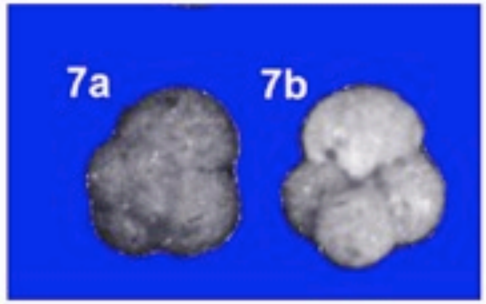
Miliammina fusca



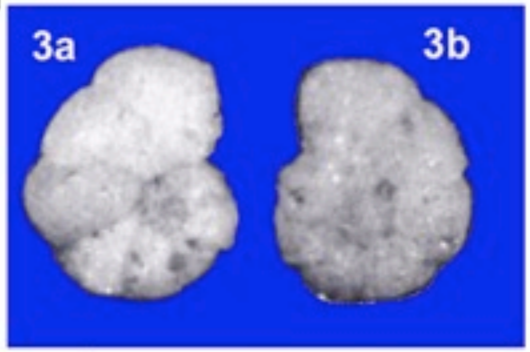
Cyclammina cancellata



Haplophragmoides bradyi



Trochammina globigeriniformis



Trochammina spp

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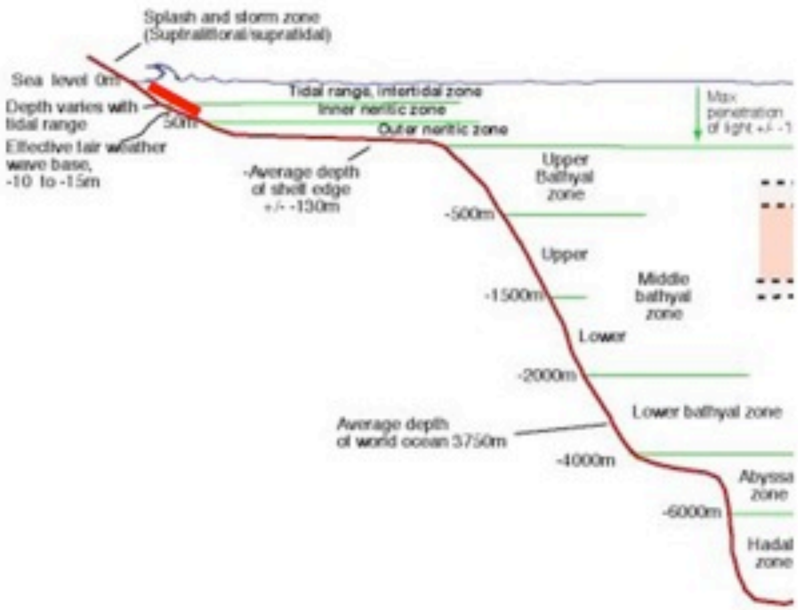
Ammodiscus latus

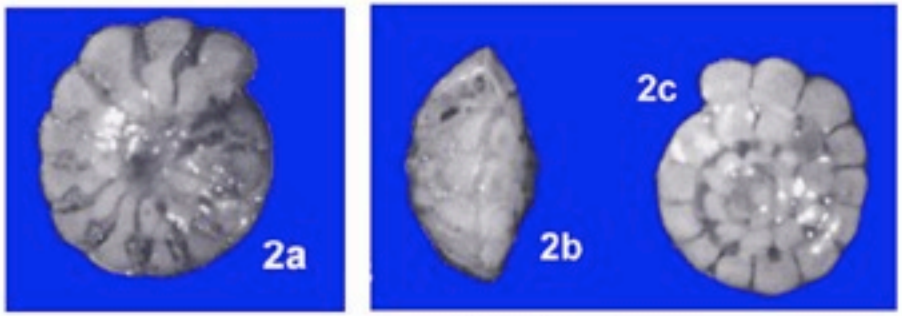
Haplophragmoides sp

3.16

3.b Eco-taxonomic groups

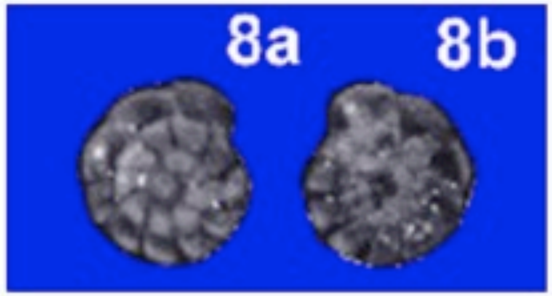
Small rotaliids - shallow photic zone variable salinity



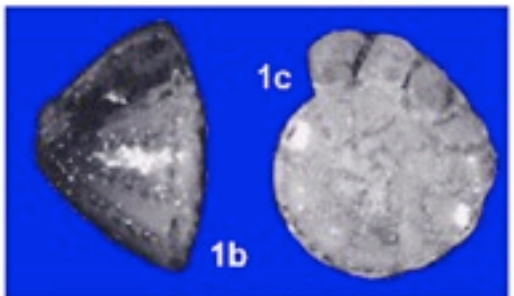


Ammonia sp

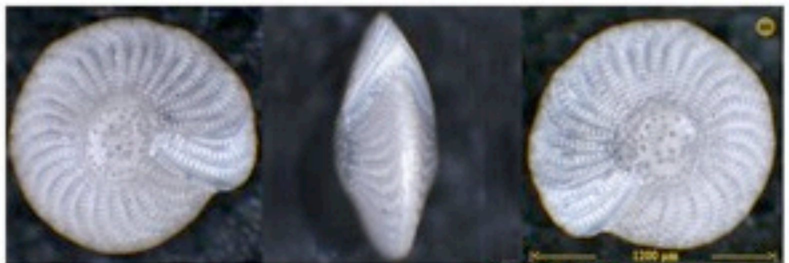
Asterotalia trispinosa



Ammonia beccarii



Pseudorotalia conoides



Elphidium crispum

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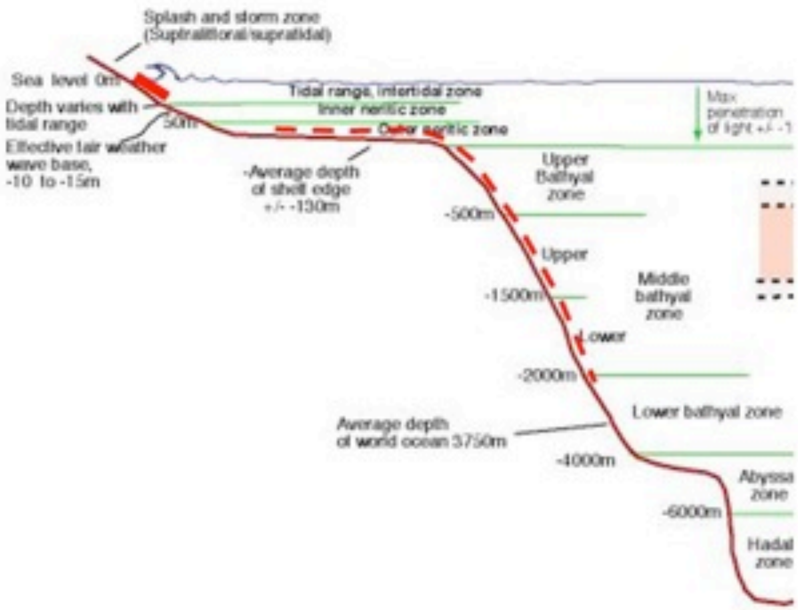
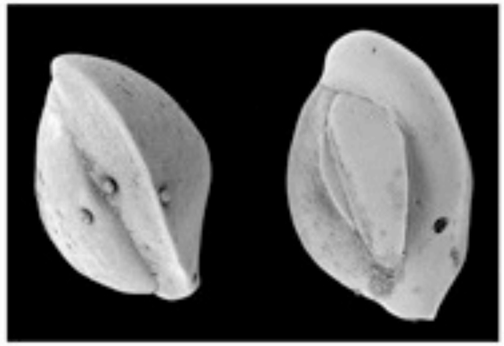
3.17

3.b Eco-taxonomic groups

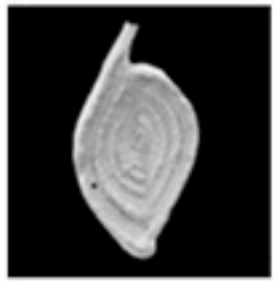
Miliolids

- shelf hypersaline settings when common

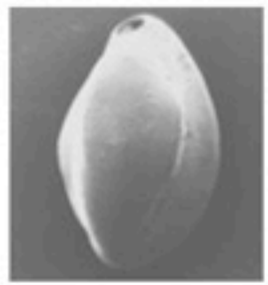




Quinqueloculina spp



Spiroloculina ornata



Quinqueloculina sp

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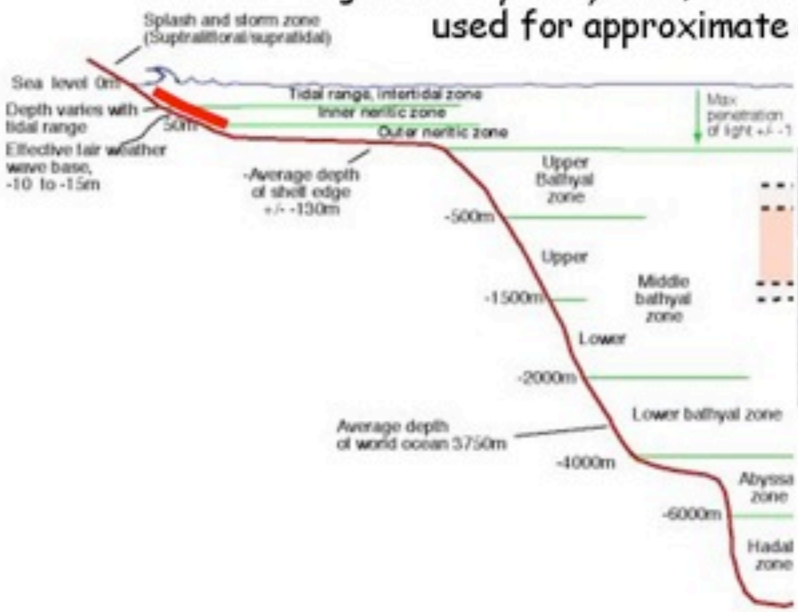
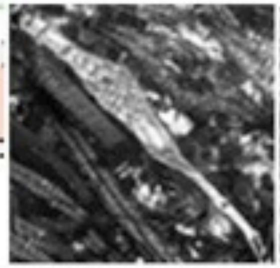
3.b Eco-taxonomic groups

Larger forams

- clear water shelf settings in photic zone

- Larger foraminifera, large planispiral foraminifera, with algal symbionts. typical genera *Lepidocyclina, Nummulites, Discocyclina, Miogypsina, Flosculinella*, can be used for approximate age interpretation through Middle Eocene to Middle Miocene





Heterostegina sp

Lepidocyclina pustulosa

Nummulites sp

Amphistegina E

Operculina sp

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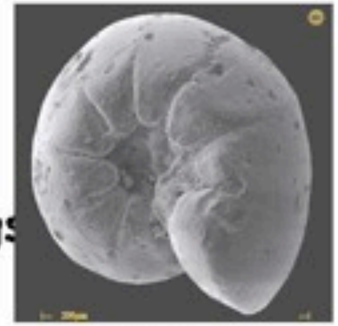
3.19

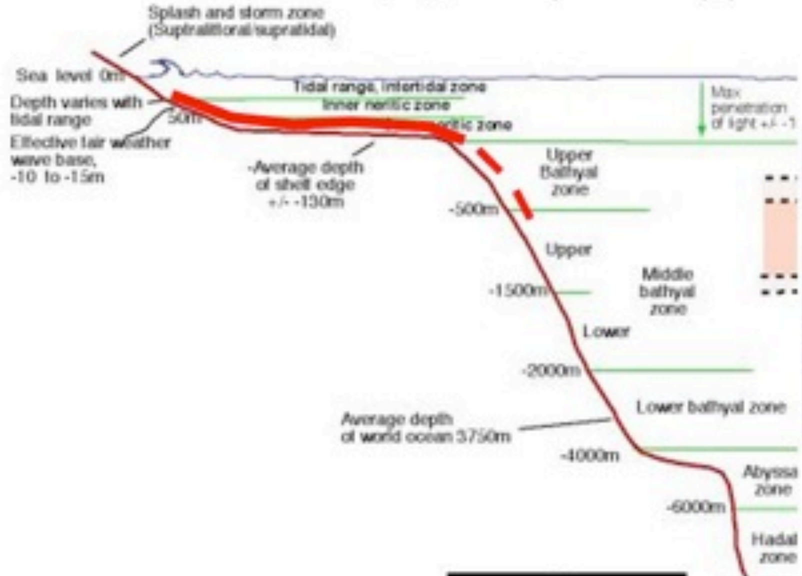
3.b Eco-taxonomic groups

Misc shelf group

- diverse habitats in stenohaline settings on shelf (and poss upper slope)

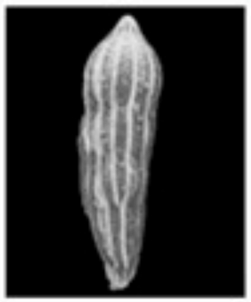


Heterolepa sp



Lenticulina cf. wallacei (Cris S)

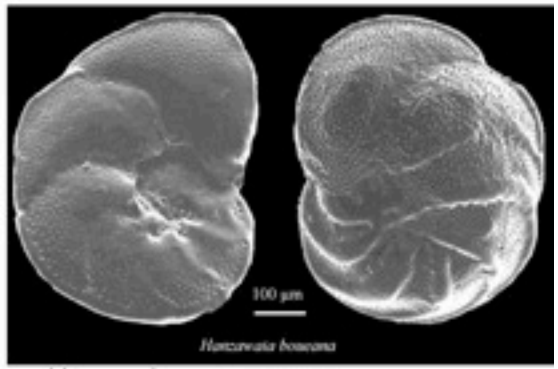
Lenticulina cristi (Cris I)



Nodosaria sp

Nodosaria angularis

Lagenia striata



Hanzauwia sp

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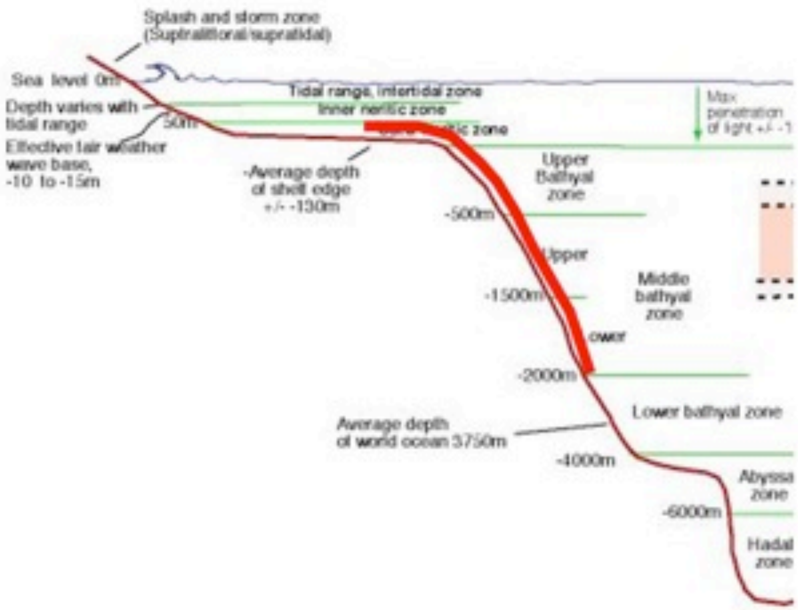
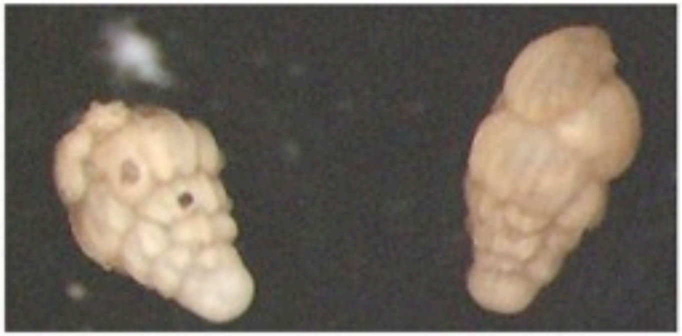
3.b Eco-taxonomic groups

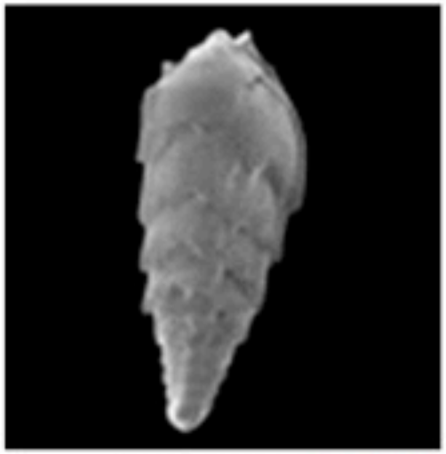
Oxygen deficient group

- muddy substrates poor in oxygen (mainly upper slope)





Bi/triserial *Uvigerina basirotunda*



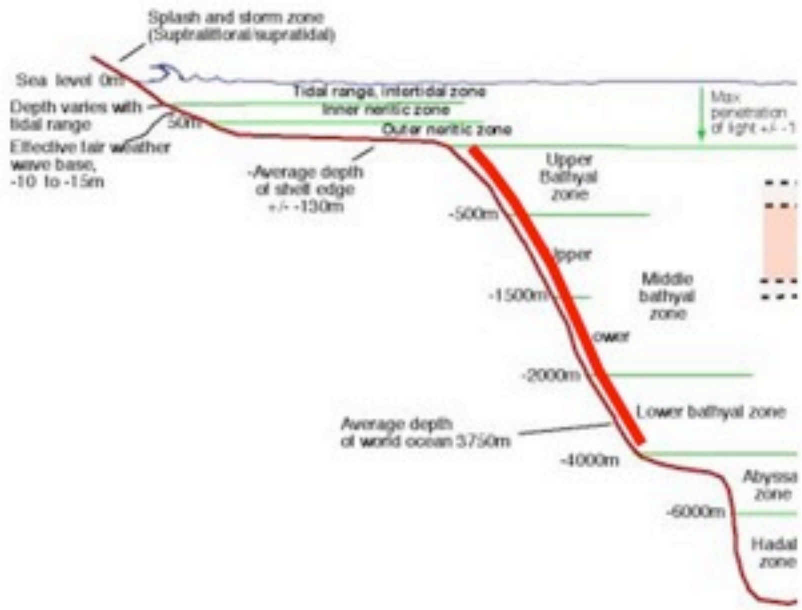
Brizalina alata PALYNOVA

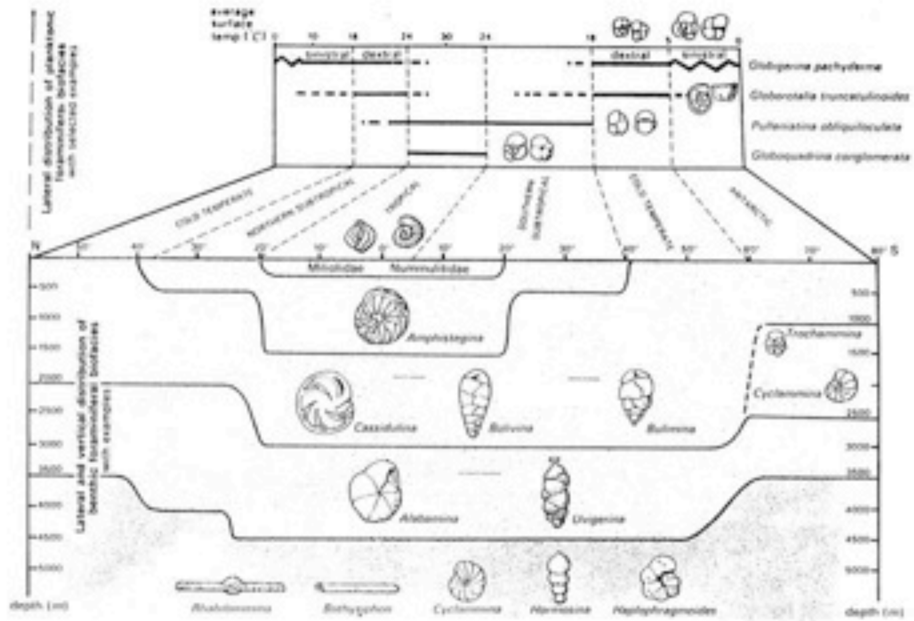
3.21

3.b Eco-taxonomic groups

'Deep/cold' group

- prefer water depths below 150m





3.22

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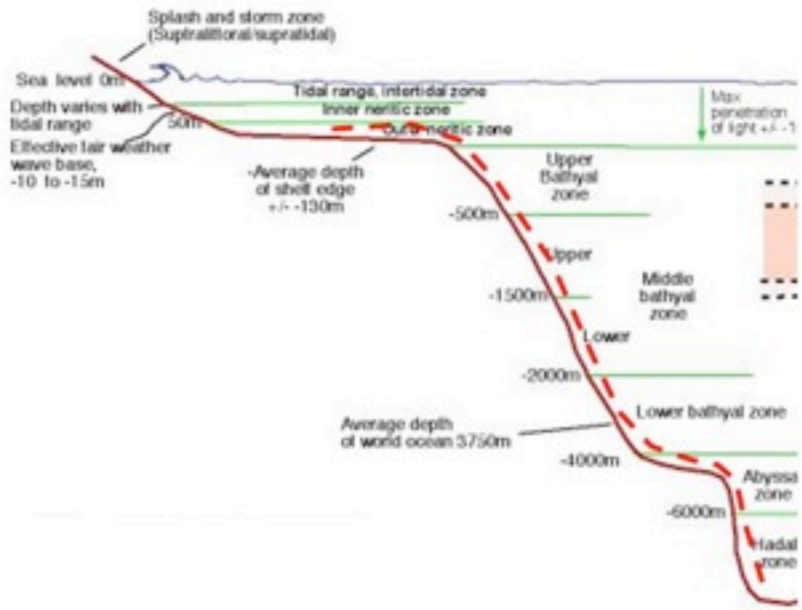
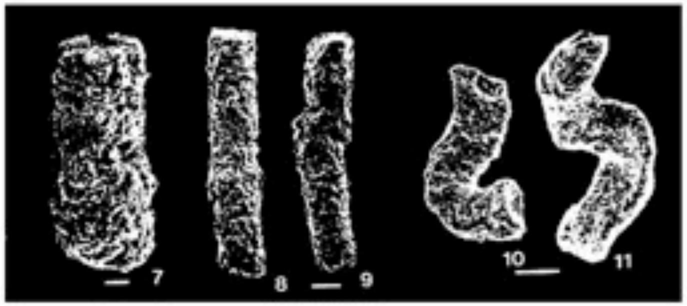
3.b Eco-taxonomic groups

Primitive agglutinated

- typically tubular forms - tolerate strongly restricted environments





Single chambered - simple tubes - typical genera *Bathysiphon*

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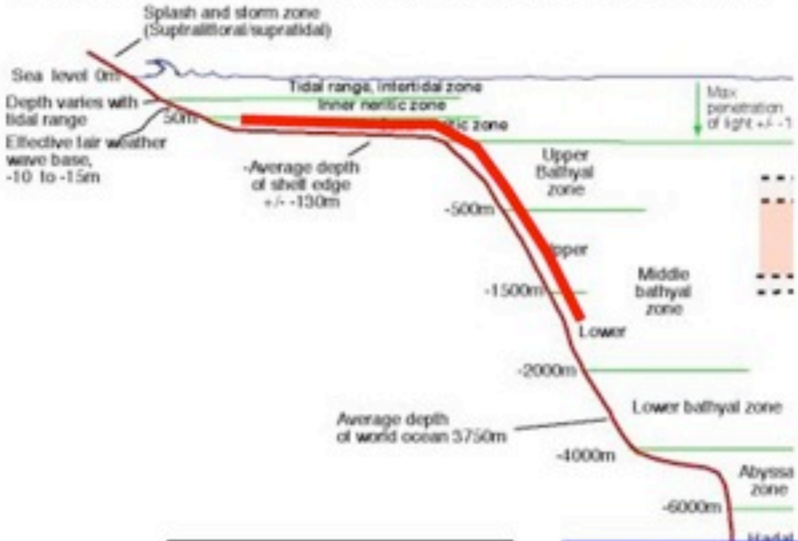
3.b Eco-taxonomic groups

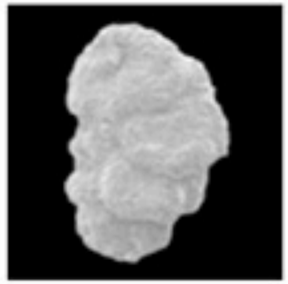
Complex agglutinated
-common in 'normal' slope settings

- Biserial – *Textularia, Valvulina, Eggerella* etc

Spiroplectammina spectabilis Textularia stanneri



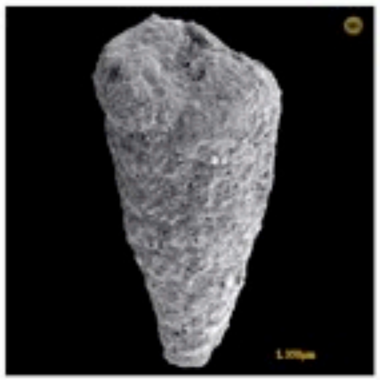
Siphotextularia concava



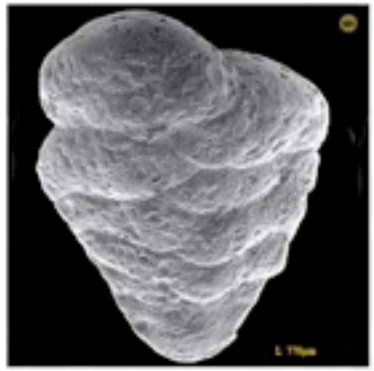
Valvulina flexilis

Vulvulina arenacea

Ammobaculites agglutinans



Textularia sp



Textularia gramen

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Makassar Straits environment interpretation using foraminifera and palynomorphs

1) Effects of 'Throughflow'
2) Sequence model
3) Microfossils and depositional environments
4) Logging techniques and eco-taxonomic groupings for foraminifera
5) **Characterisation of depositional environments**
   - Shelf environments
   - Slope environments
   - Carbonate dissolution issues
   - Delta front and delta plain, Mahakam Delta
6) Palynology and environments
   - Coastal plain and mangroves
   - Mangroves in temporal perspective
   - Upper coastal plain and lacustrine deposits
   - Coals

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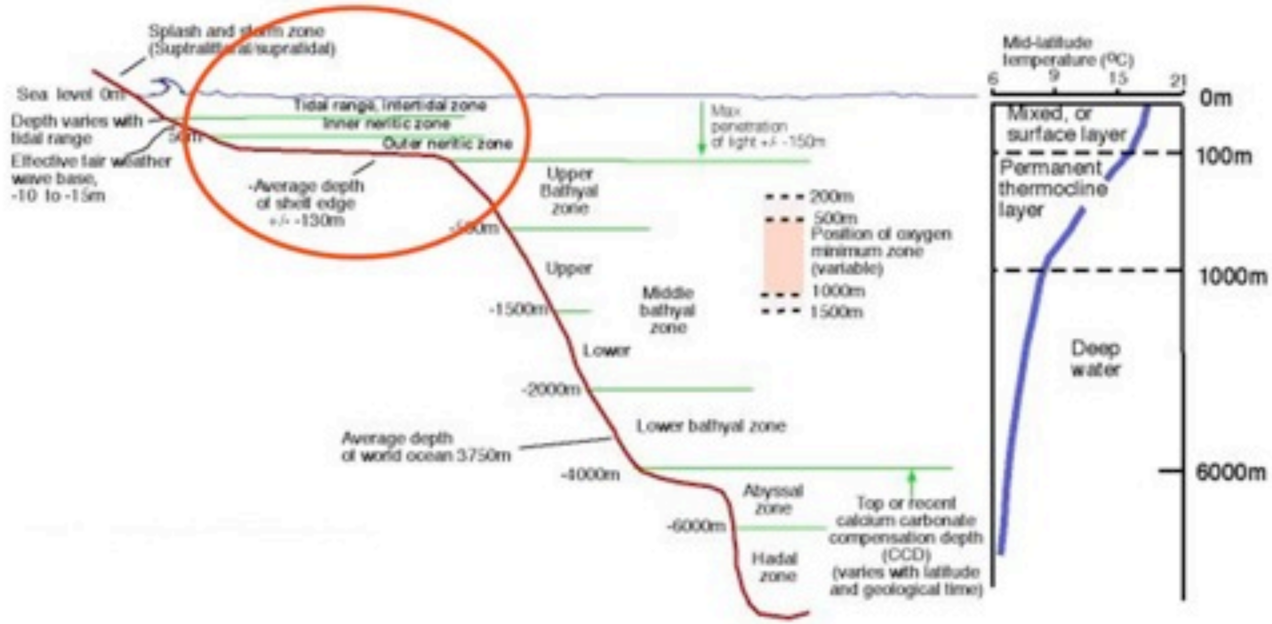
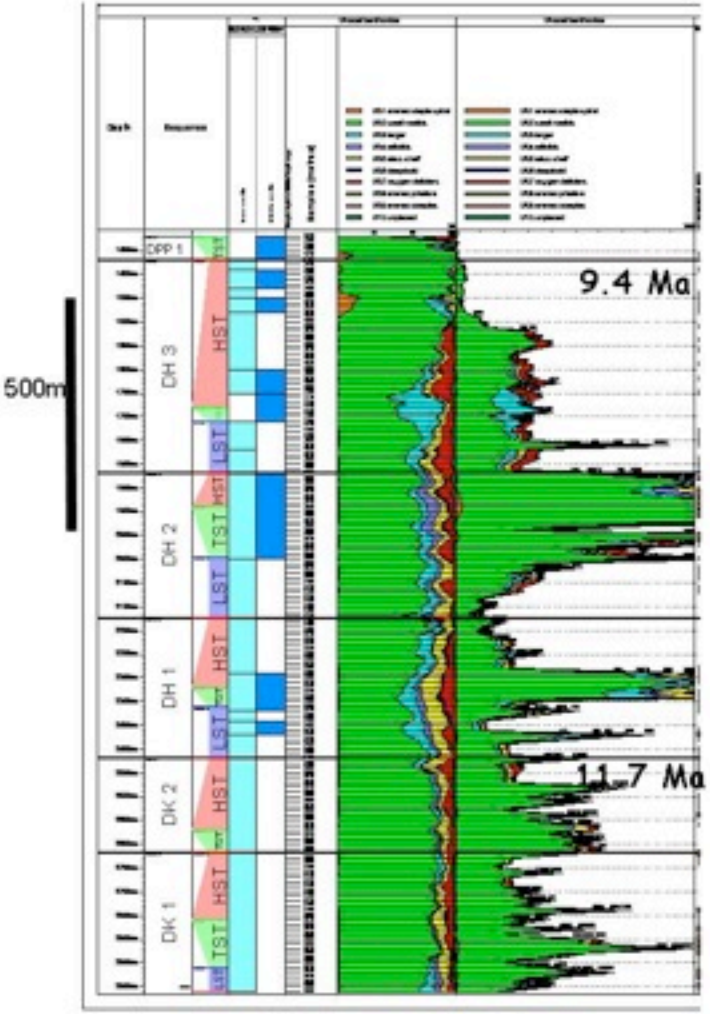
shelf deposition

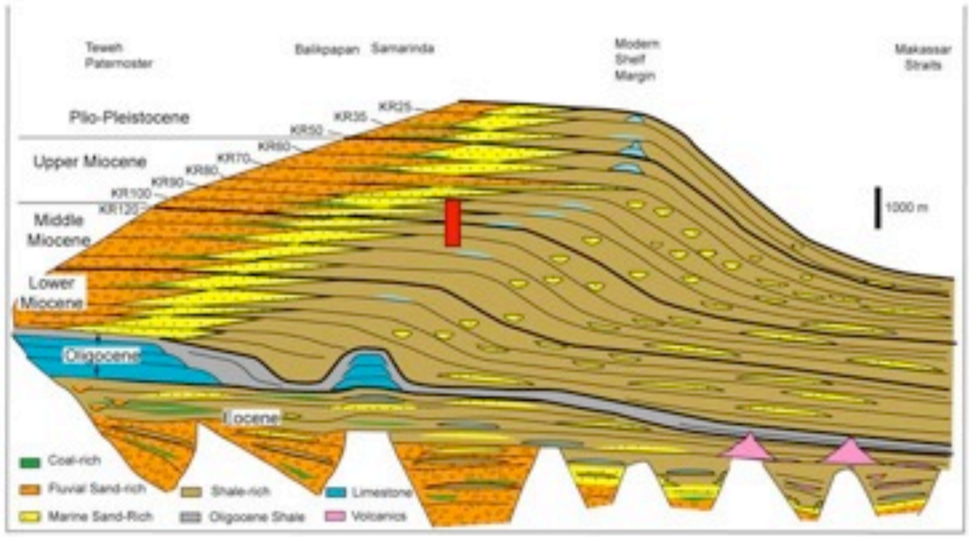


6.43

6 Shelf environments

- shallow shelf well - depth groups





- U01 arenac simple spiral
- U02 small rotalids
- U03 larger
- U04 miliolids
- U05 misc. shelf
- U06 deep/cold
- U07 oxygen deficient
- U08 arenac primitive
- U09 arenac complex
- U10 unplaced

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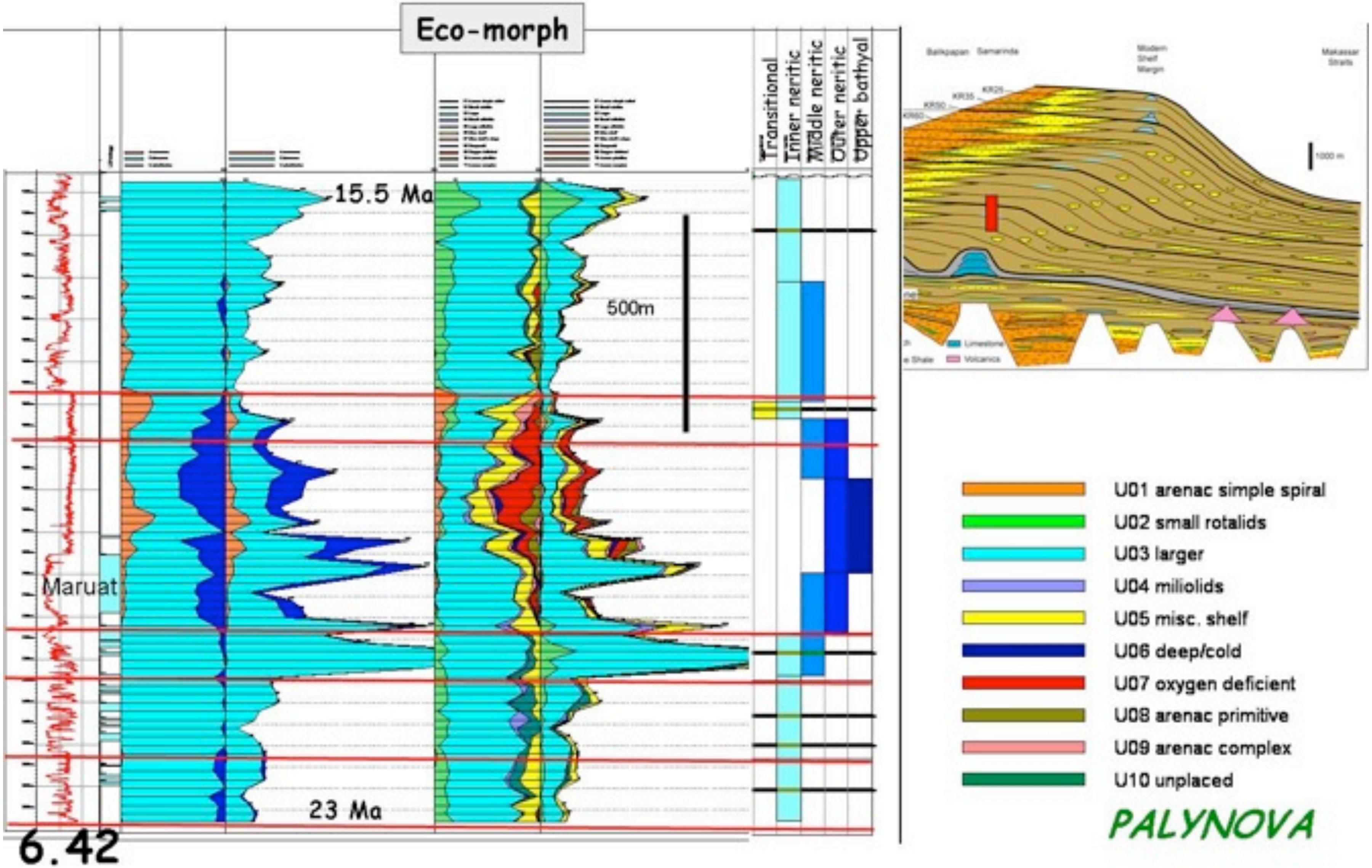
6.36

6 Shelf environments middle and outer shelf



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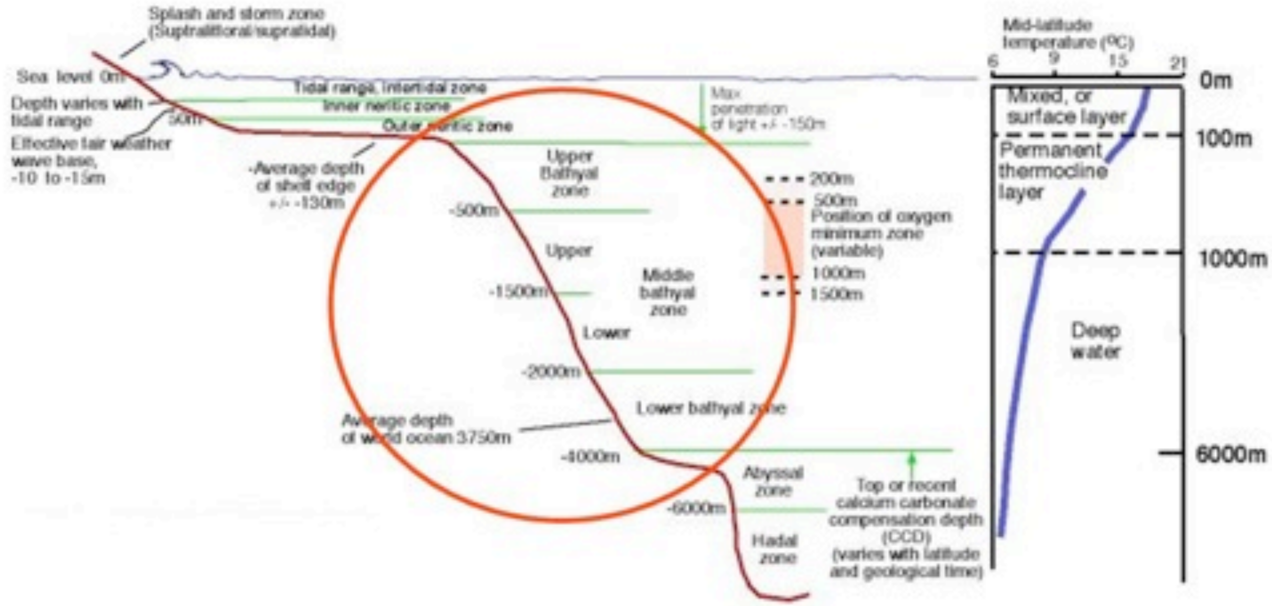
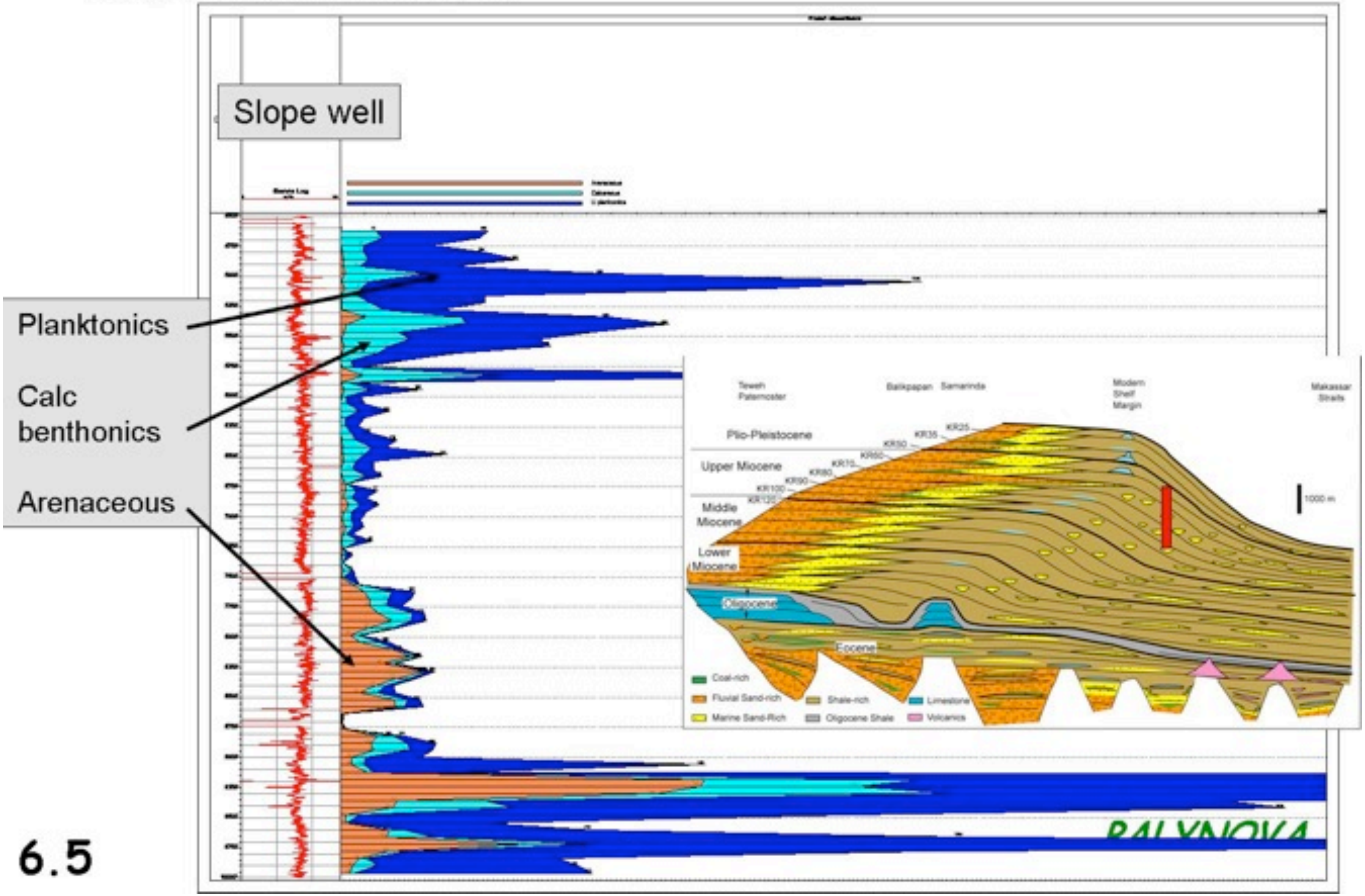
slope depositional systems



6.43

6 Deep water - water depth interpretation using foraminifera

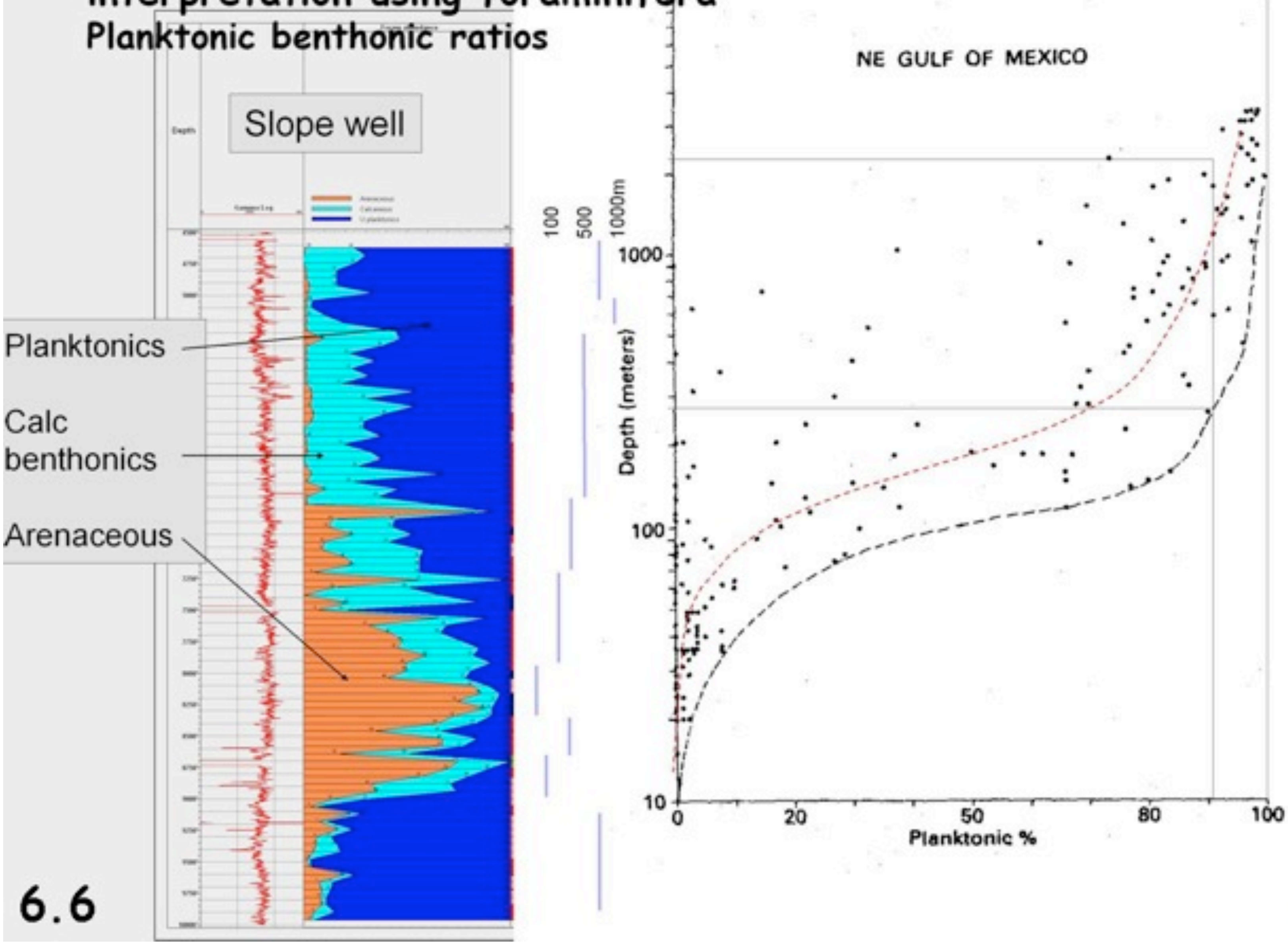
Planktonic benthonic ratios



6.5

Deep water - water depth interpretation using foraminifera

Planktonic benthonic ratios



6.6

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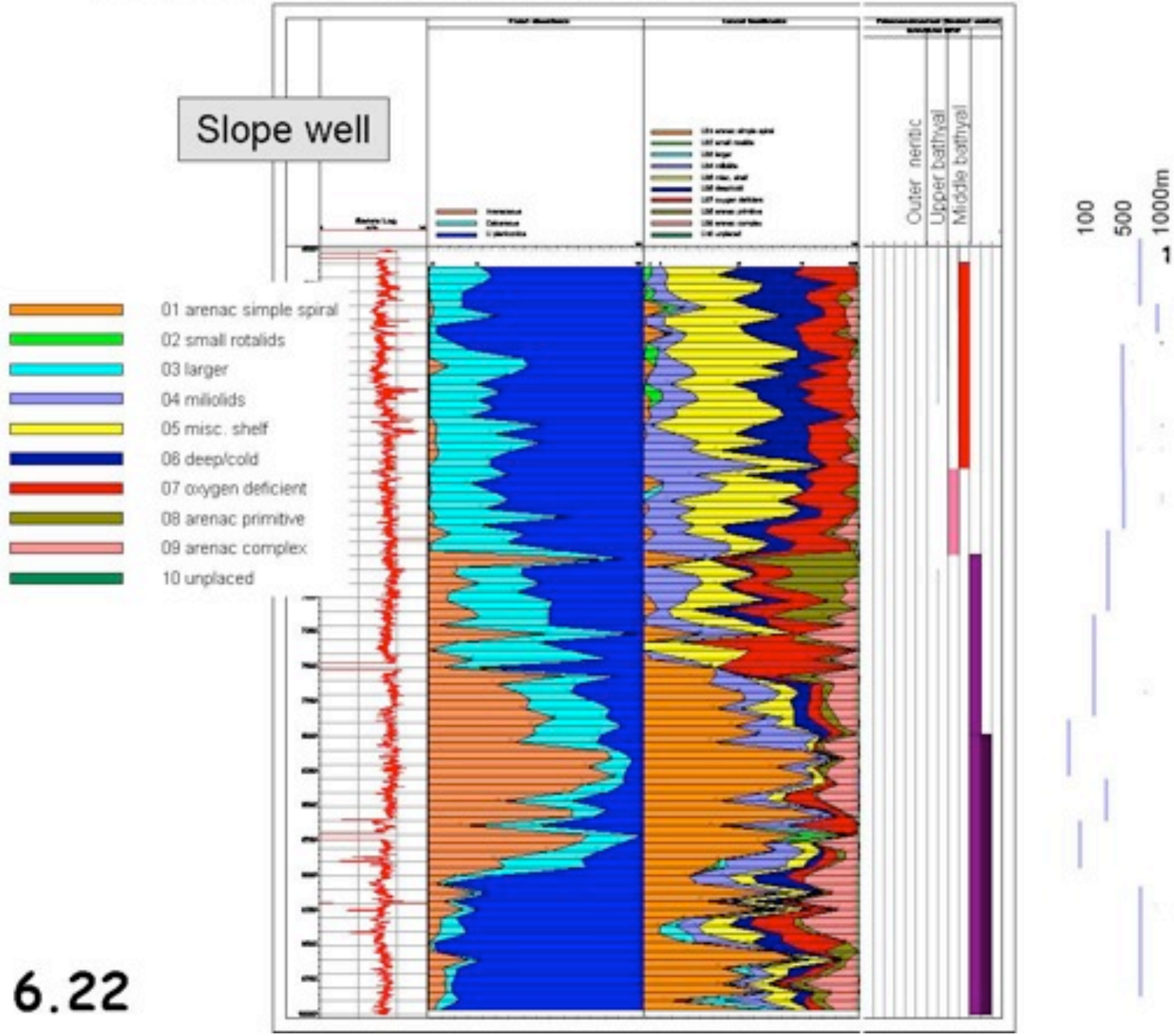
6 Deep water environment interpretation

Foraminiferal eco-taxonomic groups



6.22

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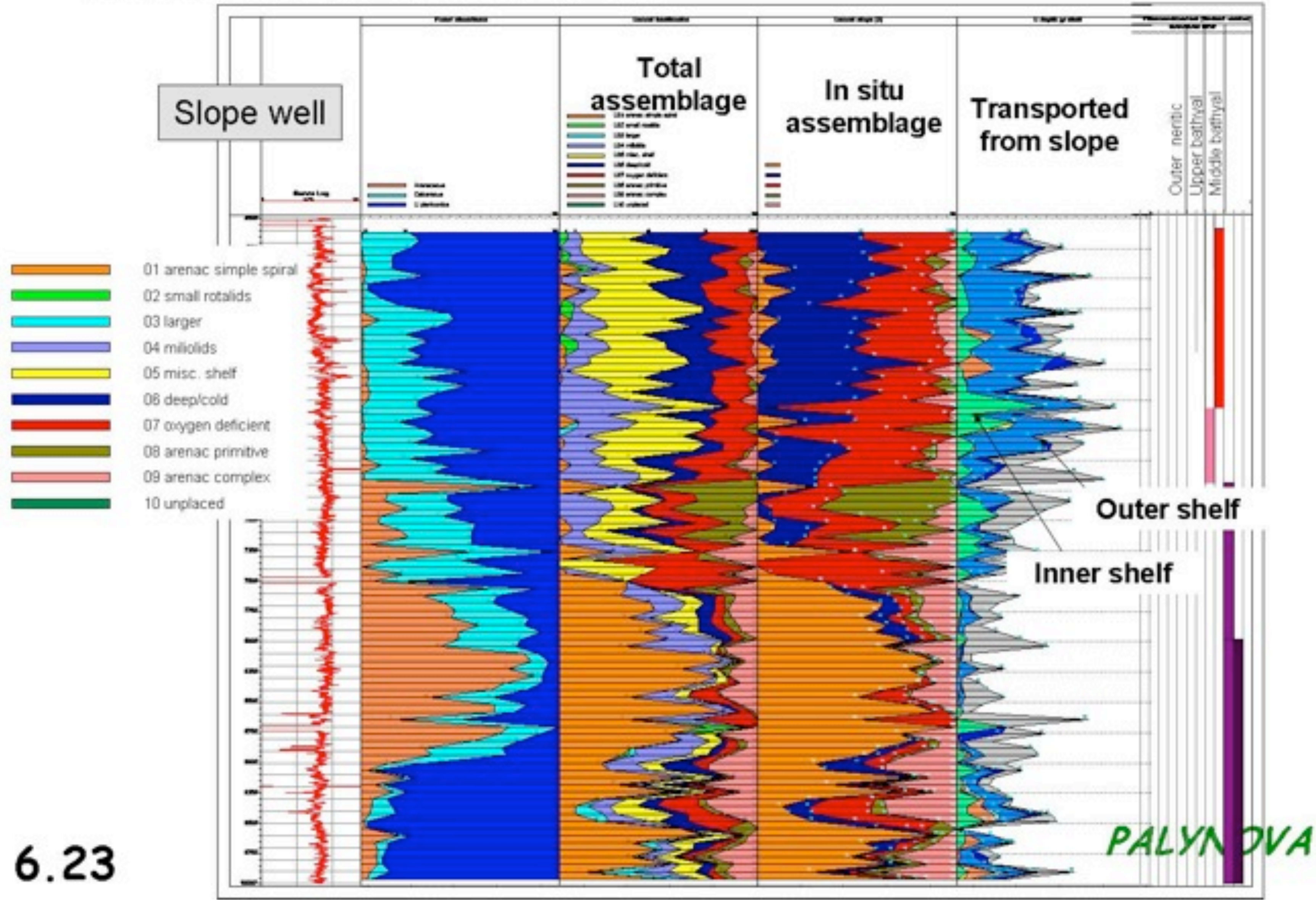
6 Deep water - environment interpretation

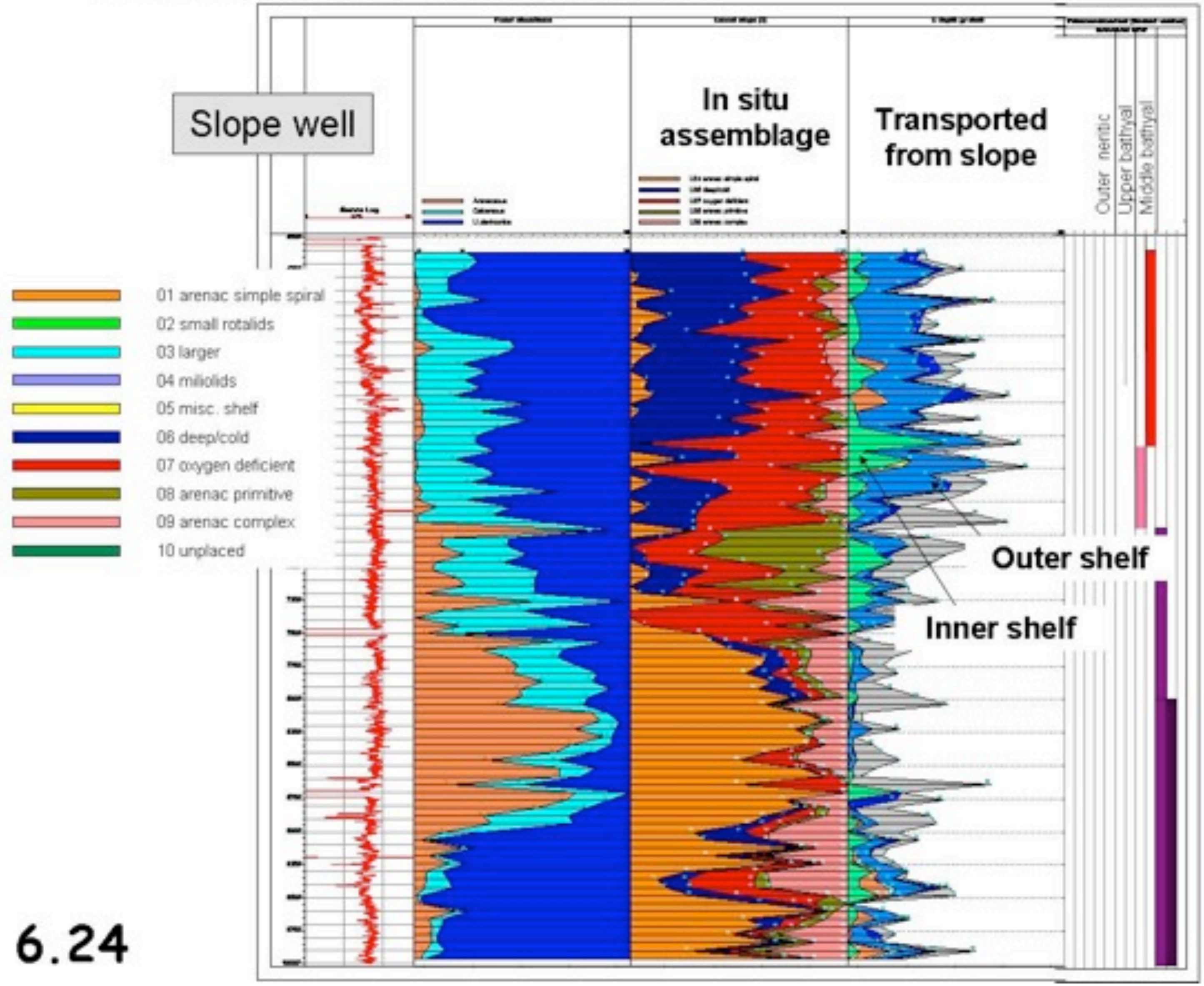
Foraminiferal eco-taxonomic groups



6.23

6 Deep water - environment interpretation

Foraminiferal eco-taxonomic groups



6.24

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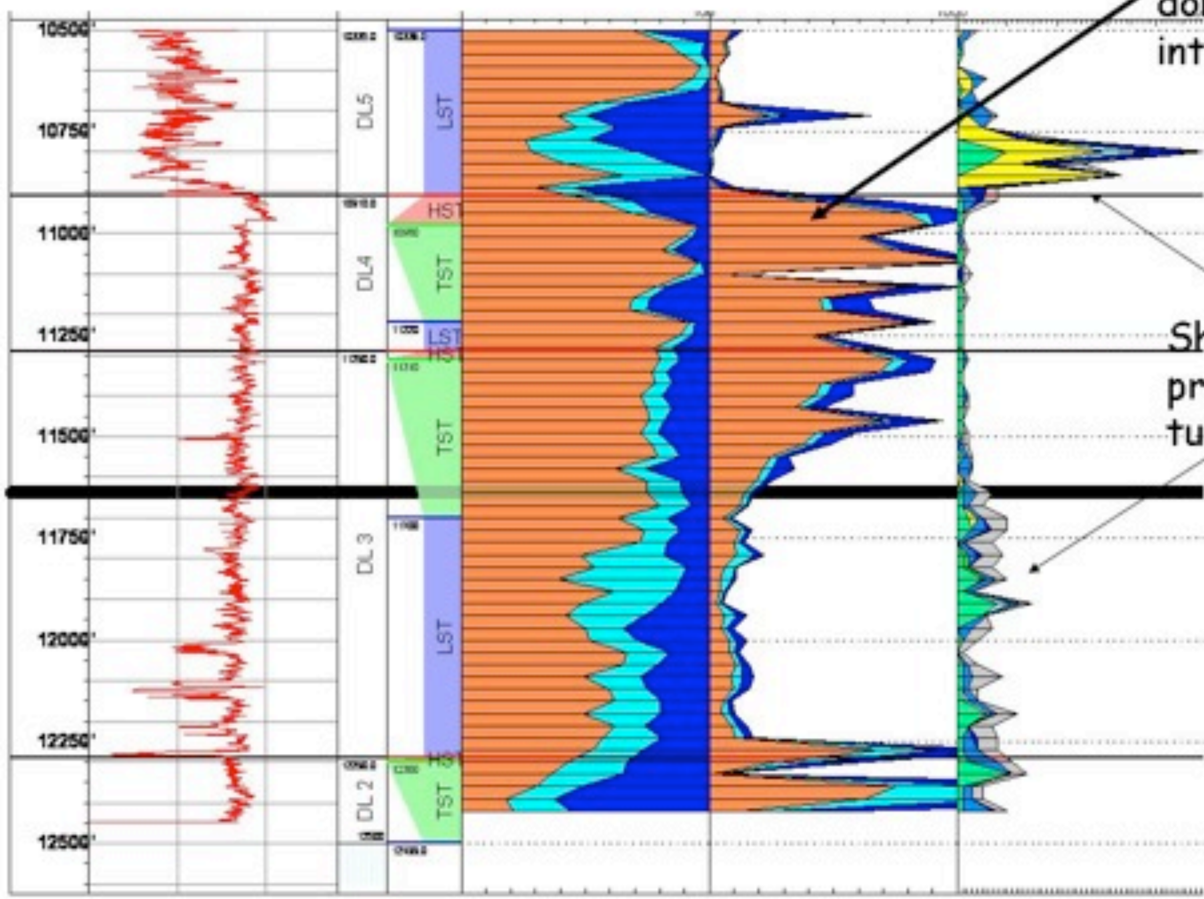
Downslope transport and turbidites

Middle bathyal section



Calcareous forms
Arenaceous forms
dominate shale
intervals

Shelf forams
preserved in
turbidites

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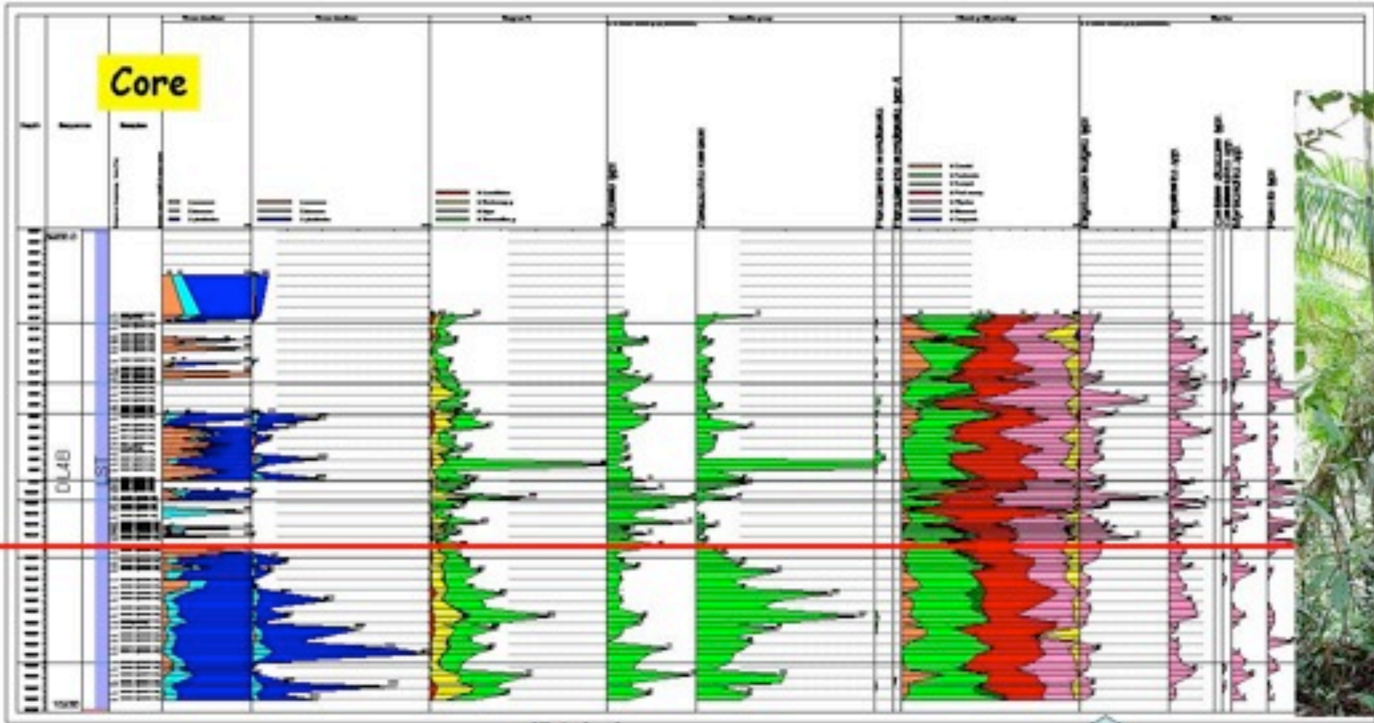

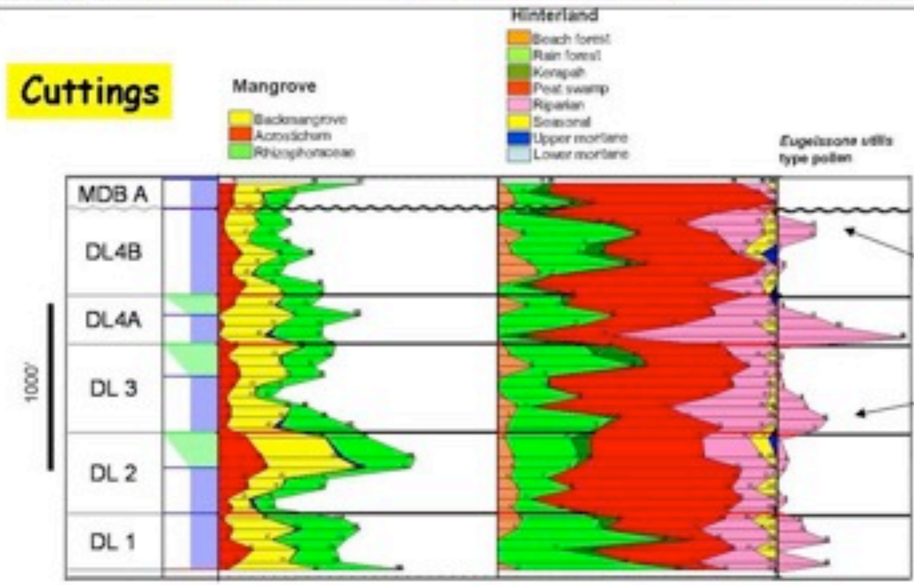

Acmes of Eugeissona insignis in deep water seds reflect point transportation from very proximal sources in foothills - ?hyperpycnal transport

Eugeissona insignis acmes

Middle bathyal turbidites

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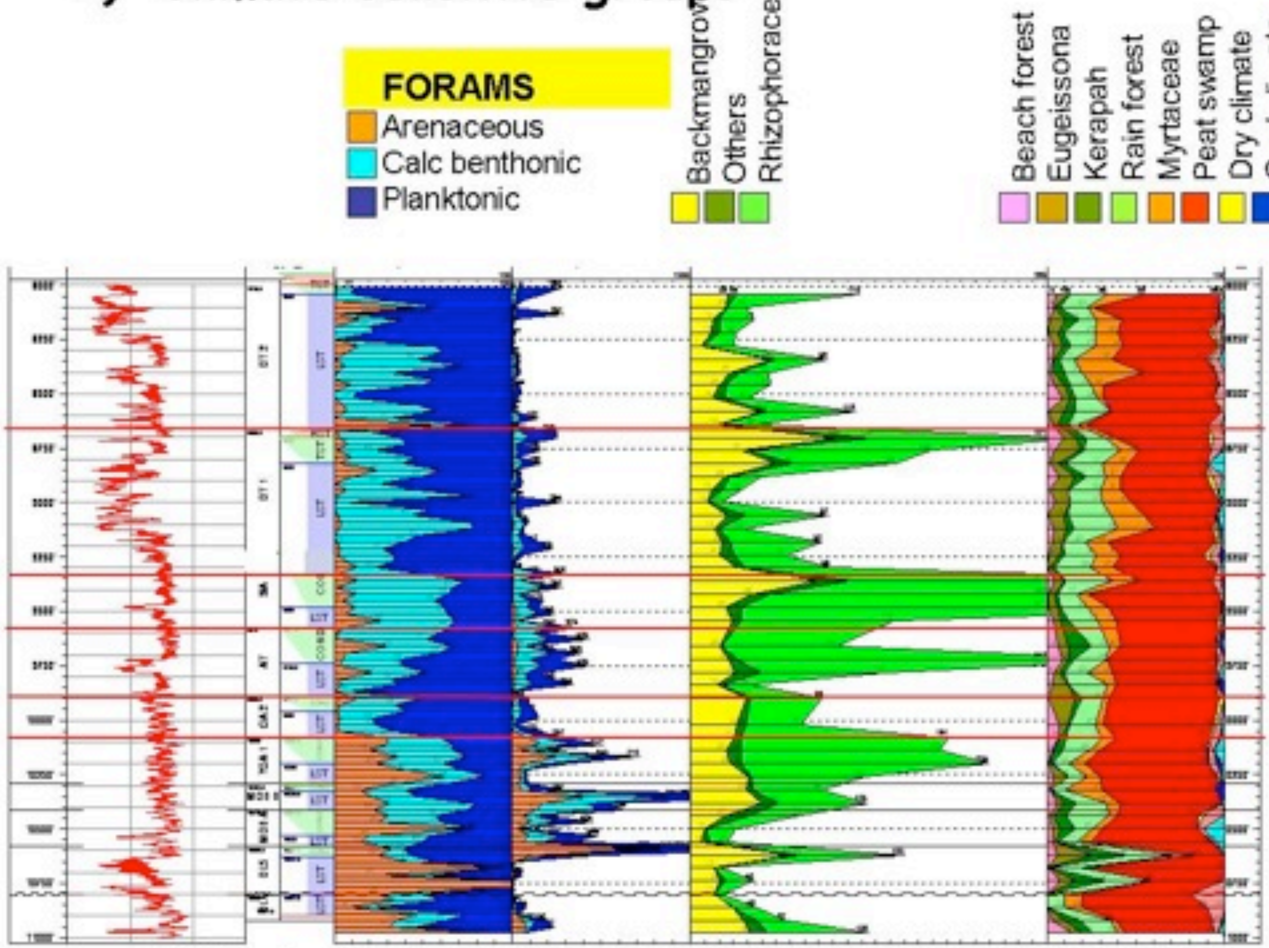
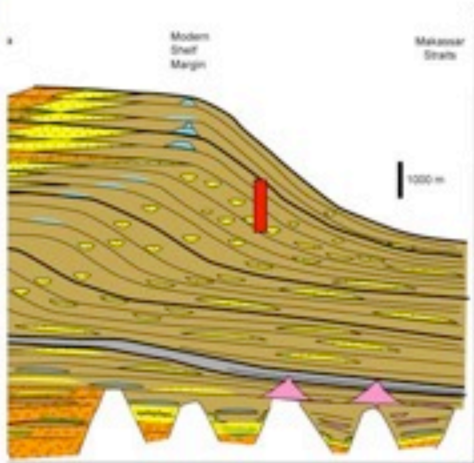
Mid slope well, palynological indicators

1) Mangroves
2) Climate sensitive groups





Less carbonate dissolution

More carbonate dissolution

Note close correspondence of changes in foram abundance/percentage and mangrove pollen maxima

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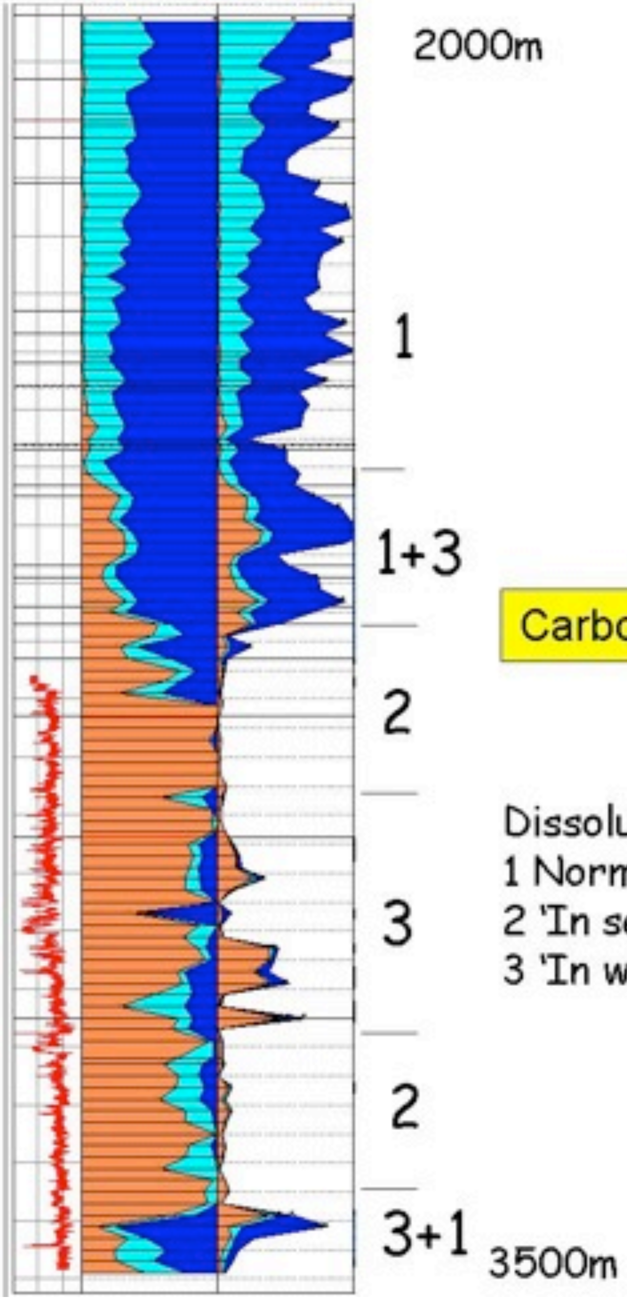

Carbonate dissolution and sedimentation rates

Dissolution scenarios
1 Normal marine – rich and diverse calcareous assemblages
2 'In sediment' dissolution – may be barren of foraminifera
3 'In water' dissolution – contain common arenaceous forams

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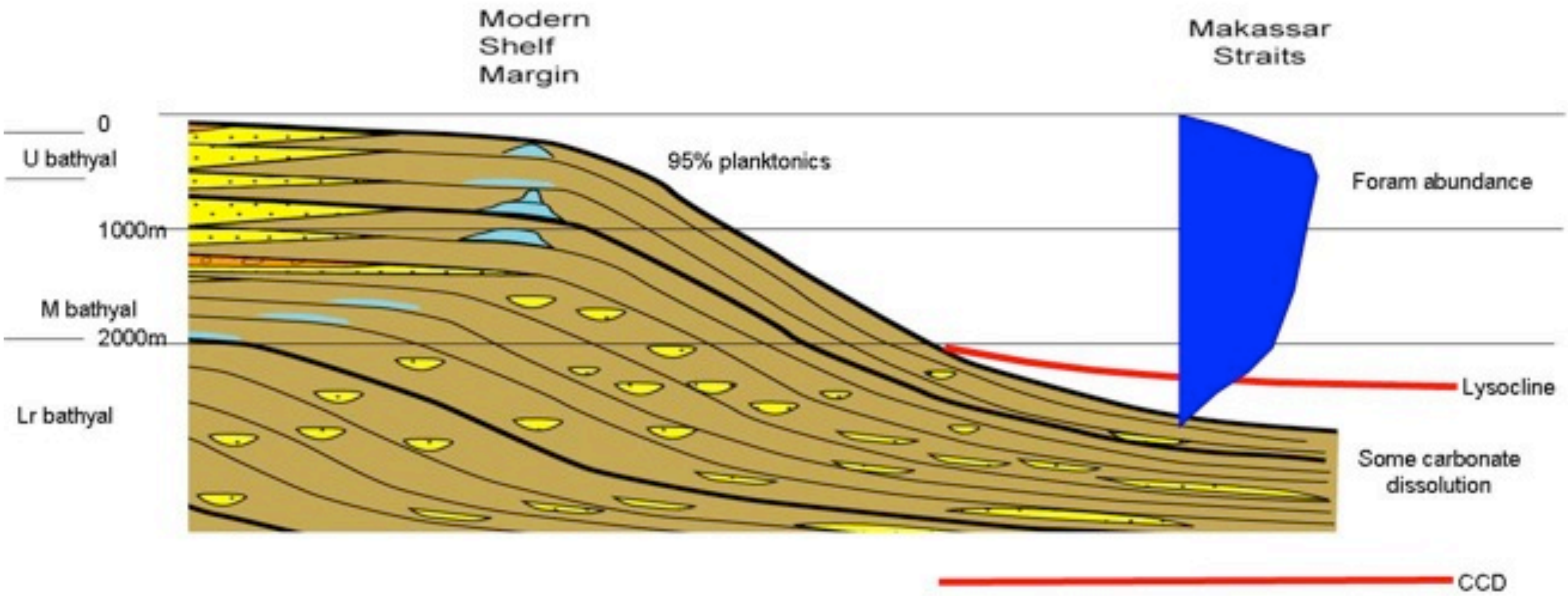
Carbonate dissolution issues

Normal marine setting



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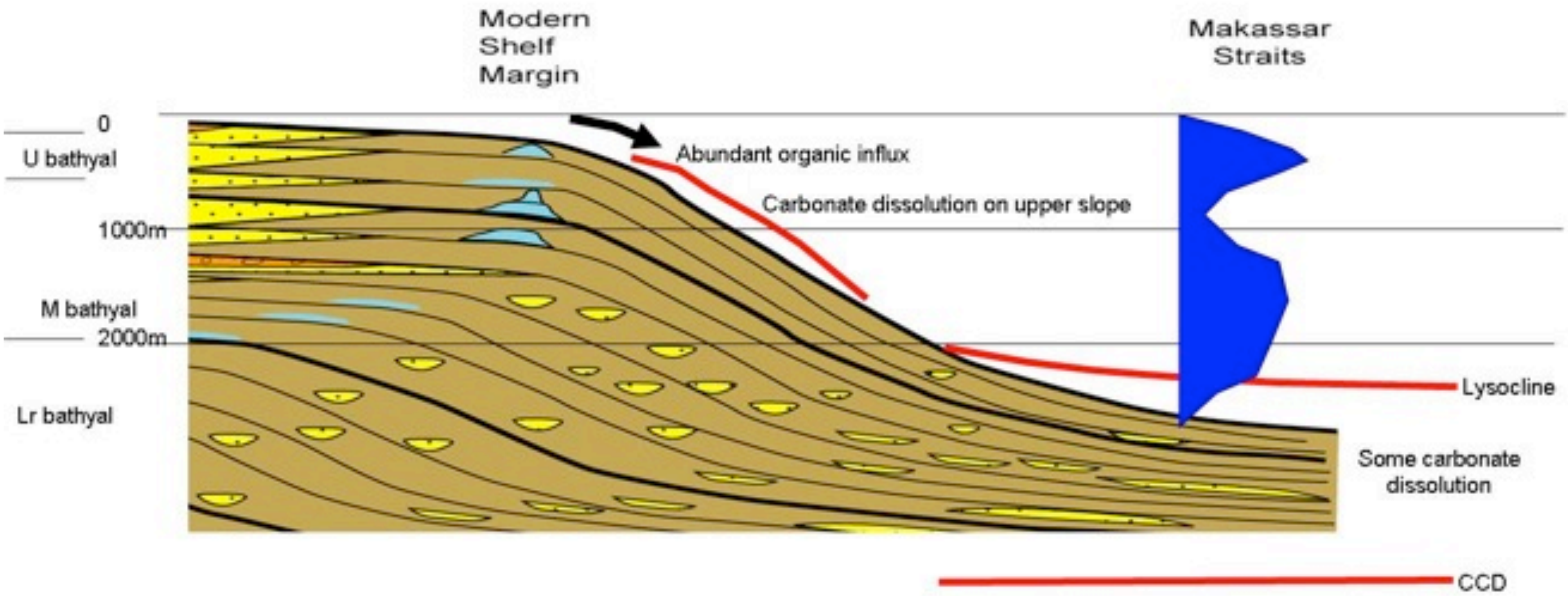
Carbonate dissolution issues

Normal marine setting 'in sediment' dissolution



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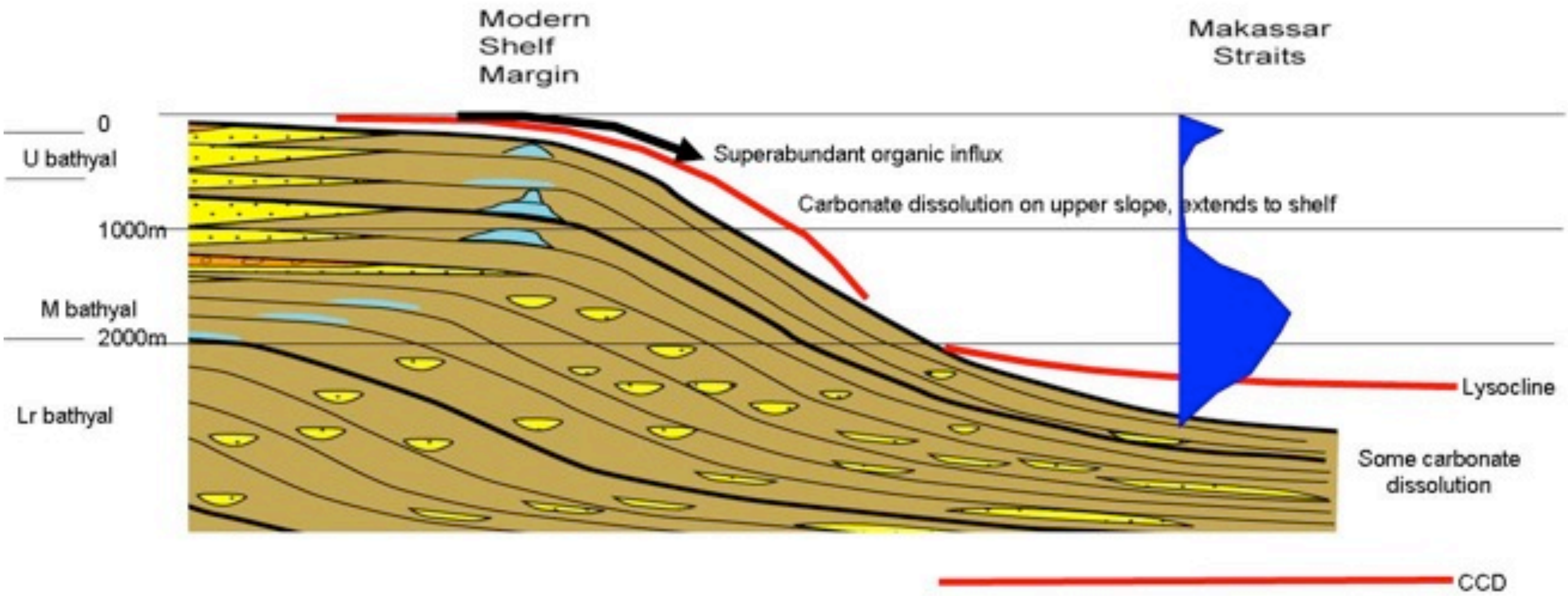
Carbonate dissolution issues

Normal marine setting pronounced 'in sediment' dissolution



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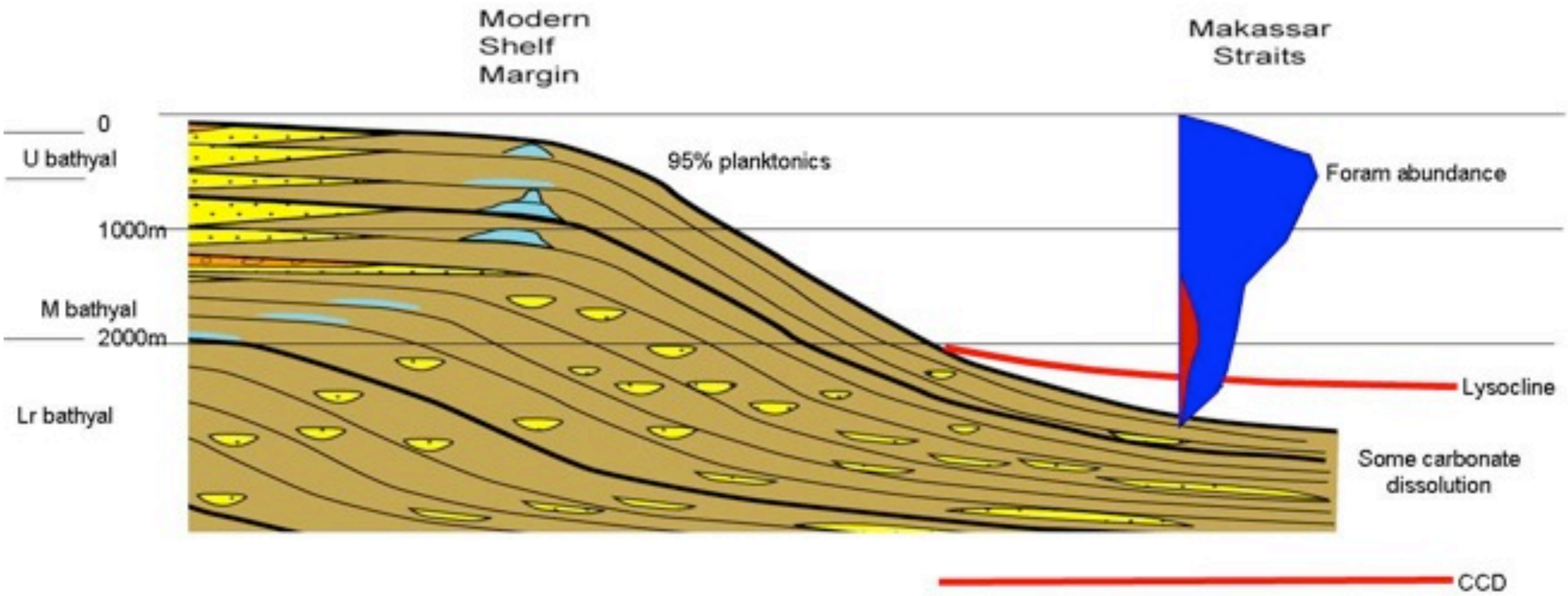
Carbonate dissolution issues

Carbonate dissolution setting



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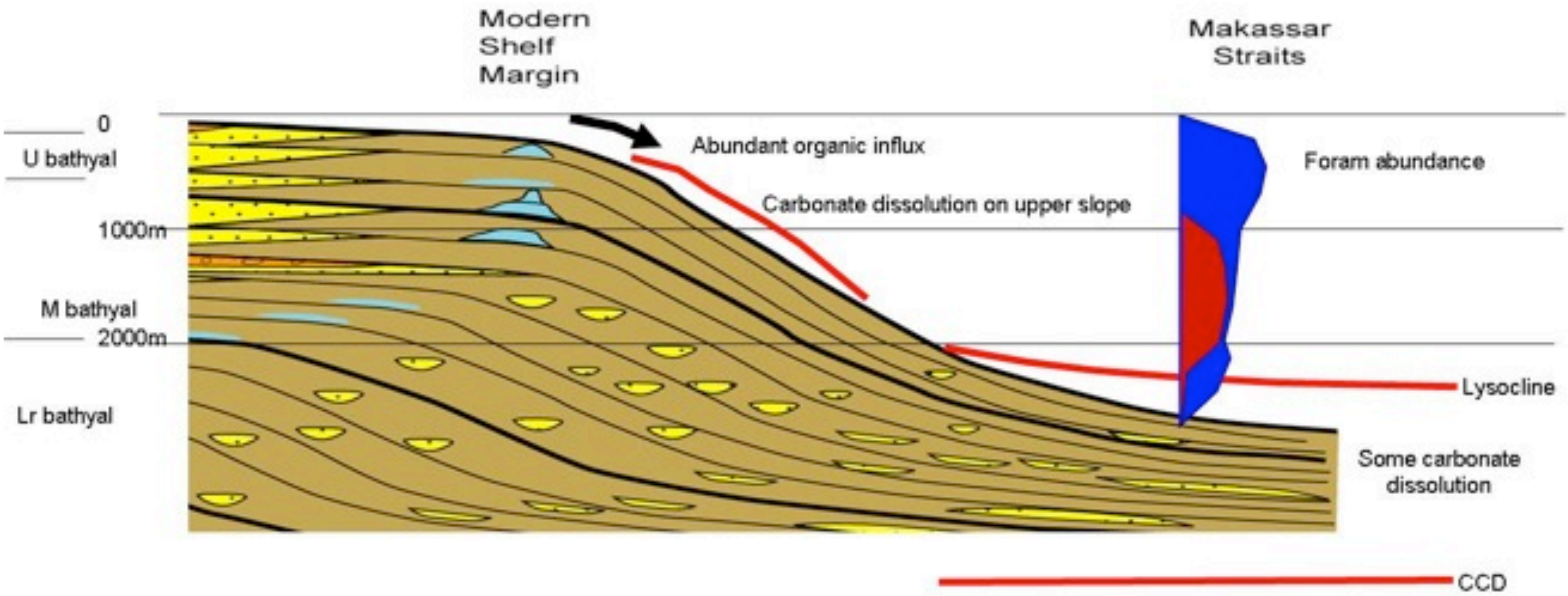
Carbonate dissolution issues

Carbonate dissolution setting 'in water' dissolution



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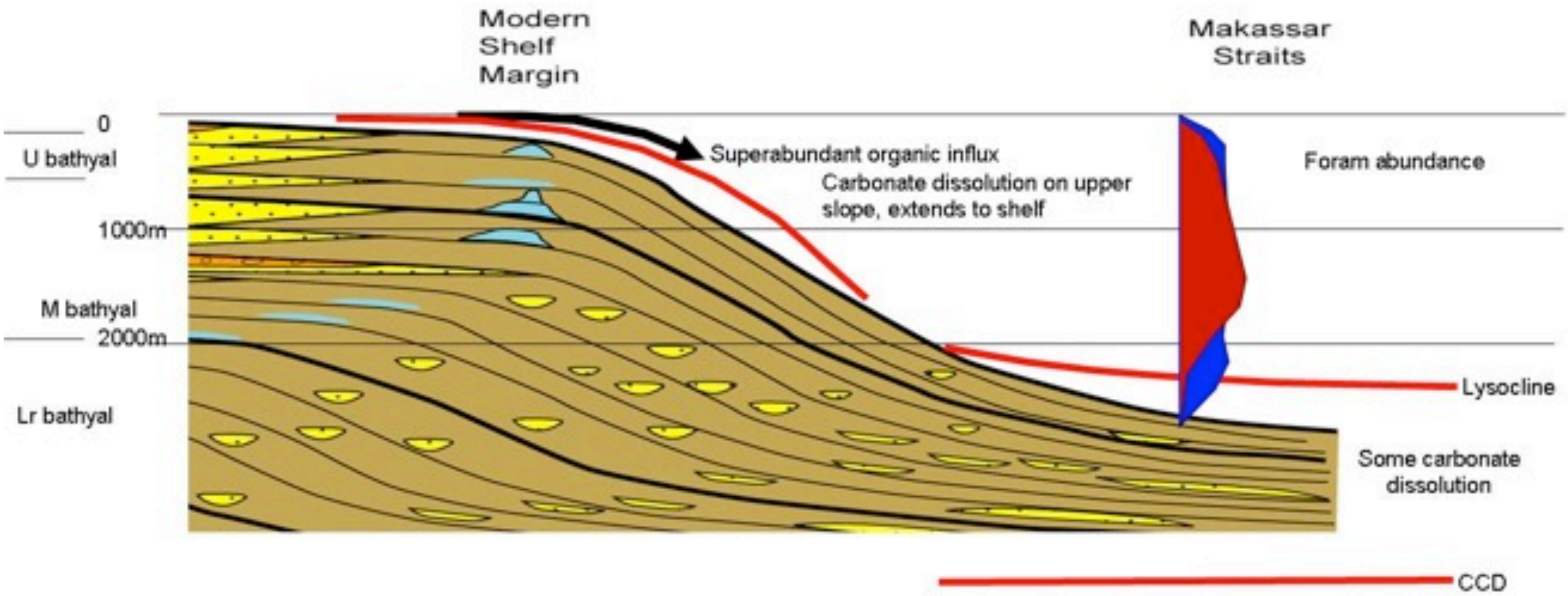
Carbonate dissolution issues

Carbonate dissolution setting pronounced 'in water' dissolution



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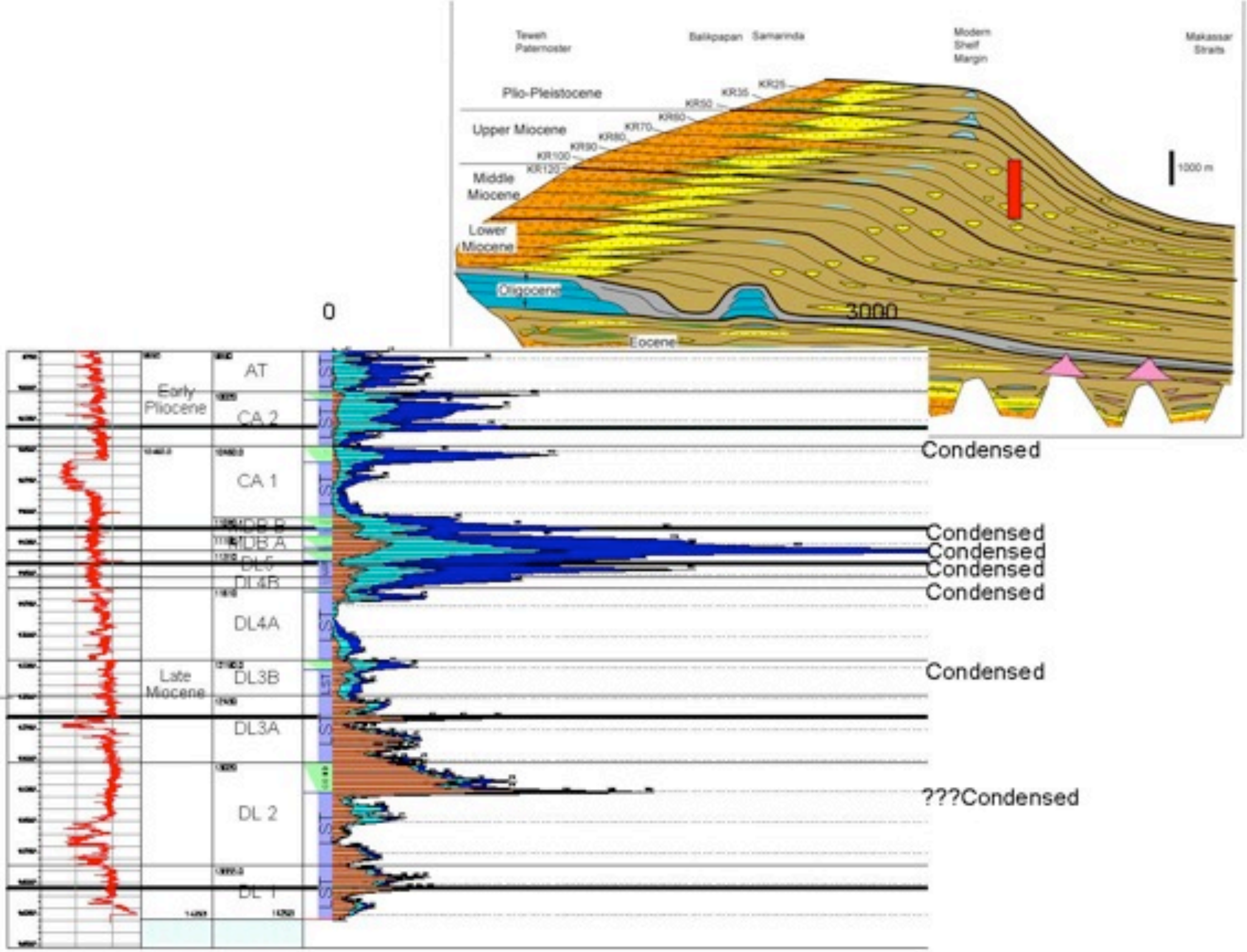

Less carbonate dissolution

More carbonate dissolution

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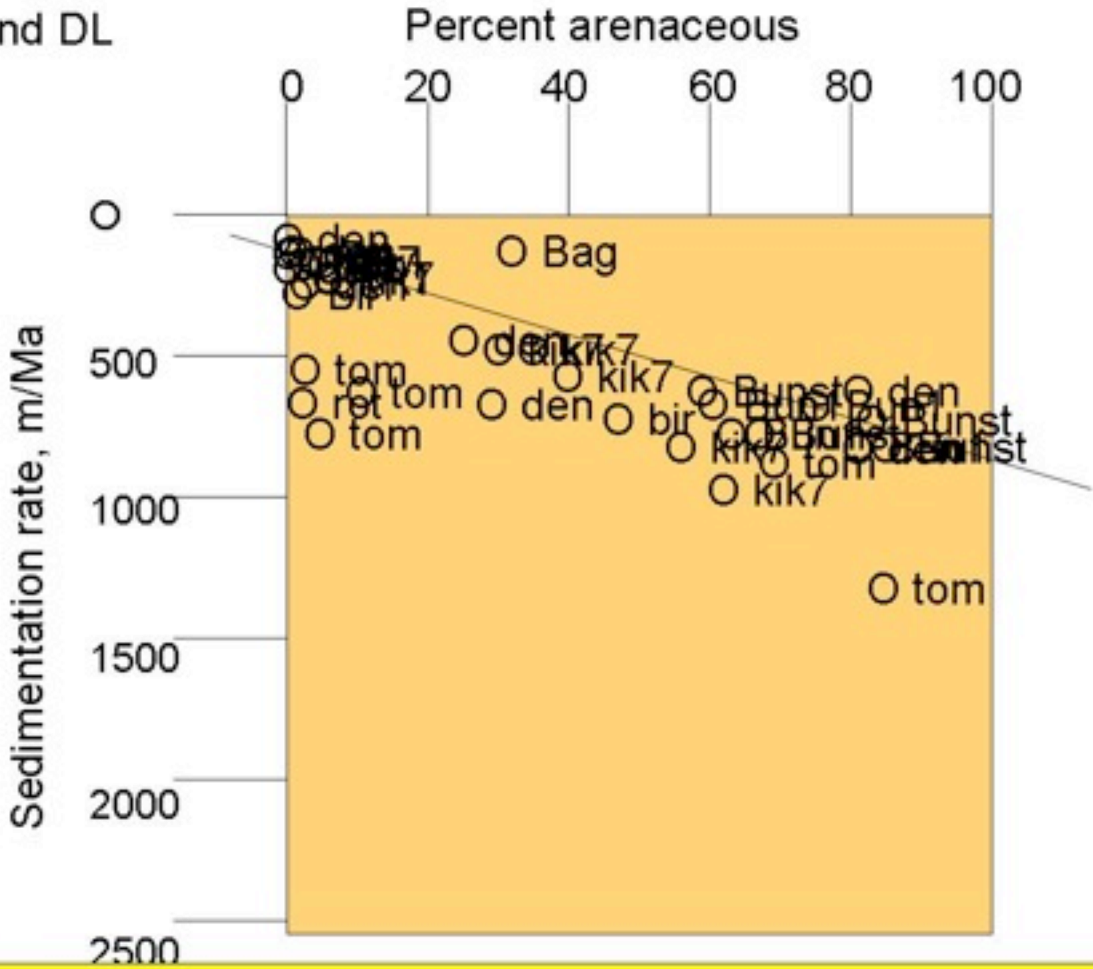
DD, DH and DL



This tells us:

1) Acmes of arenaceous forams are probably not condensed sections
2) Divergences from this trend probably identify misinterpretations or periods of erosion

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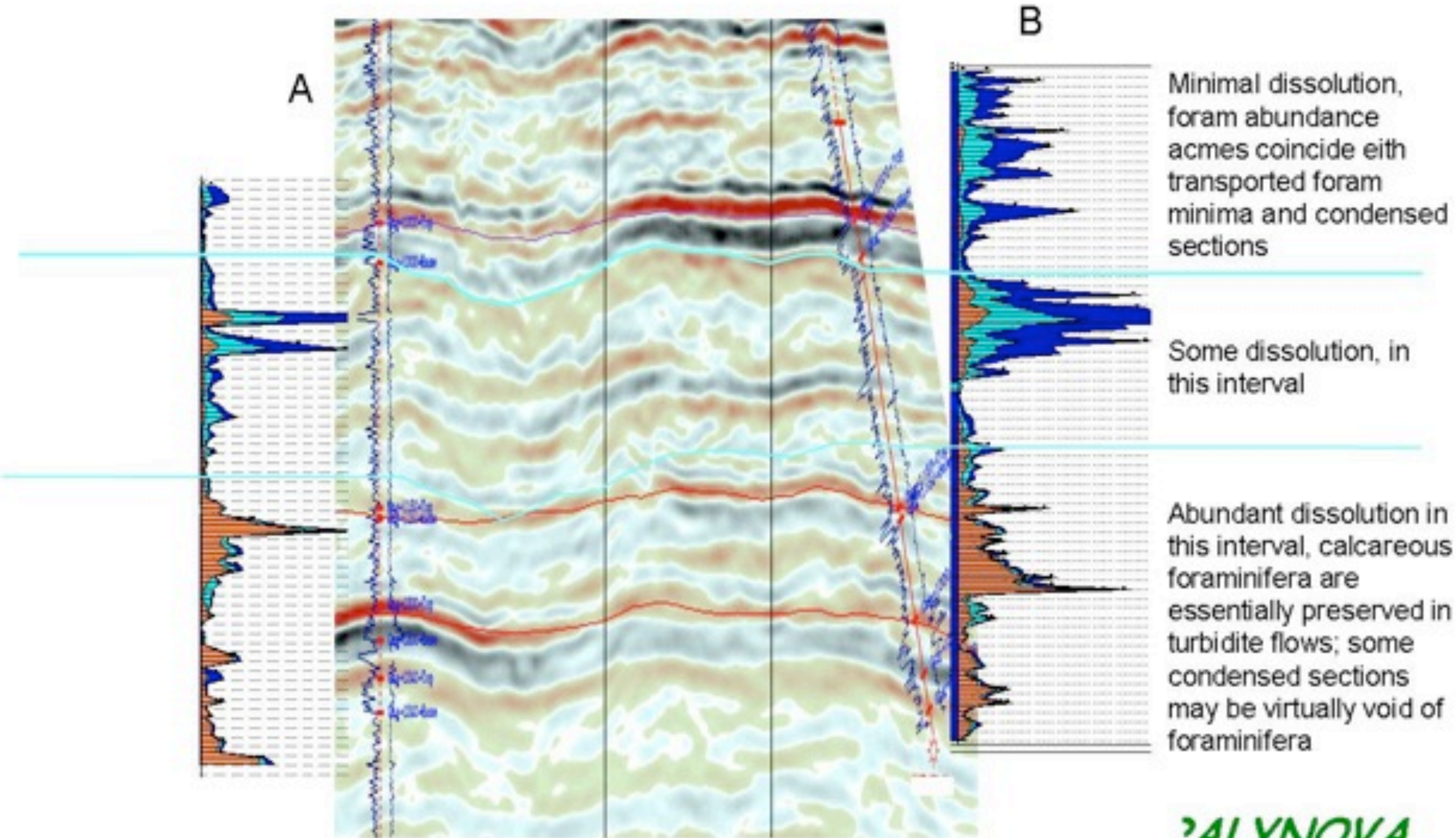
Well A and Well B

The main control on microfossil deposition is carbonate dissolution, which displays three different levels of intensity through the succession. Different biostratigraphic models are needed to explain sequence characteristics in each of these intervals



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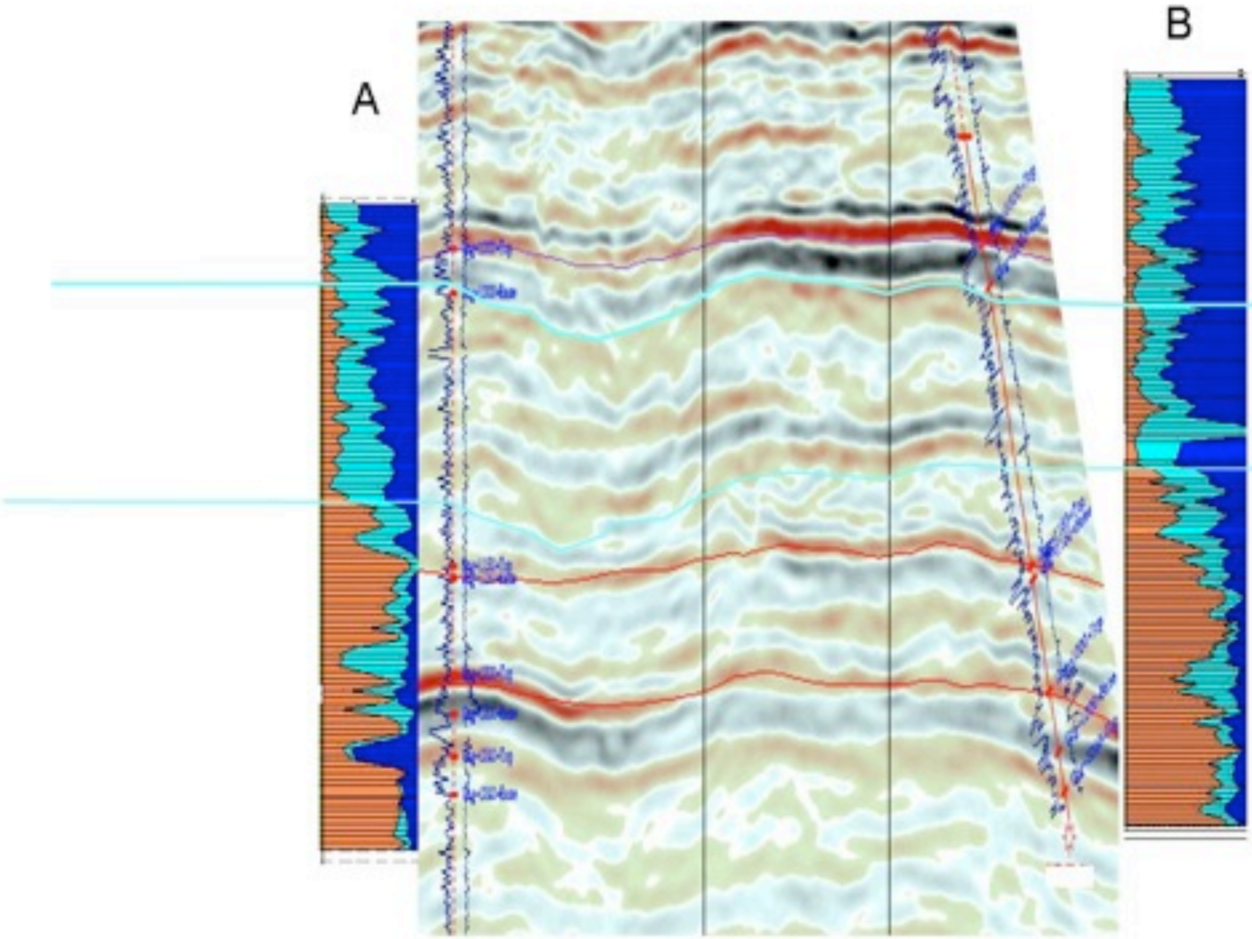
Well A and Well B

The main control on microfossil deposition is carbonate dissolution, which displays three different levels of intensity through the succession

This is shown particularly clearly by plotting foram arenaceous vs calcareous forams as a %. .



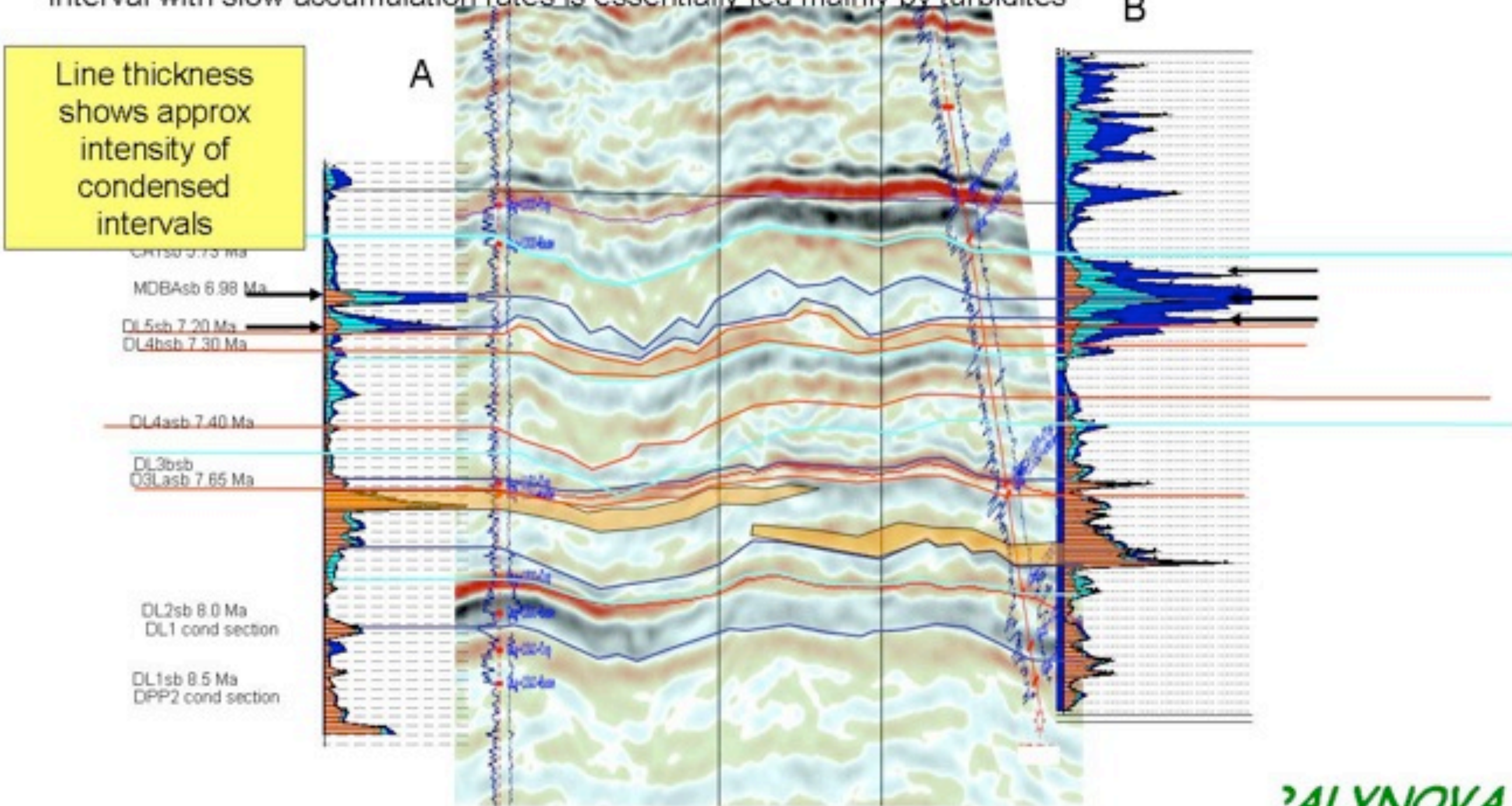
Minimal dissolution, foram abundance acmes coincide eith transported foram minima and condensed sections

Some dissolution, in this interval

Abundant dissolution in this interval, calcareous foraminifera are essentially preserved in turbidite flows; some condensed sections may be virtually void of foraminifera

Plot shows foraminiferal abundance

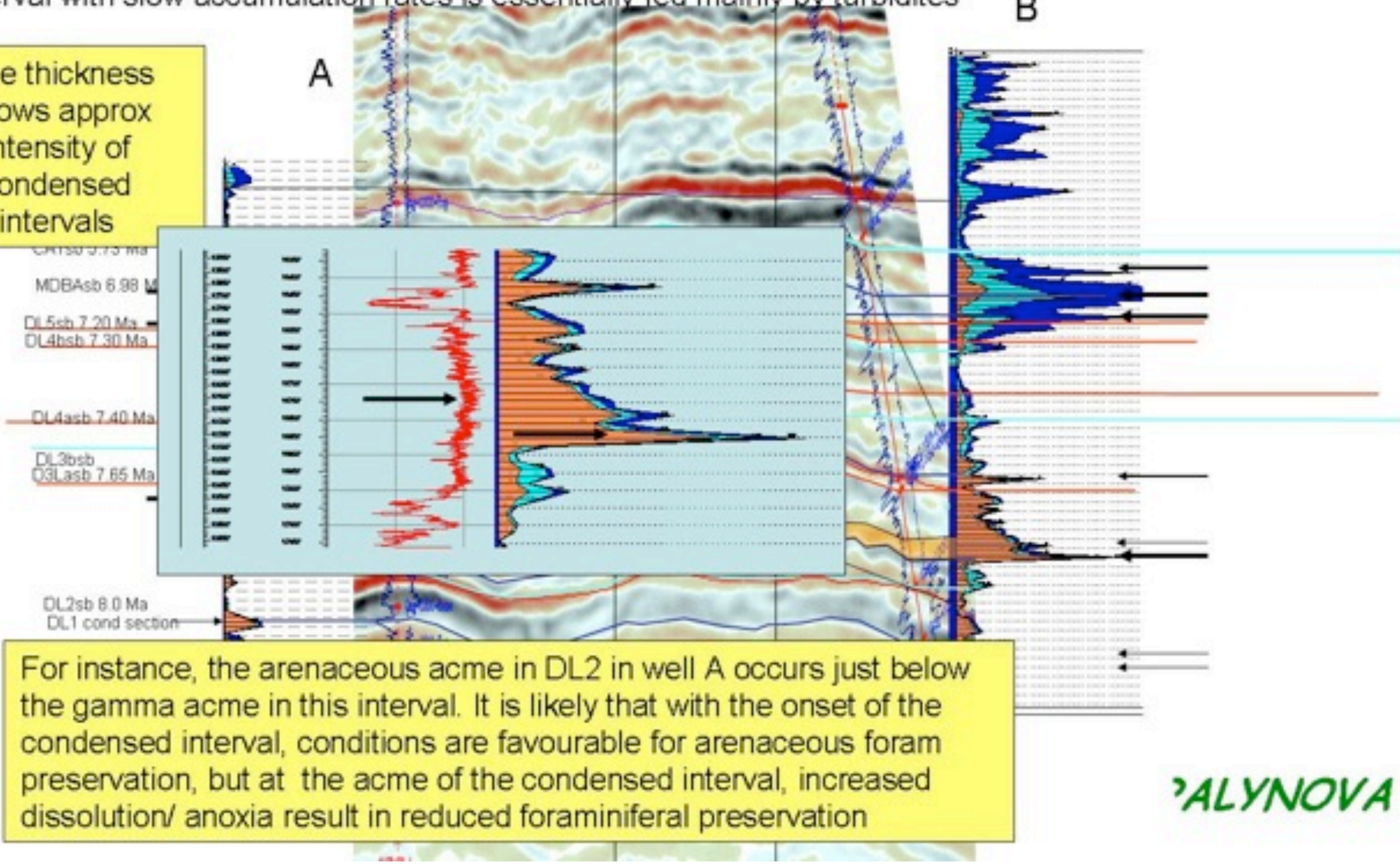
Acmes (arrowed) suggest intervals of more condensed deposition, However, few of these acmes really reflect true condensed sections, in DPP/DL1, it is possible that true condensed are present but not reflected by strong foram acmes, in DL2, arenaceous acmes seem to just precede the condensed section, in DL5 and MDB, foram acmes contain fewer transported forams in terms of %, but increased transported forams in terms of abundance. This pattern is not fully understood, but likely suggests that even the MDB interval with slow accumulation rates is essentially fed mainly by turbidites



Plot shows foraminiferal abundance

Acmes (arrowed) suggest intervals of more condensed deposition, However, few of these acmes really reflect true condensed sections, in DPP/DL1, it is possible that true condensed are present but not reflected by strong foram acmes, in DL2, arenaceous acmes seem to just precede the condensed section, in DL5 and MDB, foram acmes contain fewer transported forams in terms of %, but increased transported forams in terms of abundance. This pattern is not fully understood, but likely suggests that even the MDB interval with slow accumulation rates is essentially fed mainly by turbidites

Line thickness shows approx intensity of condensed intervals



For instance, the arenaceous acme in DL2 in well A occurs just below the gamma acme in this interval. It is likely that with the onset of the condensed interval, conditions are favourable for arenaceous foram preservation, but at the acme of the condensed interval, increased dissolution/ anoxia result in reduced foraminiferal preservation

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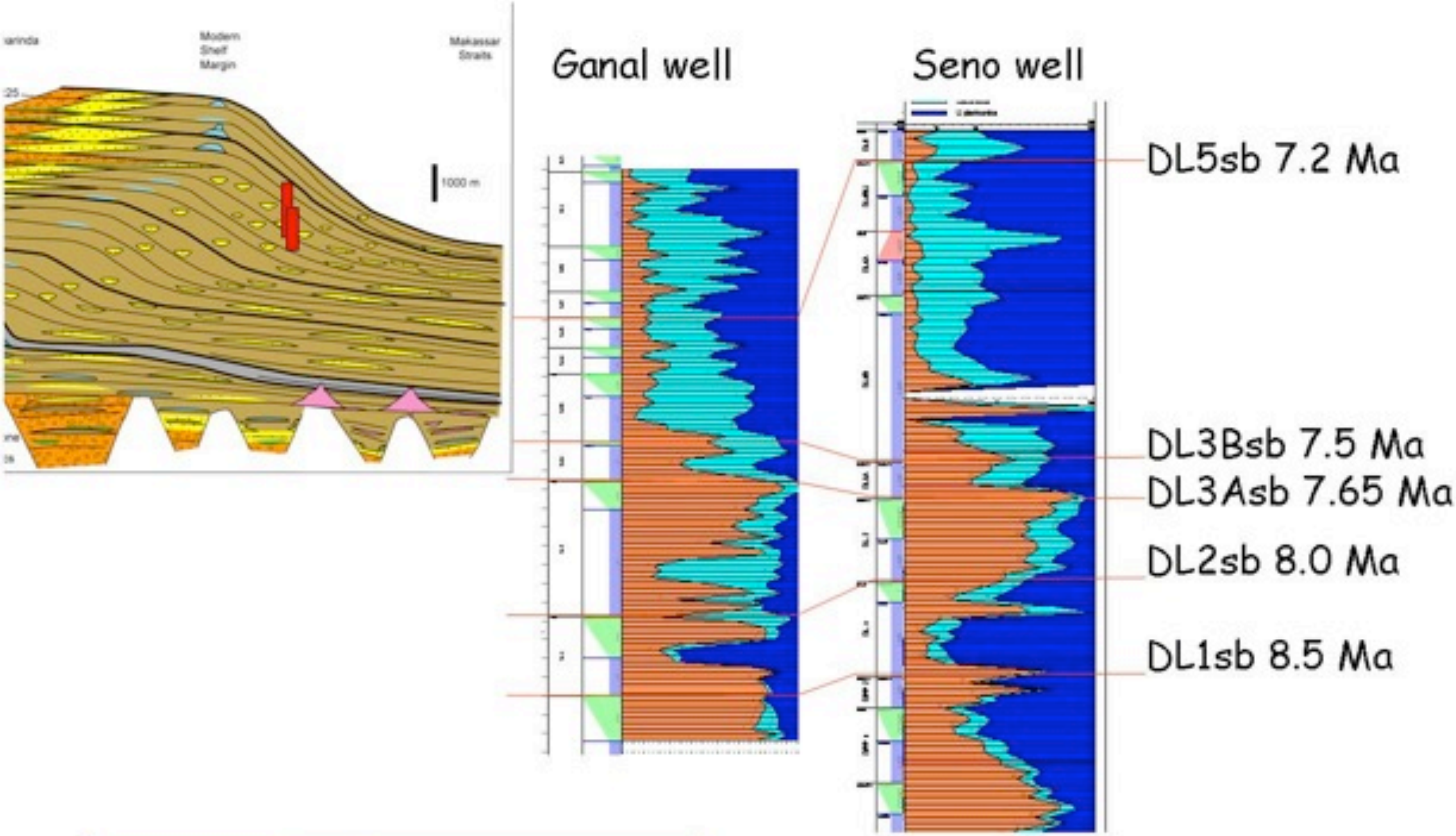

Carbonate dissolution scenarios

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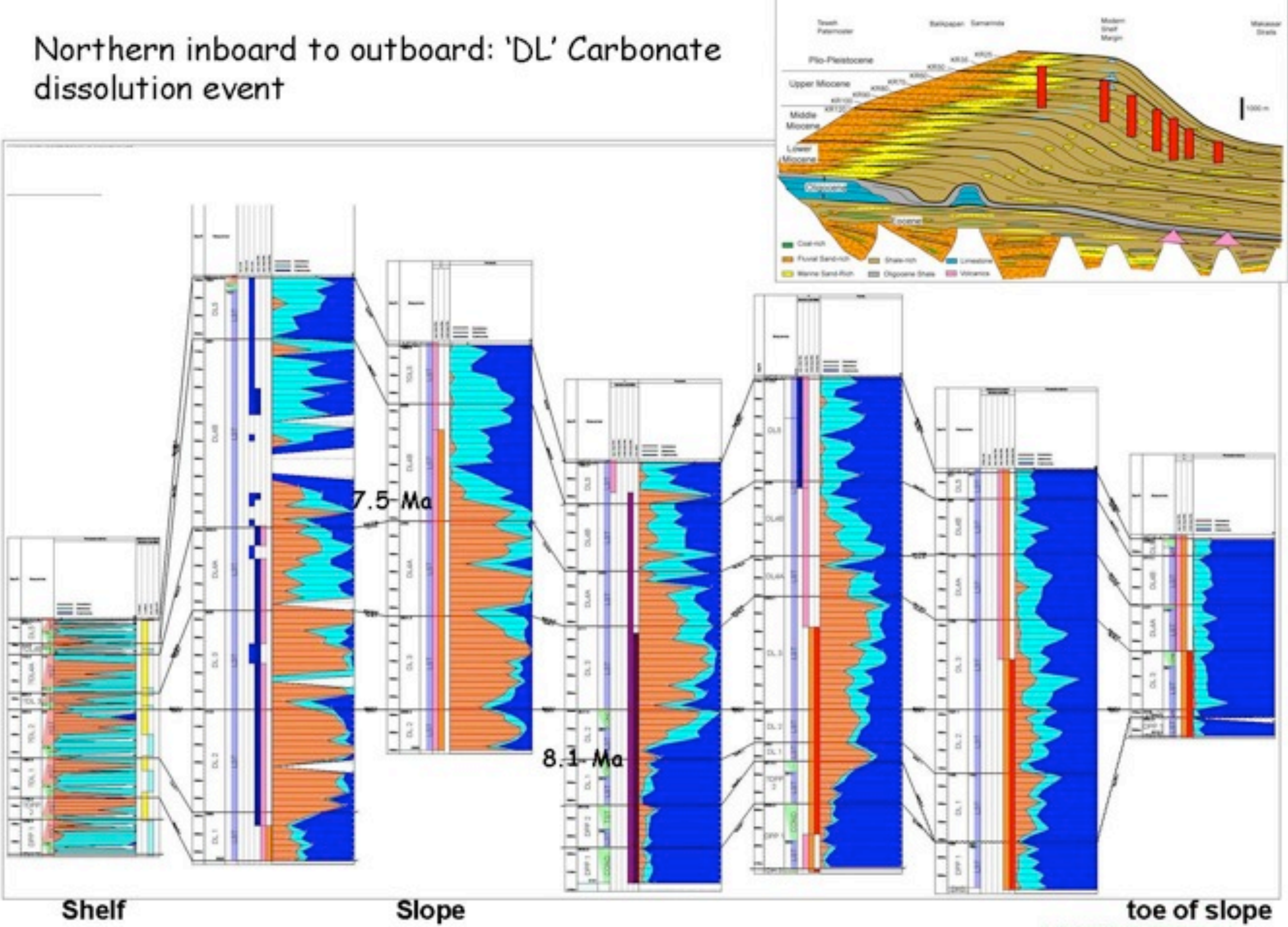
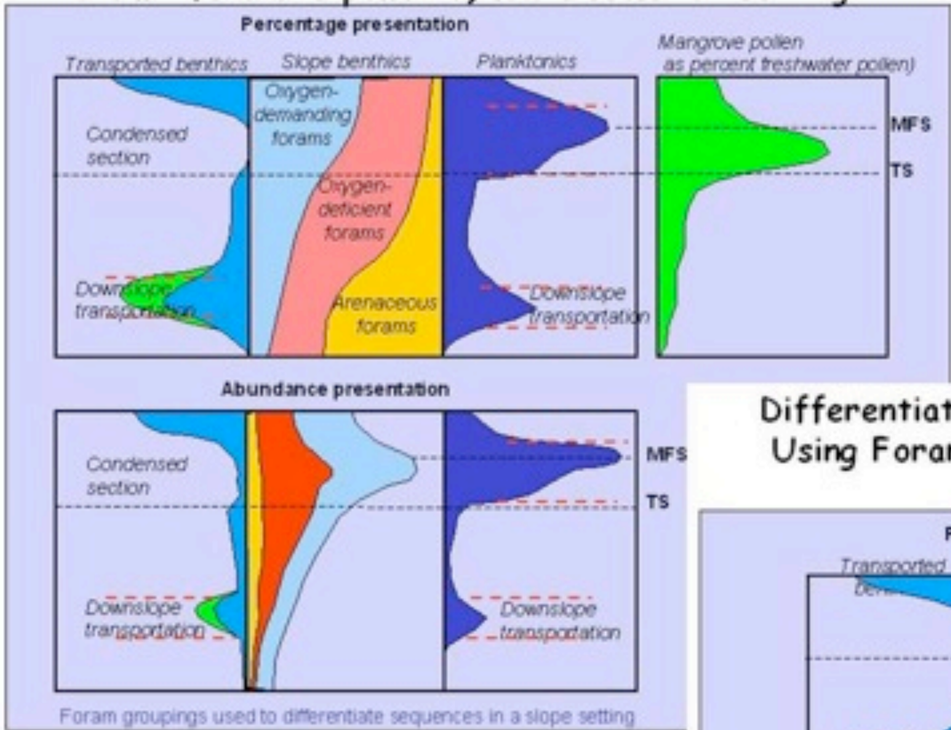
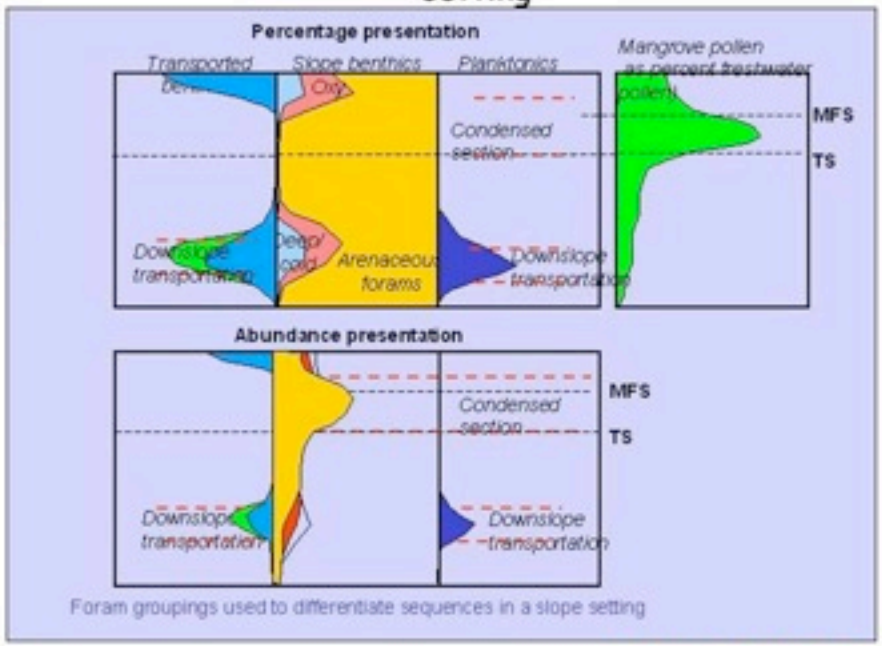
Northern inboard to outboard: 'DL' Carbonate dissolution event



Differentiation of Systems Tract in Slope Setting Using Foraminifera and pollen a) low dissolution setting



Differentiation of Systems Tract in Slope Setting Using Foraminifera and pollen b) High dissolution setting



Carbonate dissolution scenarios

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Makassar Straits environment interpretation using foraminifera and palynomorphs

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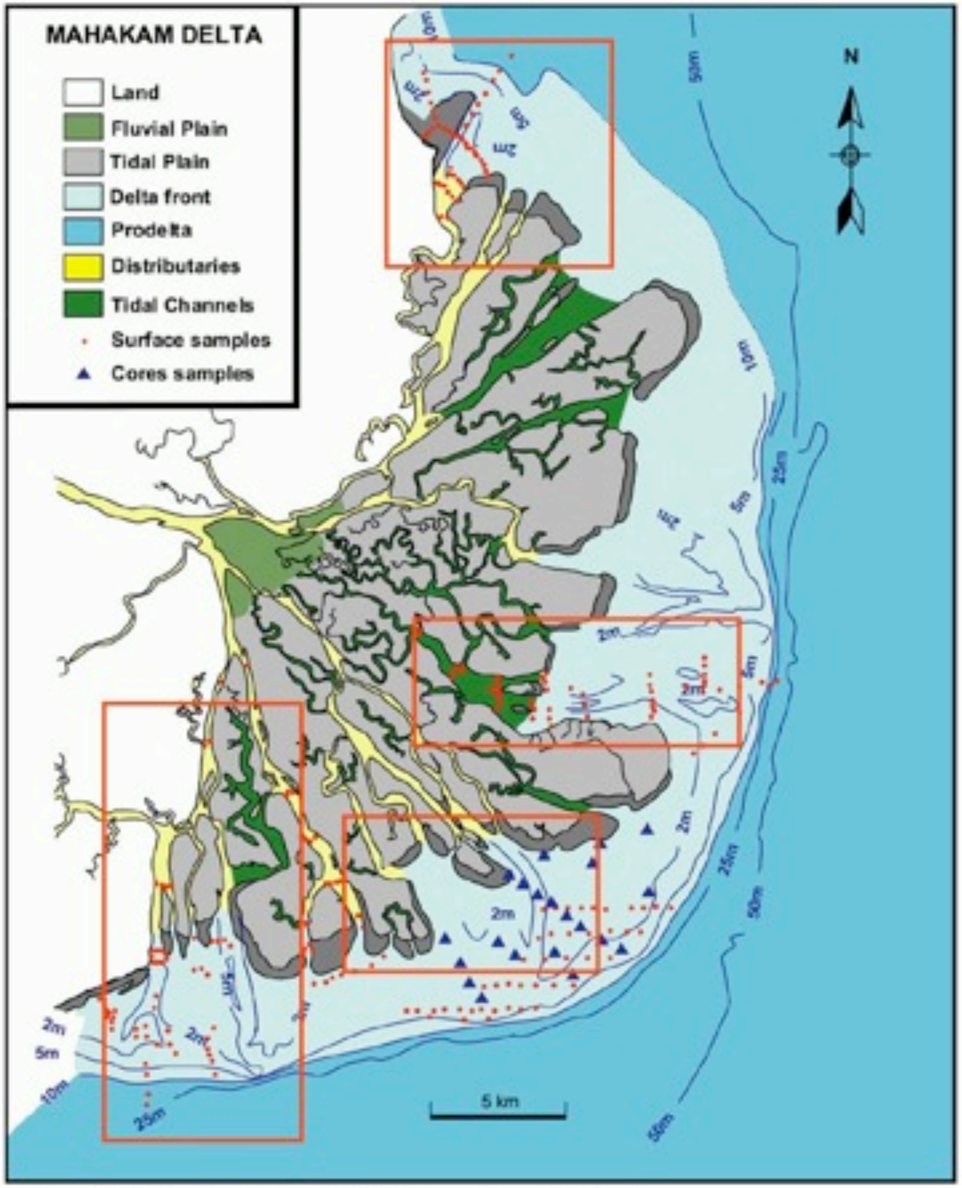


Figure 2: Mahakam delta sedimentological features and sampling locations.

6.44

Coastal plain environments: Mahakam Delta

Delta plain

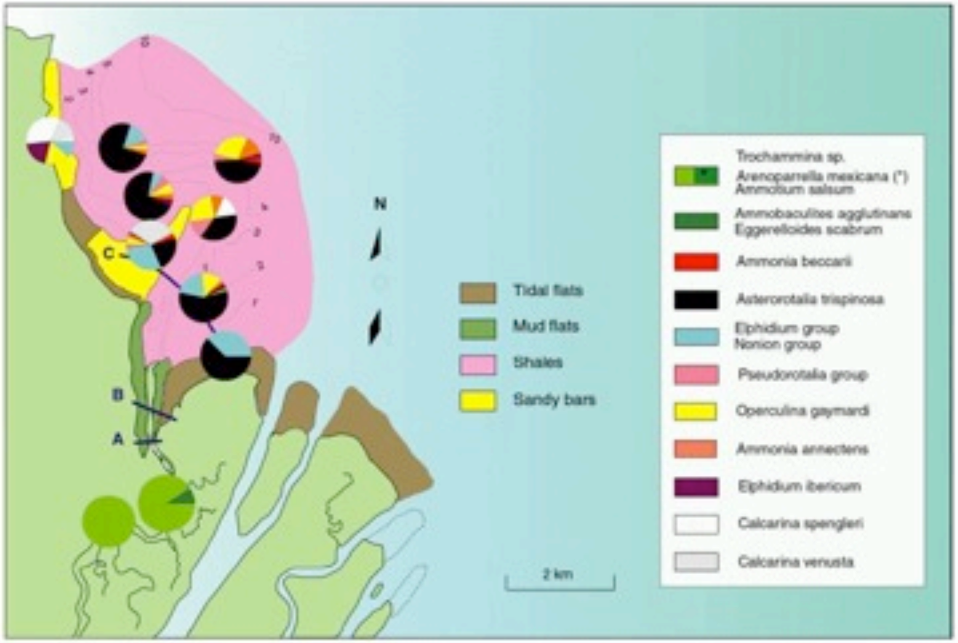
The delta plain can be subdivided into a fluvial and a tidal delta plain. The fluvial delta plain is characterized by highly compacted, well drained ground, the tidal delta plain by its low elevation and is subjection to daily tidal inundations. The plant cover is *Nypa* palms and mangroves. The tidal deltaic plain is incised by distributaries and tidal channels.

Delta front

The delta front is an intertidal to shallow subtidal platform. The topography consists of linear undulations perpendicular to the coast forming bars and shoals. It also is incised by distributary channels. They extend seaward to its outer limit, terminating in a mouth bar. The inner portion is made up of extensive tidal flats.

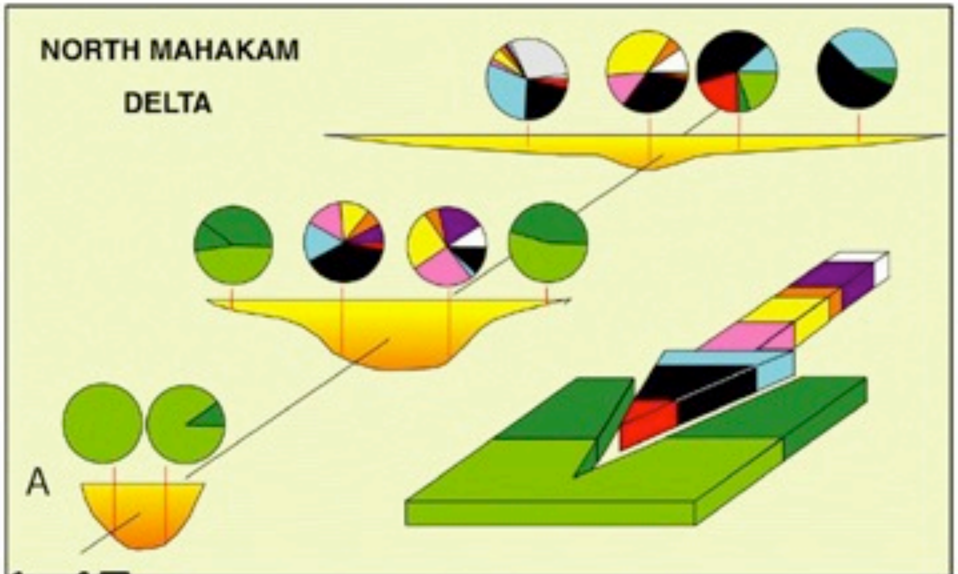
Prodelta

The prodelta is a smooth seaward slope, the inner part set off by an abrupt break in slope at the 5 m isobath. The outer limit is between the 60 and 70 m isobaths. The prodelta shows a sharp asymmetry, due to the drift current and is30 km wide in the S but 5 to 15 Km



North Mahakam delta:
Microfaunal distribution shows foraminiferal assemblages across three profiles (A, B, C) across a channel. Note the dominance of *Asterorotalia* in the muddy delta front facies and the presence of transported calcareous taxa *(Calcarina)* in the sands of beaches and bars.

Mahakam modern facies studied by Bernard Lambert of Total



Lateral distribution of the assemblages across tidal delta and delta front channels. The main feature is the penetration of calcareous taxa (coloured arrow) in the bottom channels (drift current , tide).

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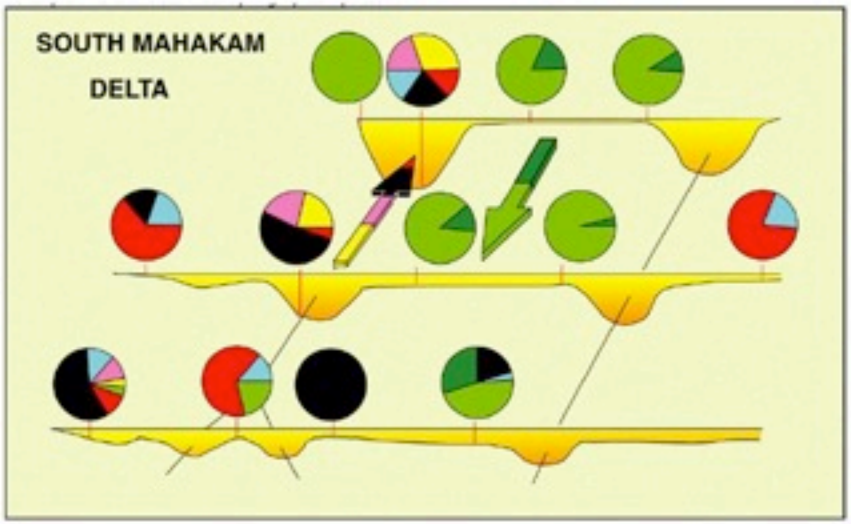
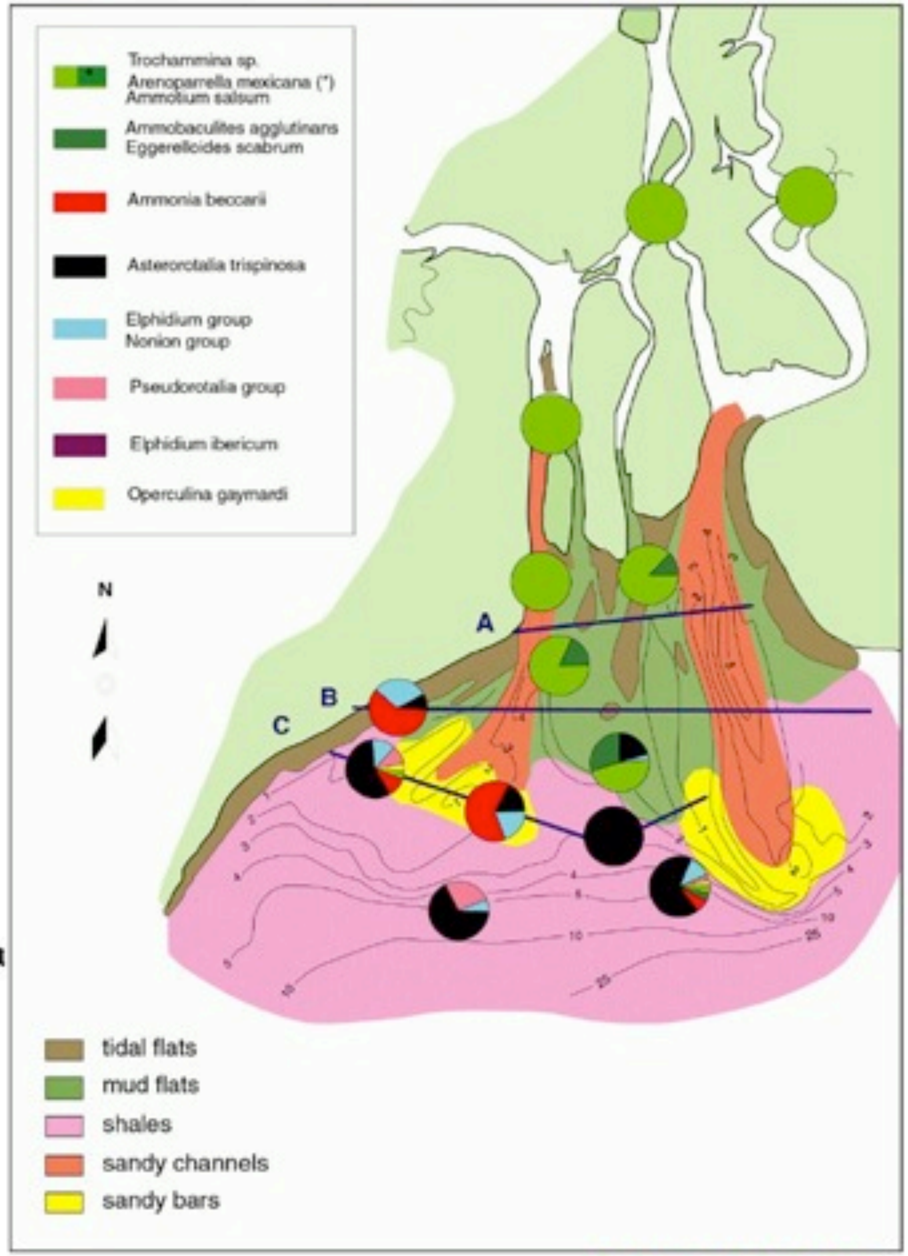
6.45

South Mahakam delta: In this area, the mud and tidal flats are very well developed. Arenaceous biofacies are widely developed. *Asterorotalia* and *Elphidium* predominate in the muddy delta front facies, the sandy beaches and bars contain populations of *Ammonia*.



Lateral distribution of the microfauna across delta front channels. Note the extent of arenaceous taxa (green arrow) associated with the mudflats advance and in contrast the deep penetration of calcareous taxa like *Operculina* never seen in the delta front itself (colored arrow).



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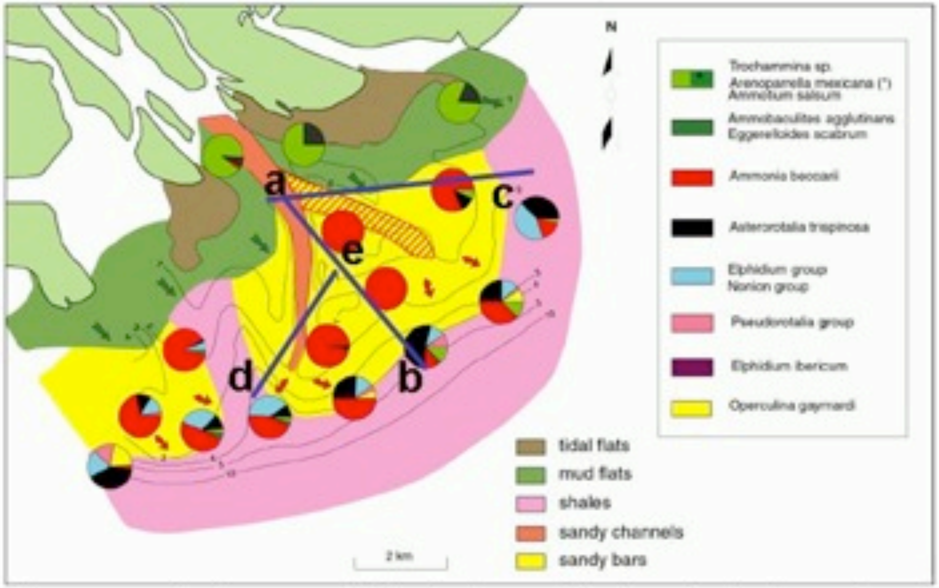
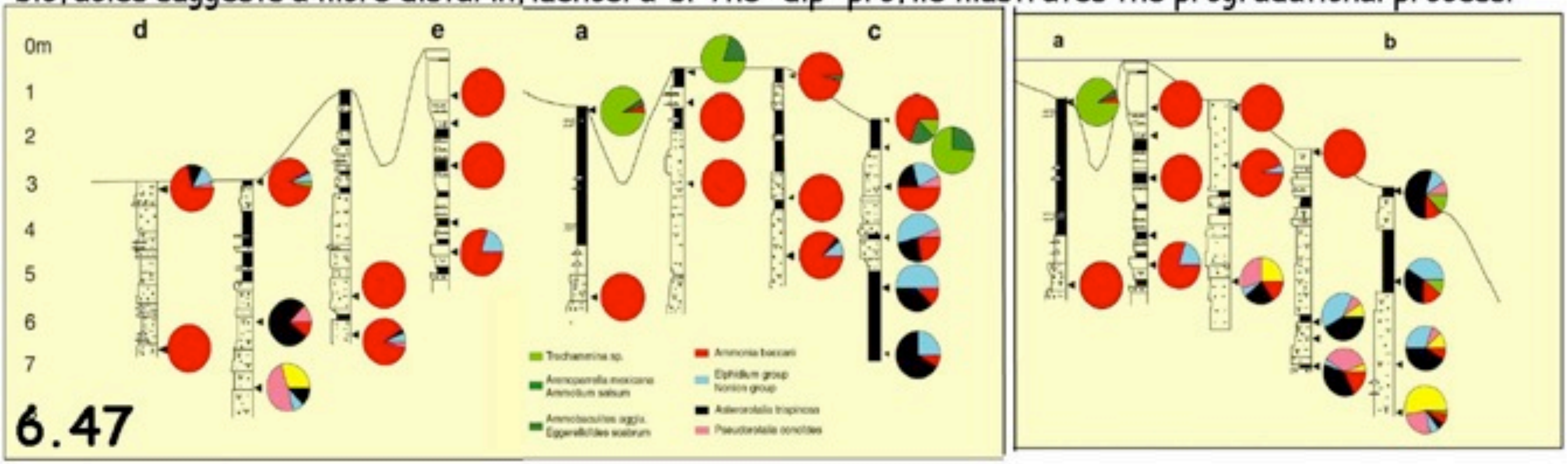


South East Mahakam delta: The dominance of *Ammonia beccari* is associated with the relative importance of sand bodies (mouth bars) in this area (red arrows indicate the sandy progradation, the green arrow shows the advance of mud flats overlying the sands (in red dashes, an old distributary channel).

Mahakam modern facies studied by Bernard Lambert of Total

Tunu mouth bar: a-c 'Strike" profile located along the tidal flats. The surface mudflats are characterised by arenaceous and *Ammonia*, delta front shales by *Asterorotalia*, *Elphidium* and *Nonion*). Tthe core sands contain numerous *Ammonia beccarii*. d-e This profile represents the sandy mouth bar; *Ammonia* predominates, however, in the deepest level of the core, the presence of a more diversified biofacies suggests a more distal influence. a-b. The "dip" profile illustrates the progradational process.



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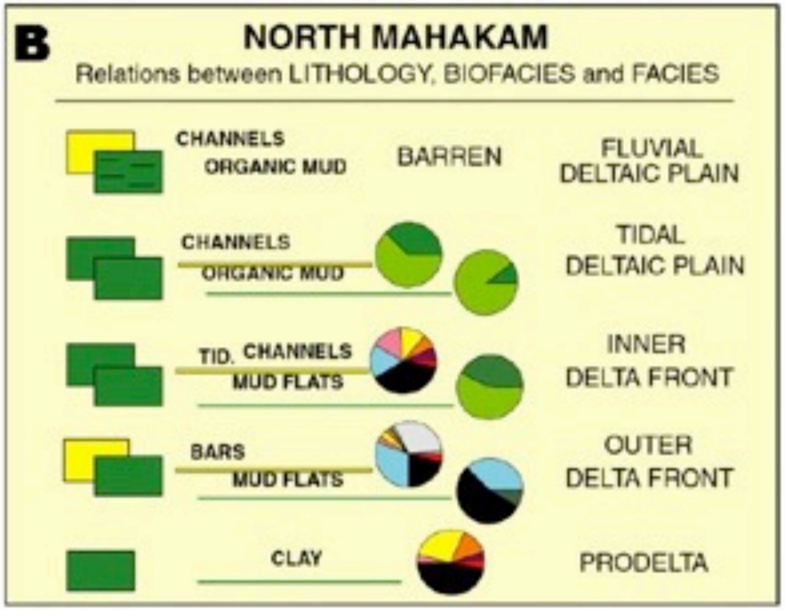
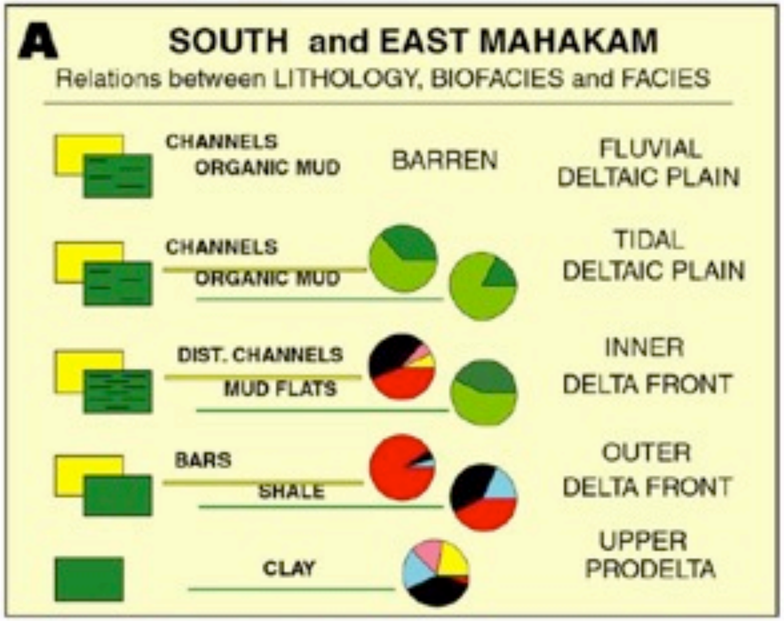
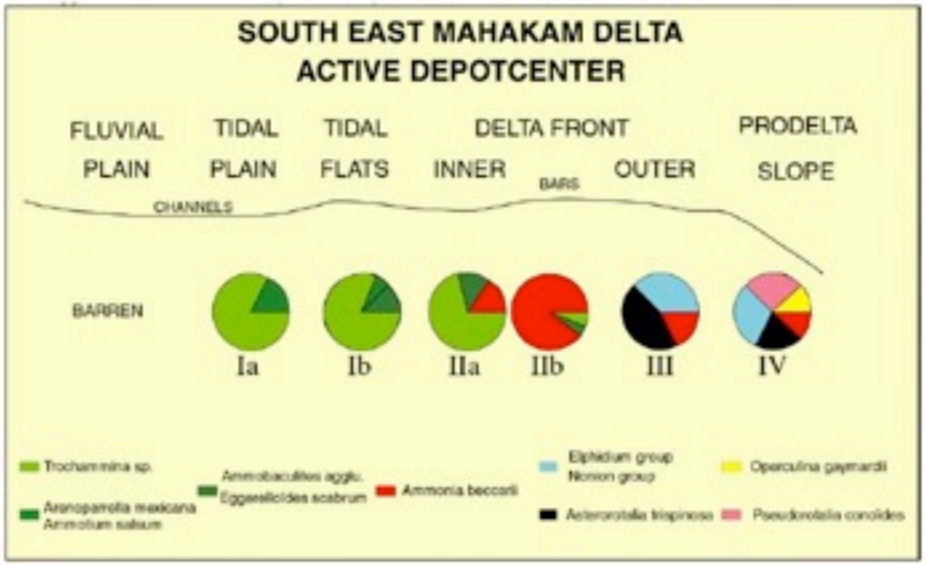




Relationship between lithology, biofacies and lithological facies. Depending on their location in the
delta, identical lithologies have different associations (especially marked between the North and the other areas).

Mahakam modern facies studied by Bernard Lambert of Total



South East Mahakam: Delta biofacies distribution. This sketch shows the general distribution of the main foraminiferal taxa in relation to topography and sedimentology.

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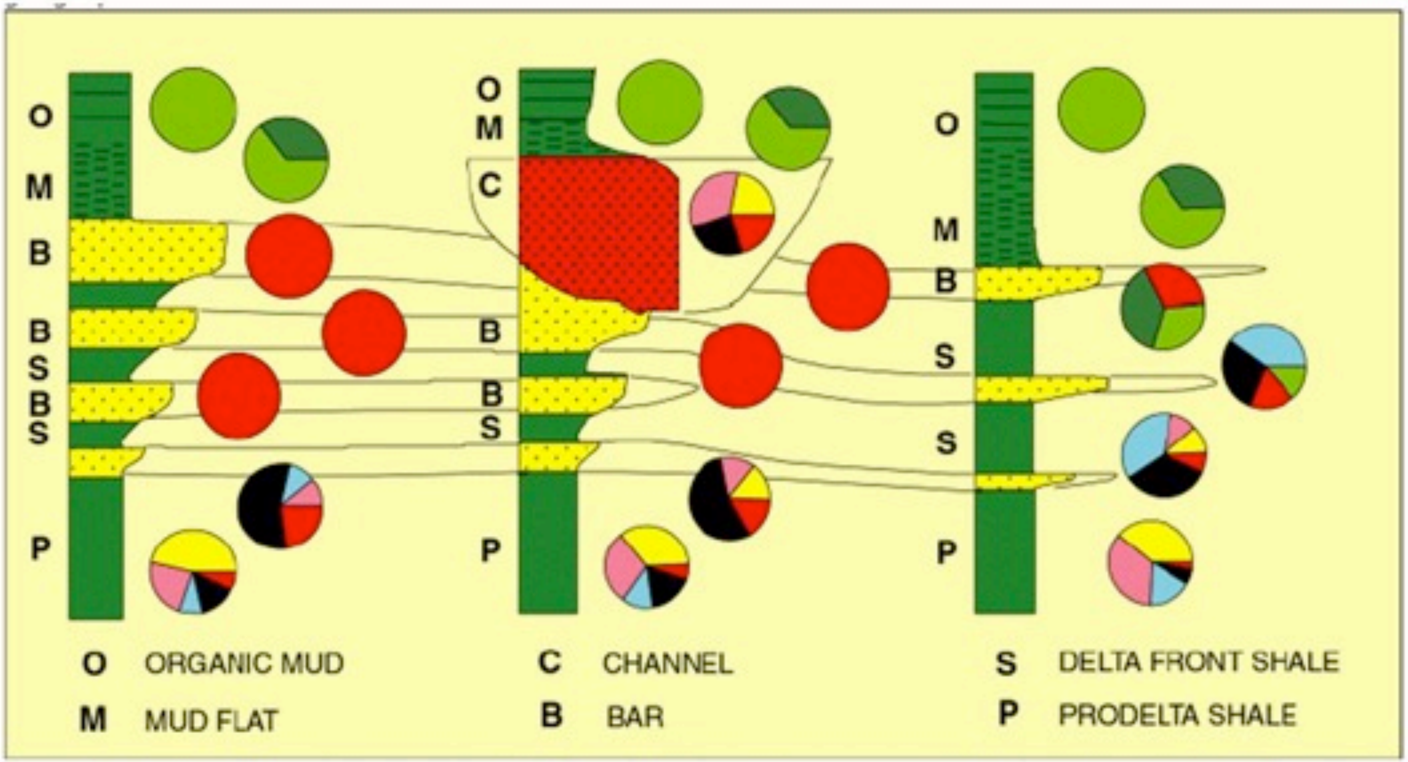

Biofacies distribution in the regressive deposits of the Mahakam delta. Most useful is information regarding the association of sandy sediments and various calcareous taxa (including large benthonics like *Operculina*). In many previous studies this association was interpreted as indicating inner shelf sand deposits. In fact this association indicates lower delta plain channels.

Mahakam modern facies studied by Bernard Lambert of Total

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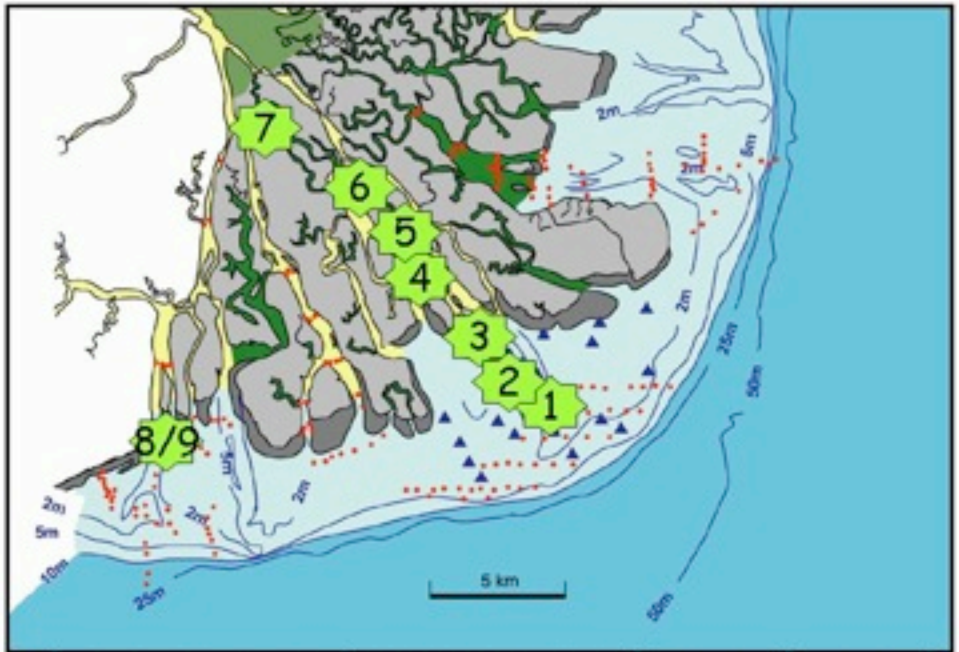
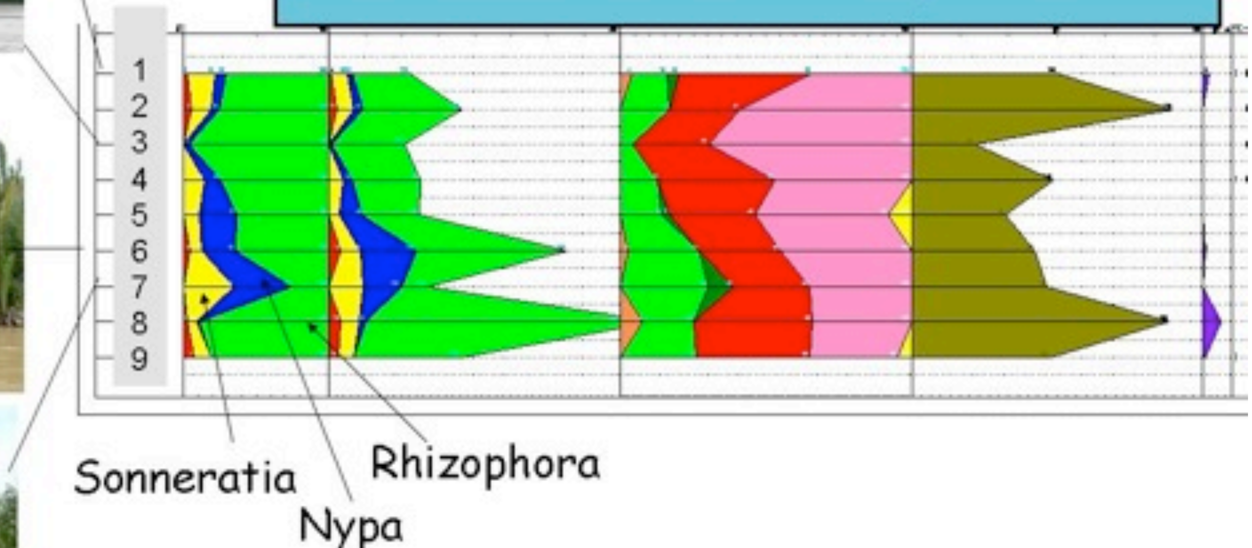
6.50

Mahakam Delta palynology





6.53

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Makassar Straits environment interpretation using foraminifera and palynomorphs

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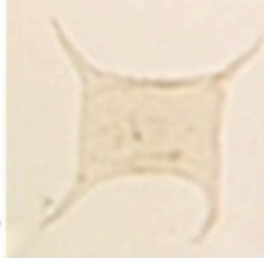
3.e Palynomorphs

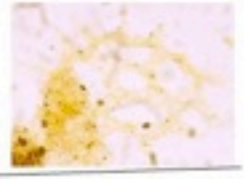
Acid-insoluble microfossils

Diverse and taxonomically unrelated groups, linked solely by acid-insoluble nature of preservable parts and small size



Algae

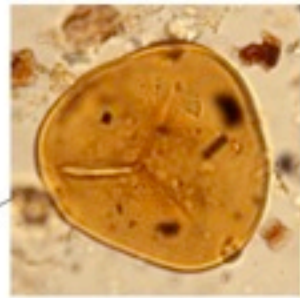
Acritarchs
Dinoflagellates
Chlorophytic algae – eg Pediastrum and Botryococcus
Prasniophyta – Tasmanites



Protists Foraminiferal test linings

Worm teeth

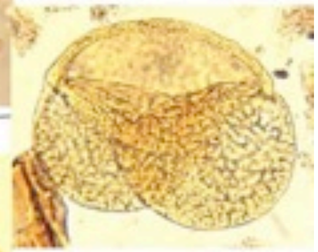
Conodonts
Scalecodonts



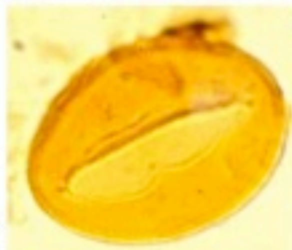
Fungi Spores

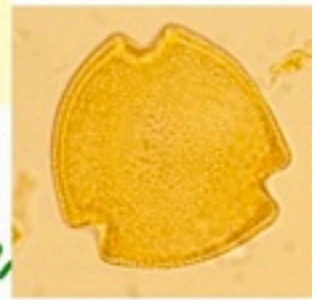
Higher plants

Spores – from mosses, hornworts, ferns, seedferns
Pollen – more simple wall structure, inaperturate or a single aperture – from gymnosperms

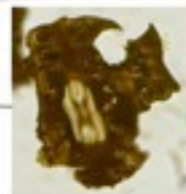


generally more complex wall structure
angiosperms
- inaperturate, single aperture or single aperture derived
'primitive' angiosperms – Magnoliidae and monocots
- triaperturate and triaperturate-derived
- more advanced angiosperms – Eudicots





Cuticle fragments – from gymnosperms and angiosperms



3.32

3.e2 Palynomorphs

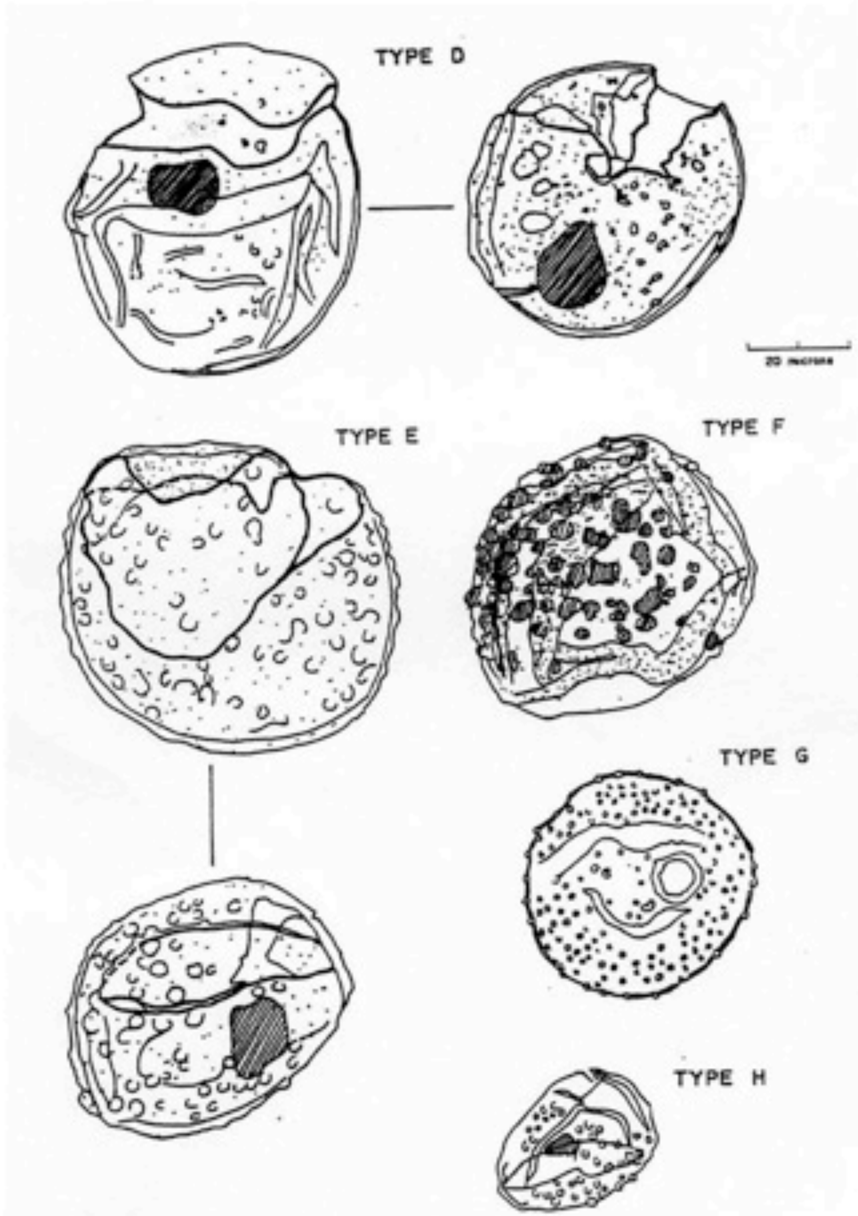
Dinocysts

Freshwater possible dinocysts

The Bosedinia/Granodiscus group are probable freshwater dinocysts, long ignored by palynologists.

They are thought to be dinocysts since

a) Many specimens seem to have archaeopyle
b) Folds on the cyst wall often suggest some form of tabulation, and
c) Most specimens possess an eye spot, or ocellus, seen especially in peridiniod dinocysts



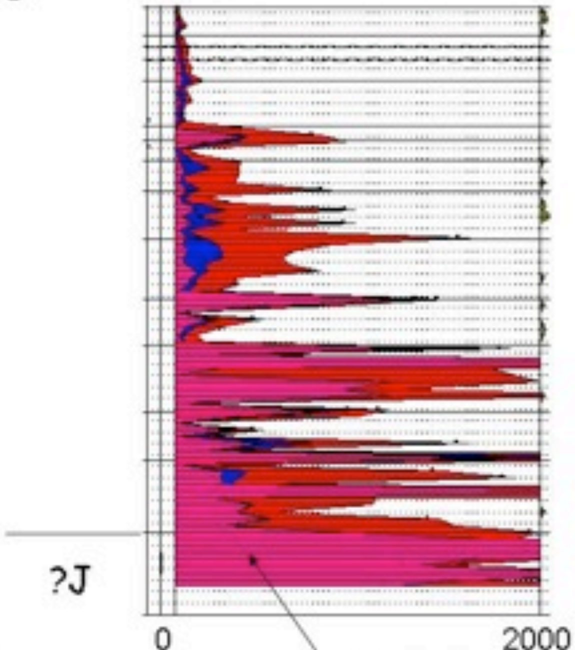
3.e2 Palynomorphs

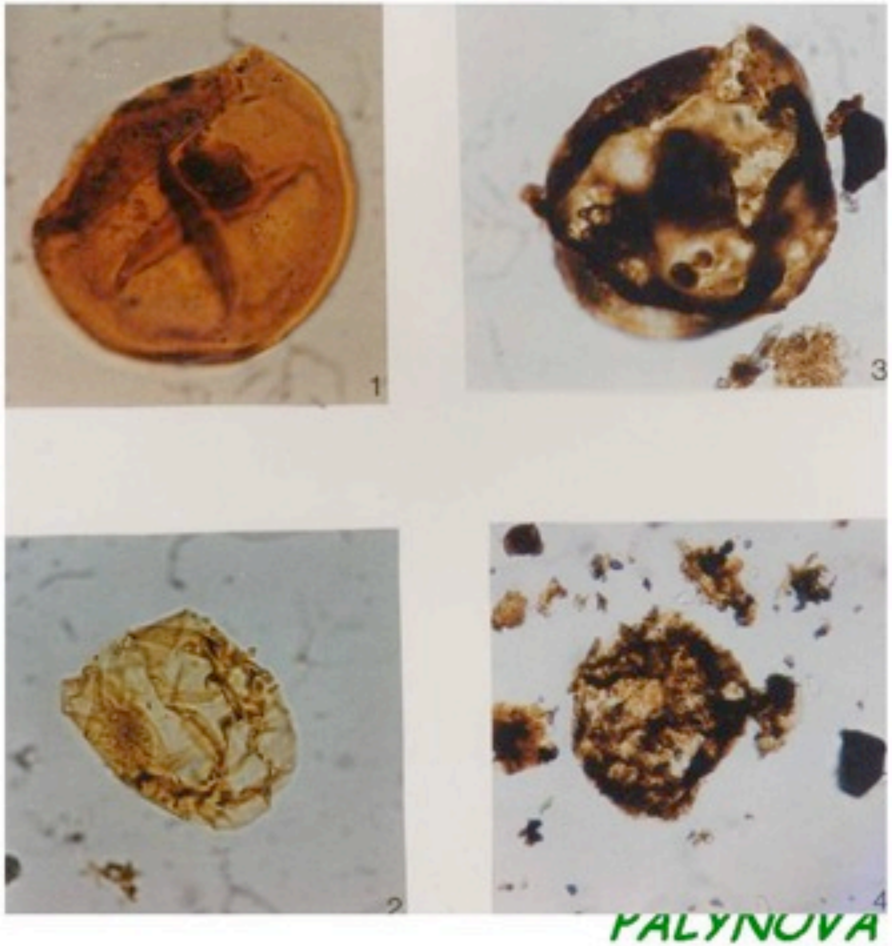
Bosedinia/Granodiscus

First appear in S Malay Basin in Oligocene

Bloom in Oligocene

Most abundant in 'M' lacustrine shales





3.46

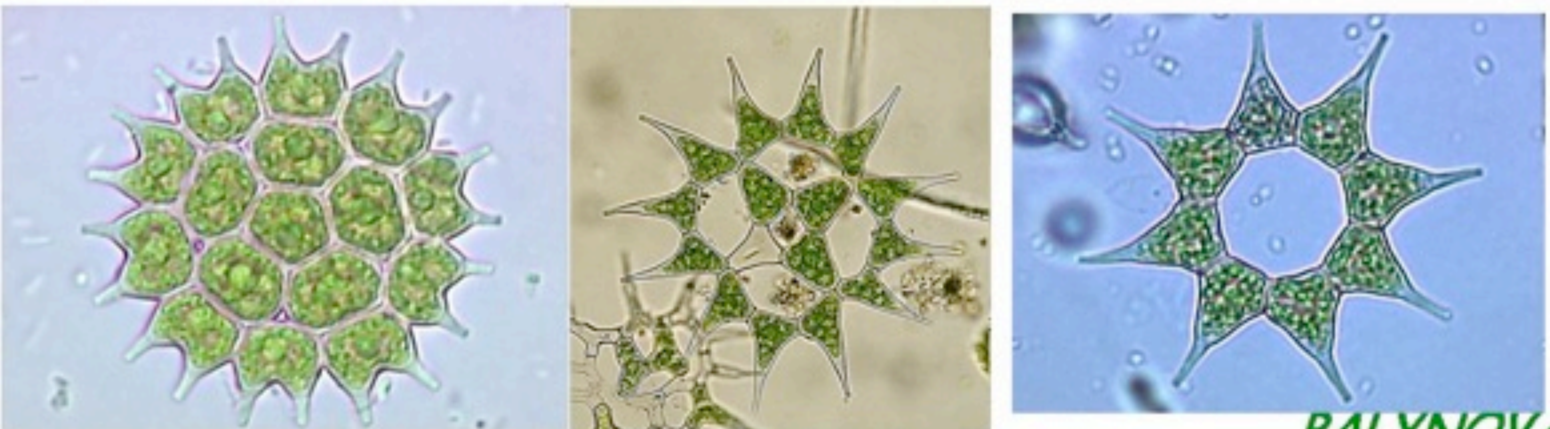
3.e5 Palynomorphs

Chlorophyllous algae

The algae *Pediastrum* and *Botyococcus* can be very abundant in both lacustrine and marine sediments in the Southeast Asian region. They are photosynthetic algae which are very important in lacustrine ecosystems. Their cells are rich in lipids, and so in deep lakes, where there is a clear thermocline with anoxic bottom conditions, they may be preserved in vast numbers, and in such settings they may contribute substantially to hydrocarbon source rocks.

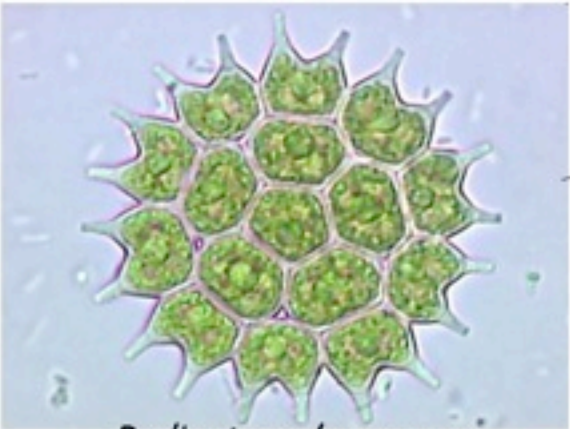
There is currently only one species of *Botryococcus, B braunii.* Similar morphologies have been reported back as far as the Ordovician, and it has been suggested that *B. braunii* is the most long-lived species known.

Pediastrum is abundant in sediments of Cretaceous and Tertiary age, but is unknown from pre-Cretaceous sediments.

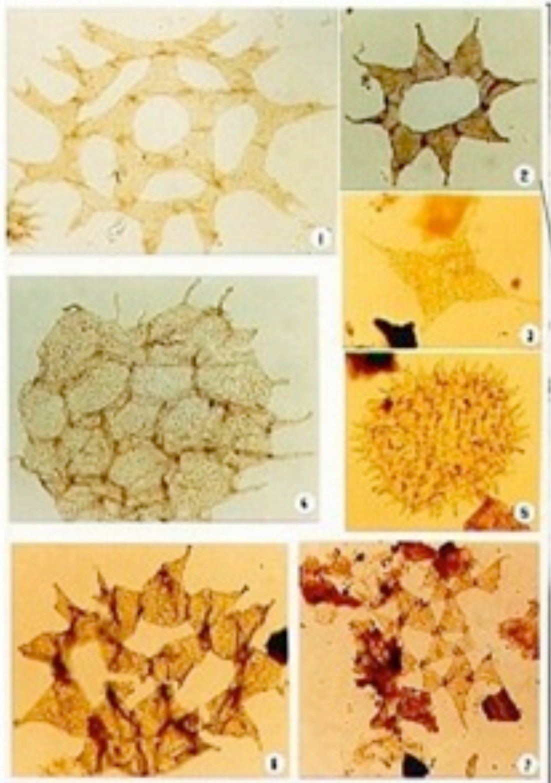


3.e5 Palynomorphs

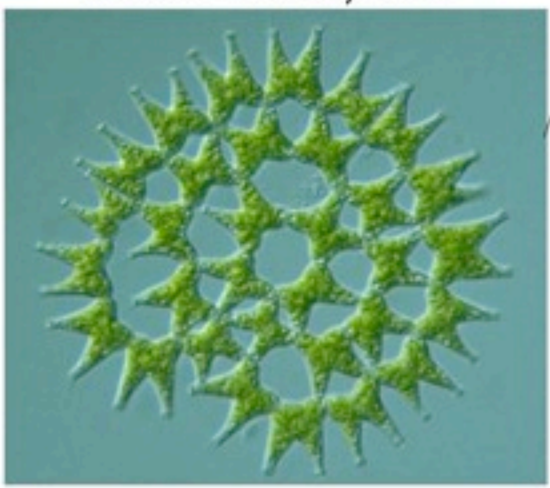
Chlorophyllous algae



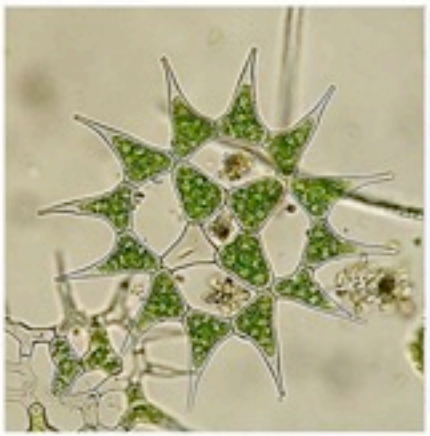
Pediastrum boryanum



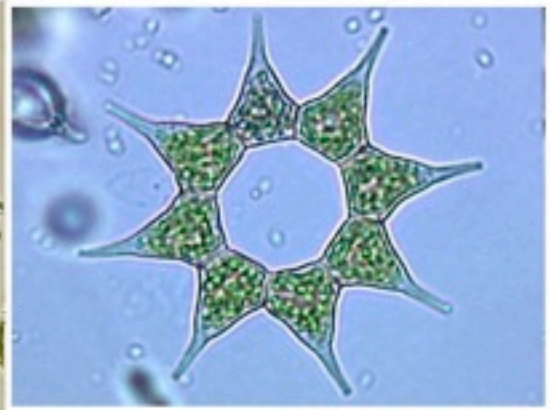
Fossil Pediastrum spp



Pediastrum duplex



P simplex



P simplex

3.51

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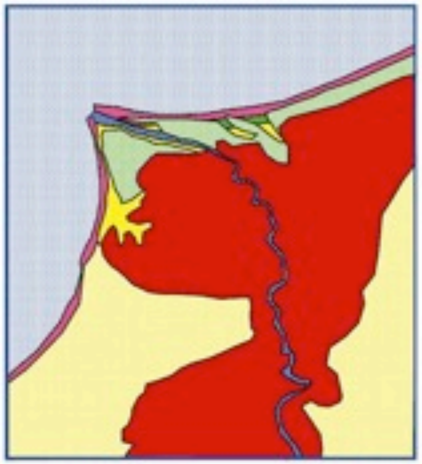
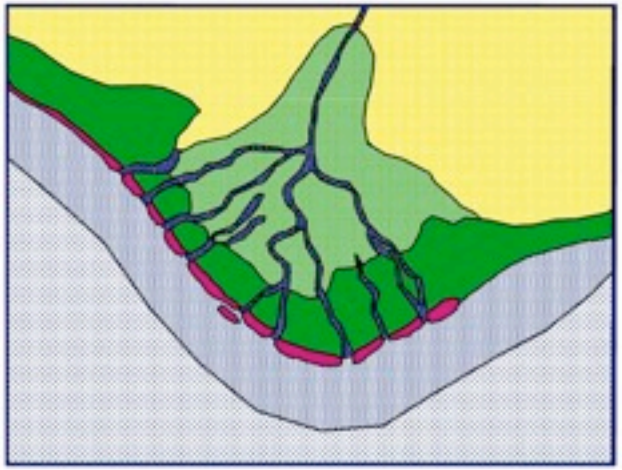
Coastal plain and mangroves





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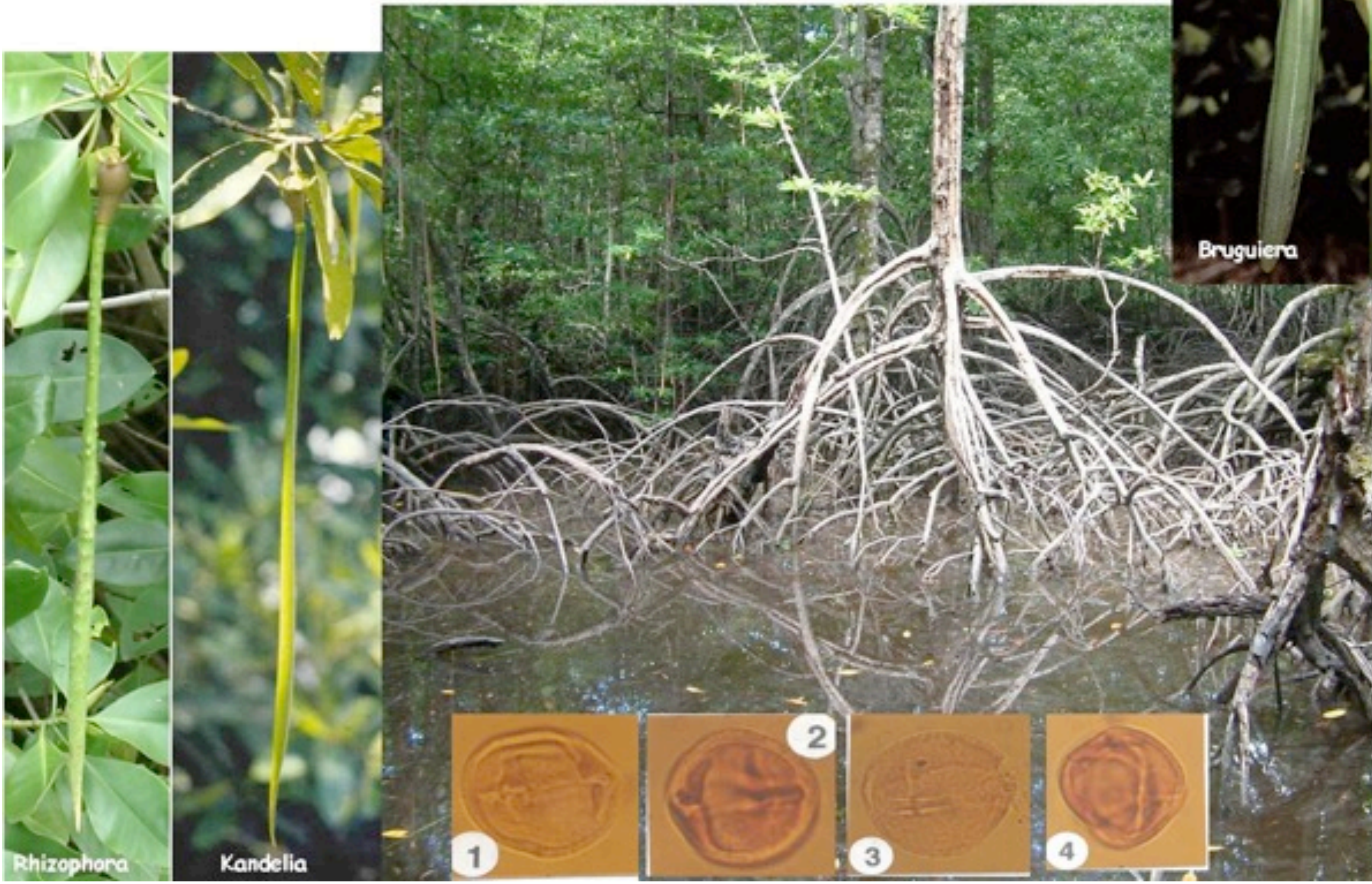
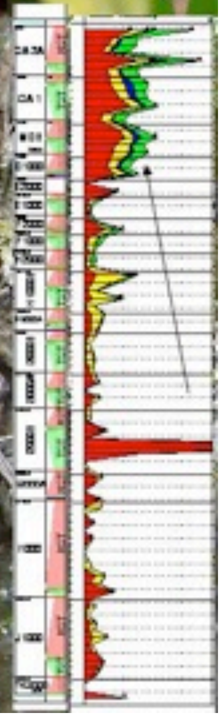
3.e6 Palynomorphs

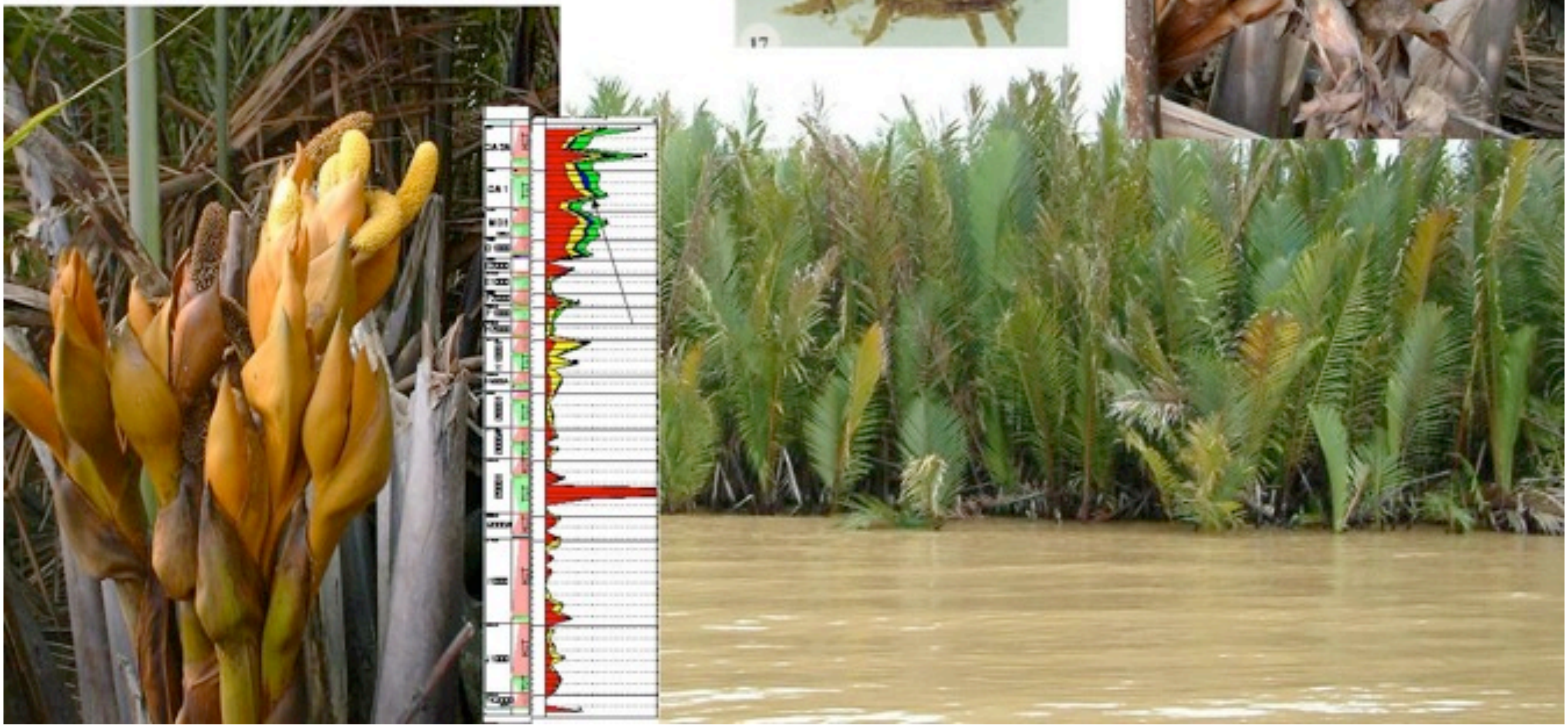
Tricolporate pollen, Rhizophora type, *Zonocostites ramonae*





3.e6 Palynomorphs

Angiosperm pollen, Nypa fruticans, Spinizonocolpites echinatus



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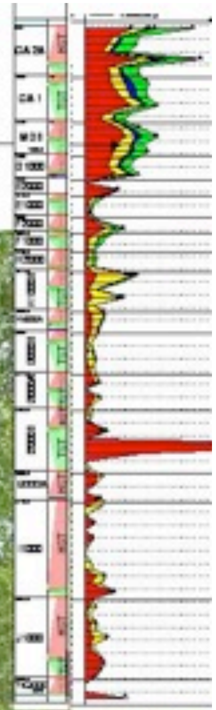
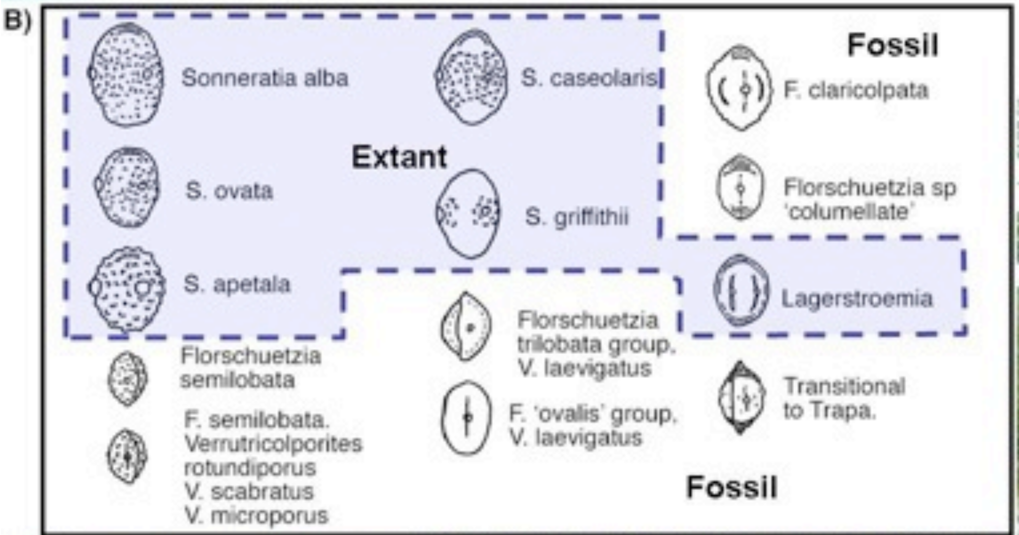


3.e8 aperturate pollen

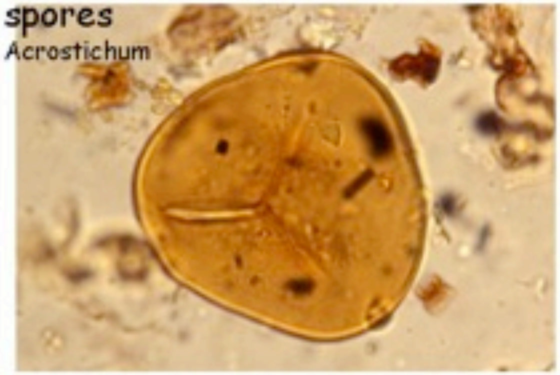
Triporate/Tricolporate Florschuetzia produced by mangrove genus Sonneratia

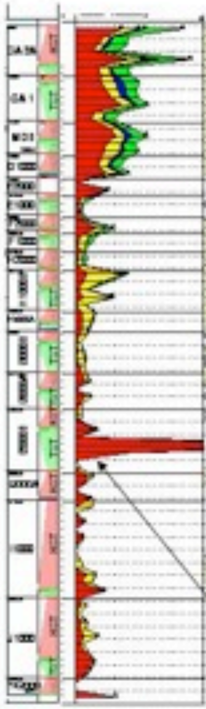


3.e6 Palynomorphs

Pteridophyte spores
Acrostichum aureum/speciosum

Trilete spores
Acrostichum





Acrostichum spores

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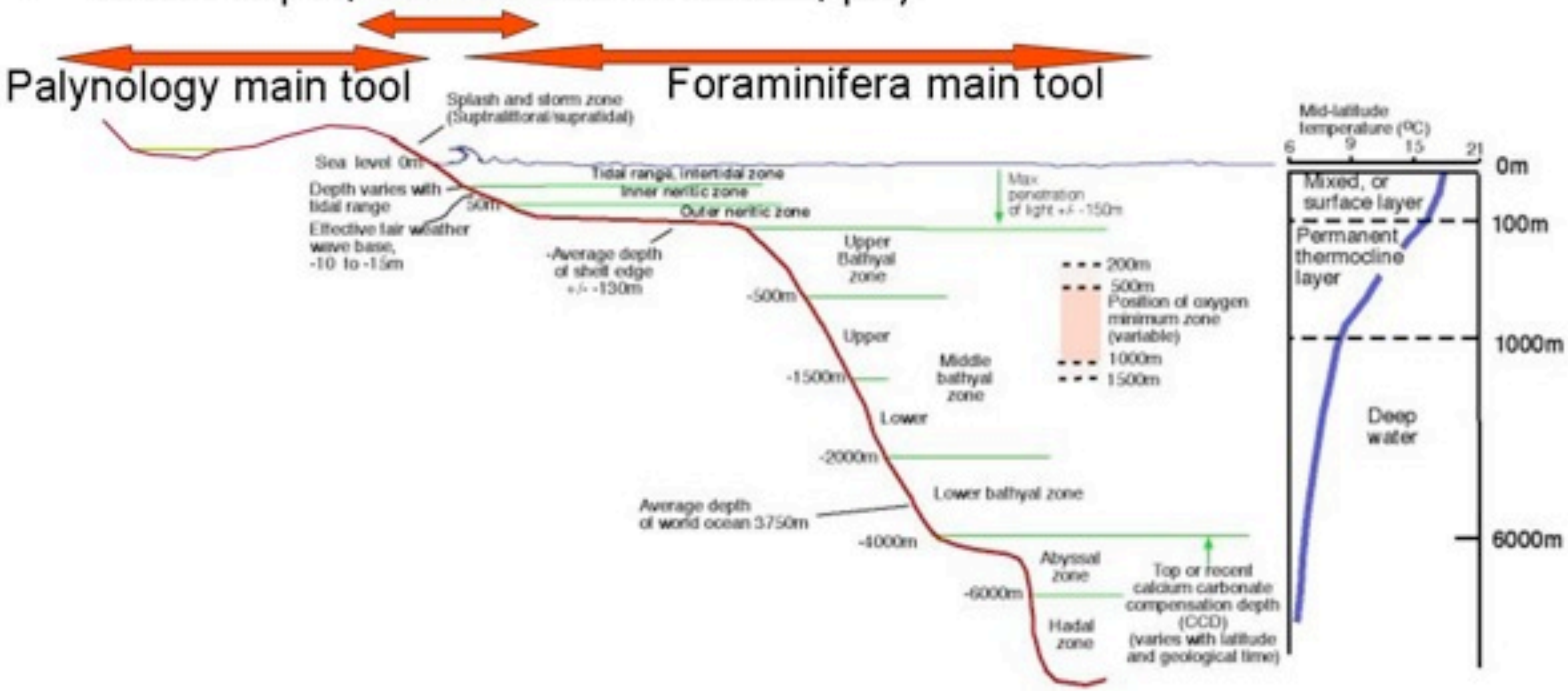
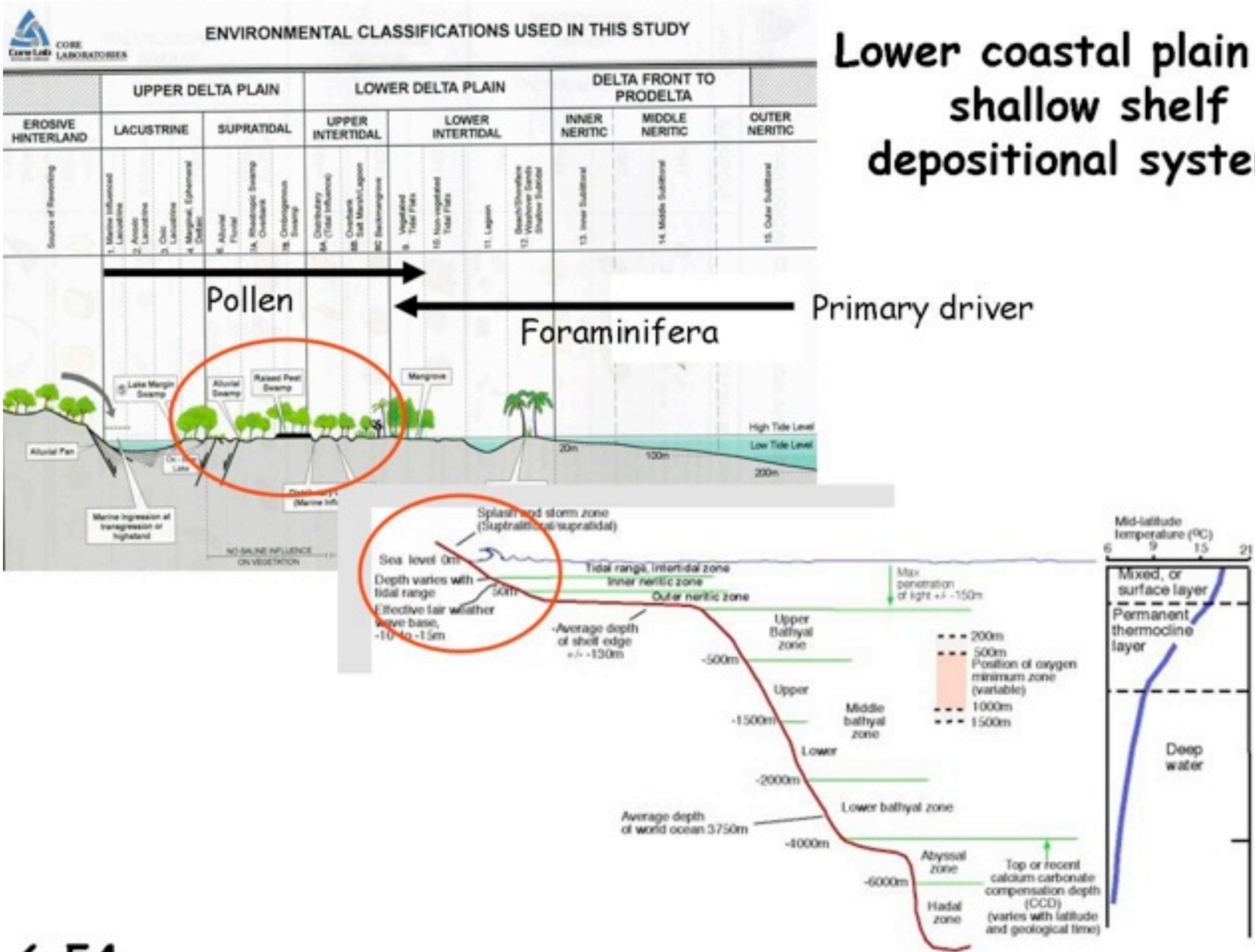
Paleoenvironmental information derived from microfossils:

- sedimentary facies - forams, nannos, paly
- Salinity – forams, paly
- ocean temperature - forams
- Climate – paly (forams)
- water mass characteristics - forams
- Productivity – upwelling – forams (nannos)
- Water depth, and sea level - forams, paly



6.2

Lower coastal plain and shallow shelf depositional systems



6.54

Understanding local, extra-local and regional pollen sources

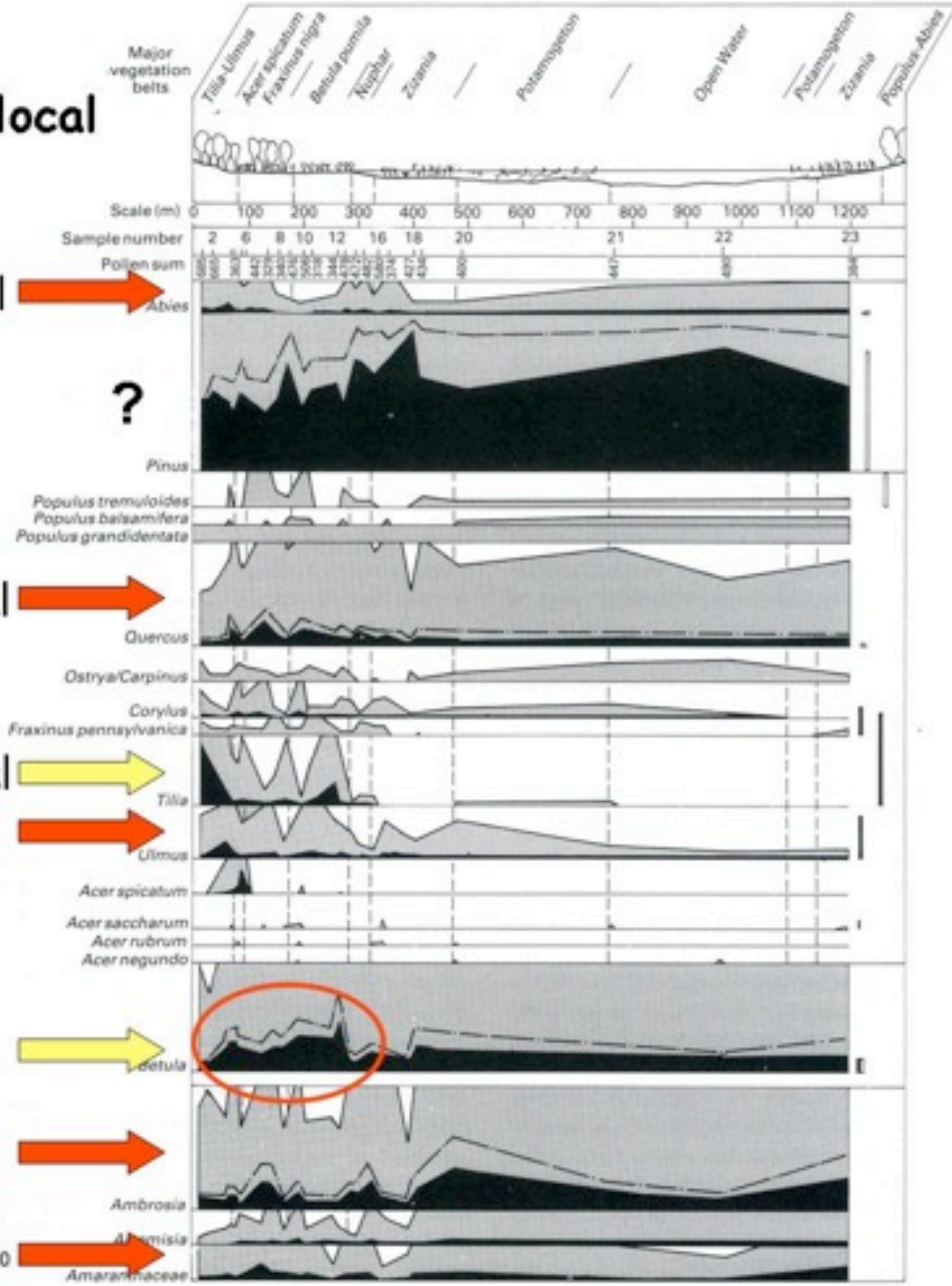
Regional

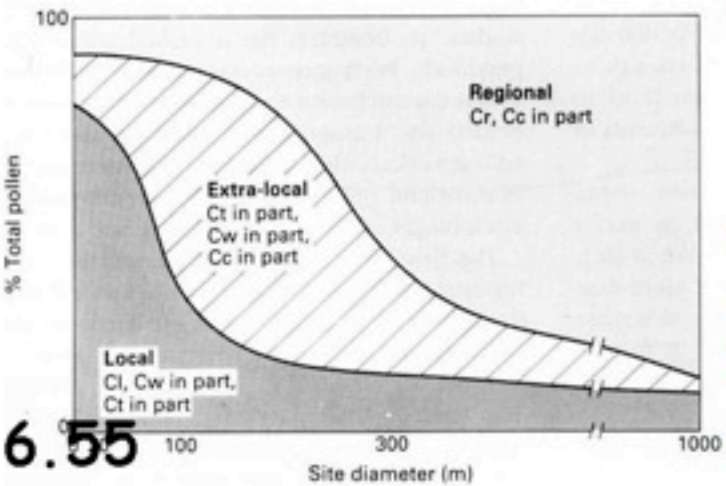
Regional and extra-local

?

Regional

Extra-local



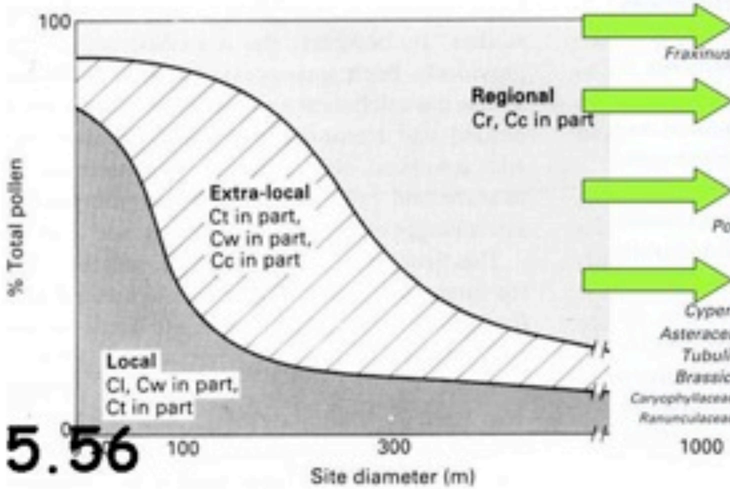


6.55

Understanding local, extra-local and regional pollen sources

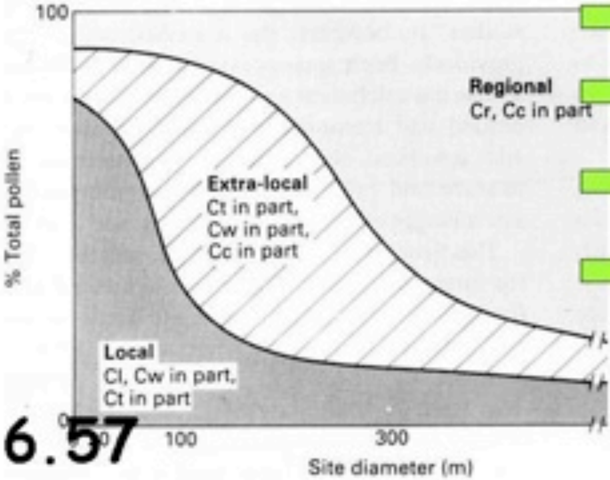
Local

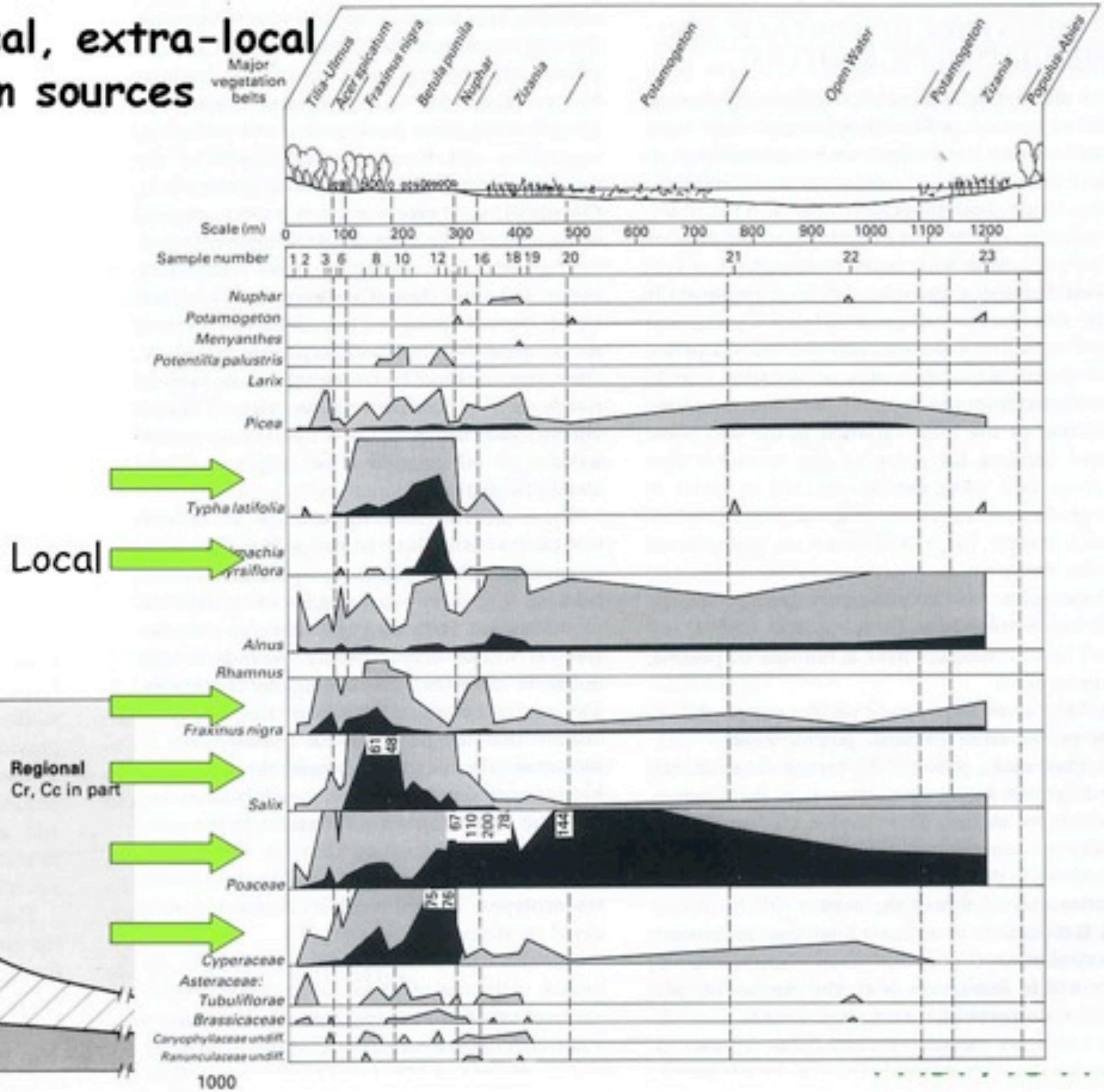
Local



5.56

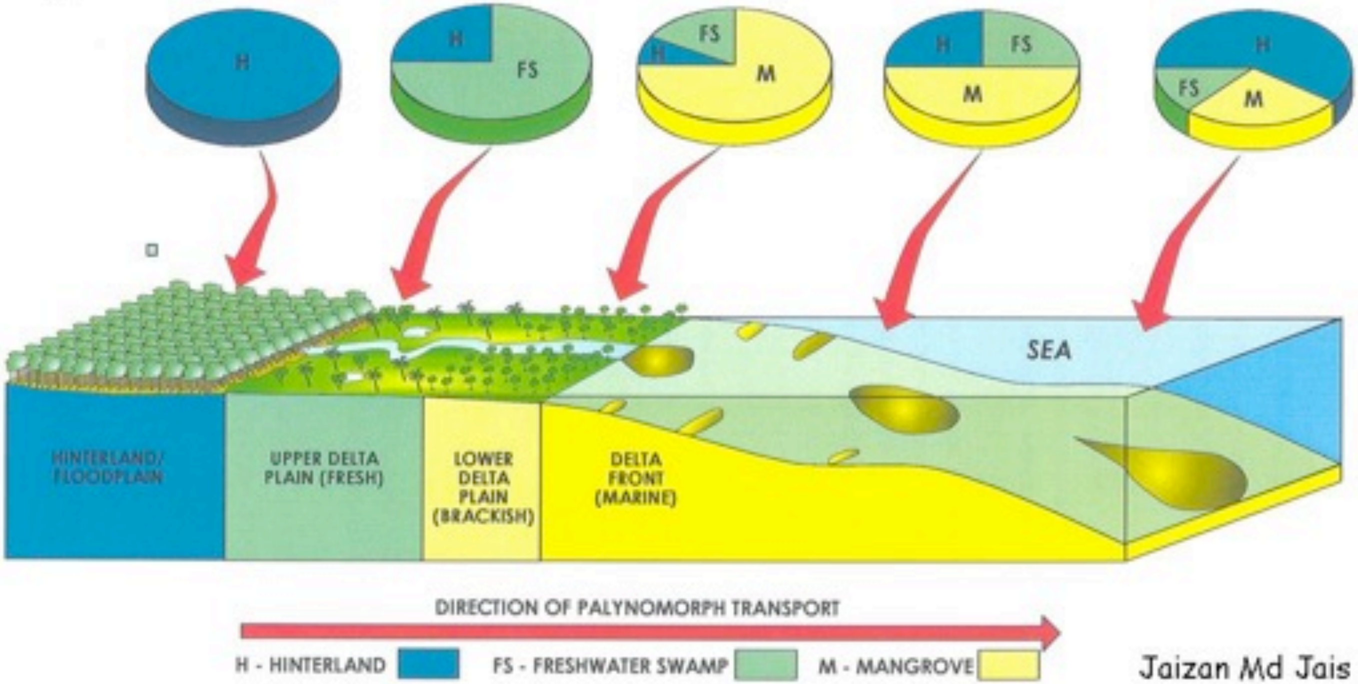
Understanding local, extra-local and regional pollen sources



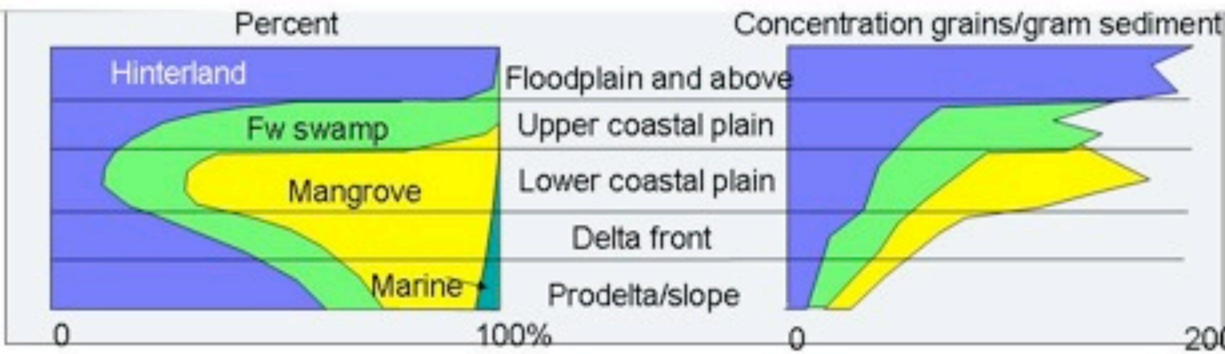


6.57

Palynomorph deposition from coastal plain to basin



Jaizan Md Jais



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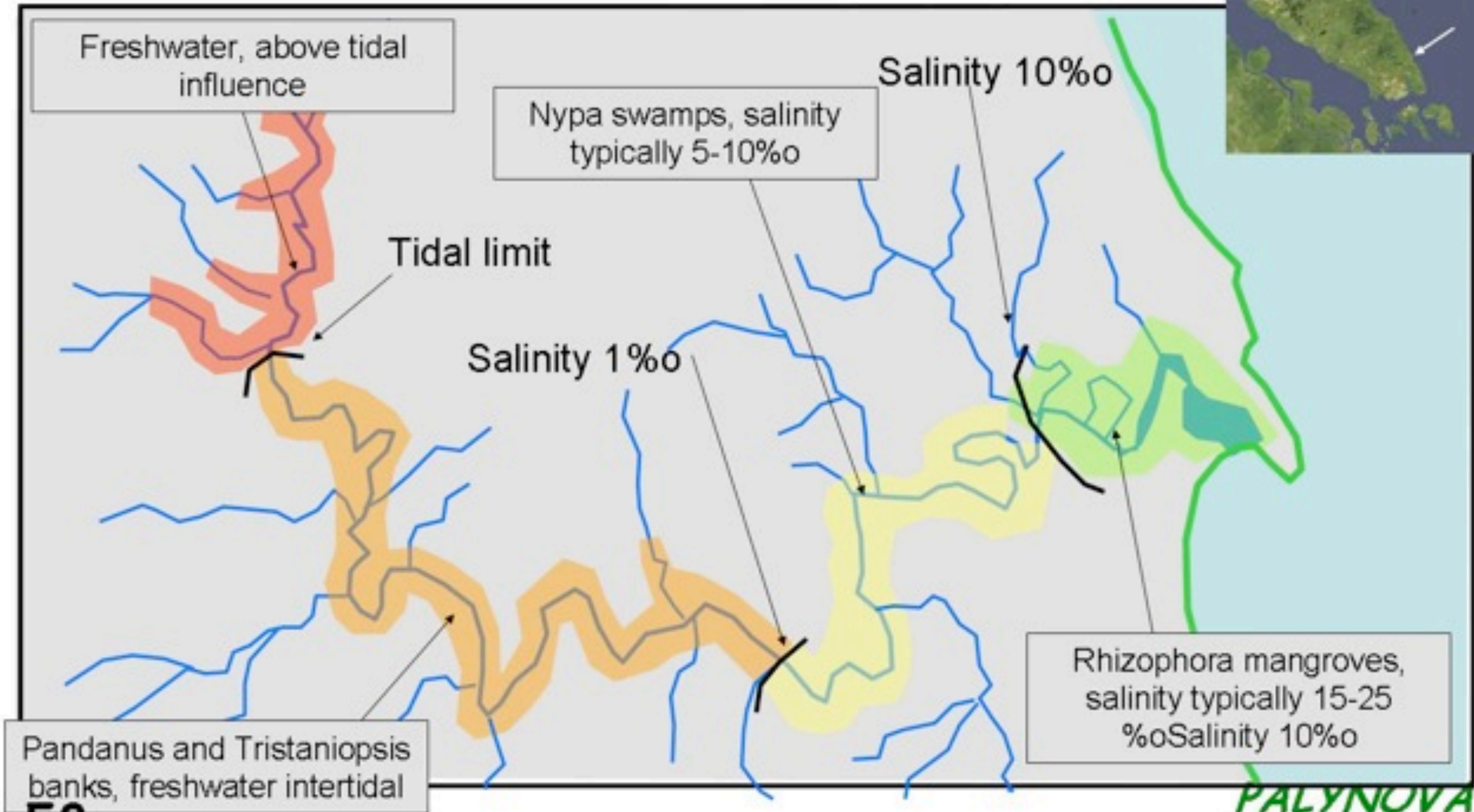
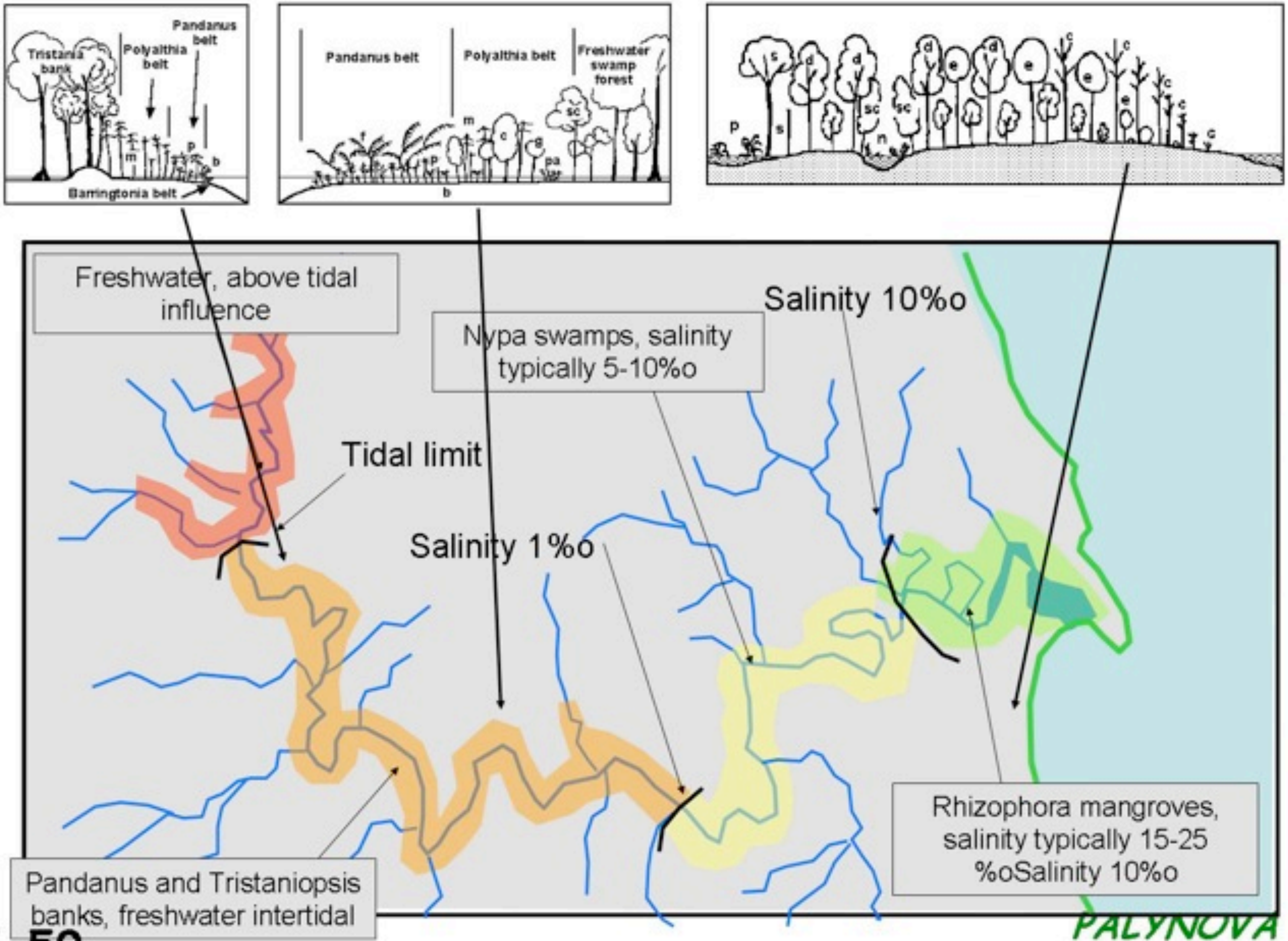
Understanding local, extra-local and regional pollen sources

Model for West Natuna – Sedili river, West Malaysia

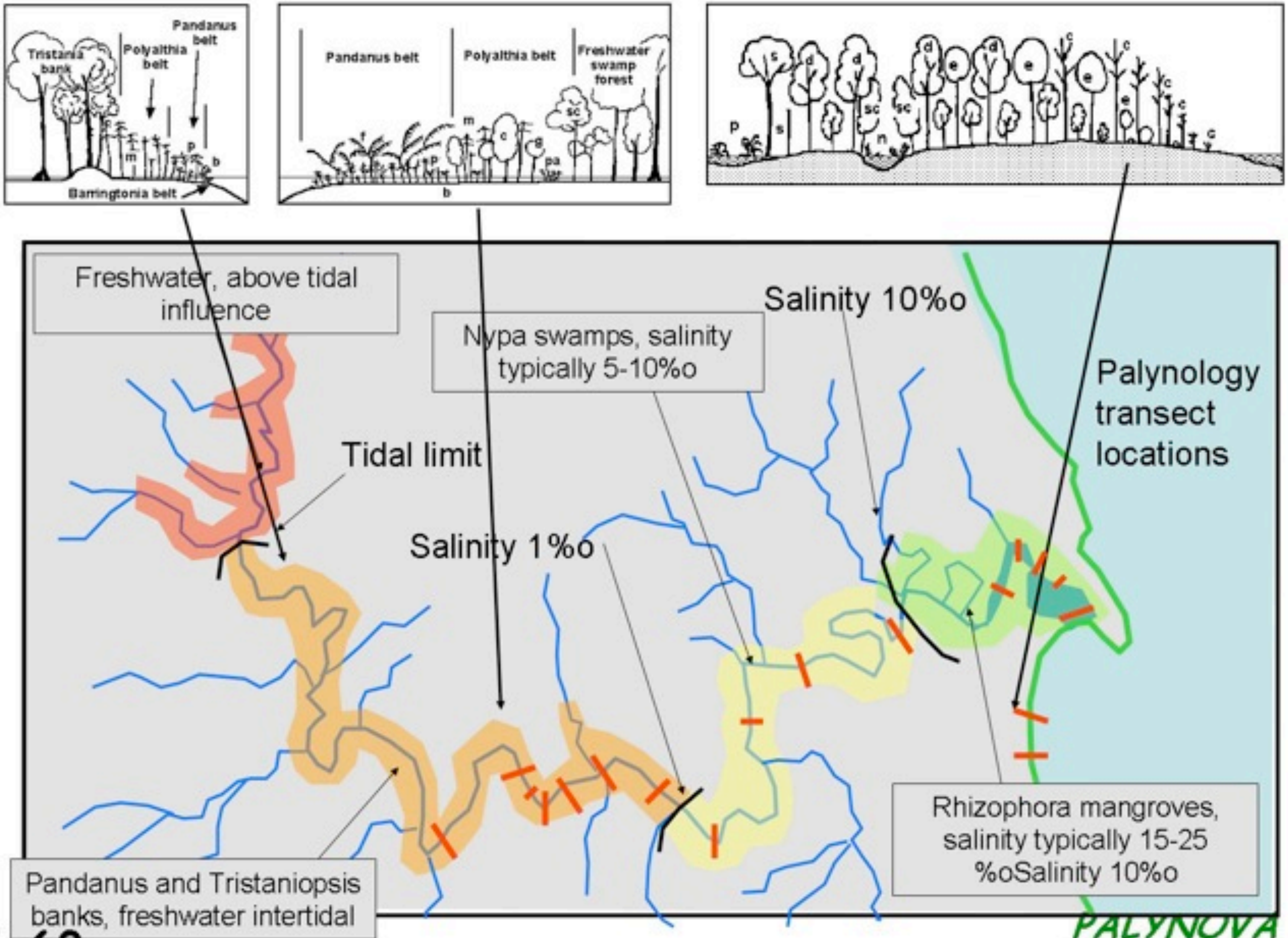


6.58



Pandanus belt
Tristania bank
Polyalthia belt
Barringtonia belt
Pandanus belt
Polyalthia belt
Freshwater swamp forest
Freshwater, above tidal influence
Tidal limit
Nypa swamps, salinity typically 5-10%o
Salinity 10%o
Salinity 1%o
Rhizophora mangroves, salinity typically 15-25 %oSalinity 10%o
Pandanus and Tristaniopsis banks, freshwater intertidal
PALYNOVA

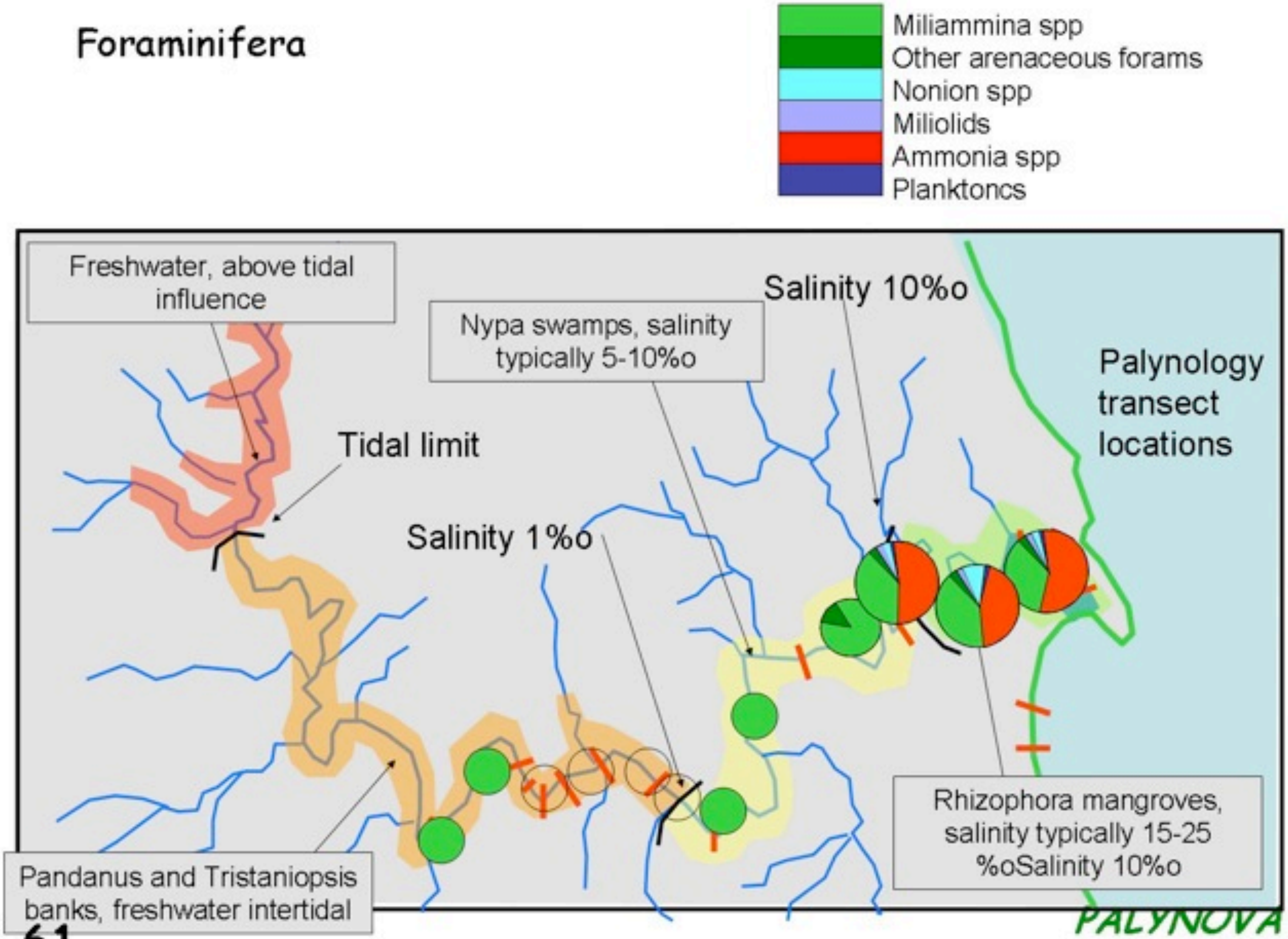
6.59



Tristania bank
Polyalthia belt
Pandanus belt
Barringtonia belt
Pandanus belt
Polyalthia belt
Freshwater swamp forest
Freshwater, above tidal influence
Tidal limit
Salinity 1%o
Nypa swamps, salinity typically 5-10%o
Salinity 10%o
Palynology transect locations
Pandanus and Tristaniopsis banks, freshwater intertidal
Rhizophora mangroves, salinity typically 15-25 %oSalinity 10%o
PALYNOVA

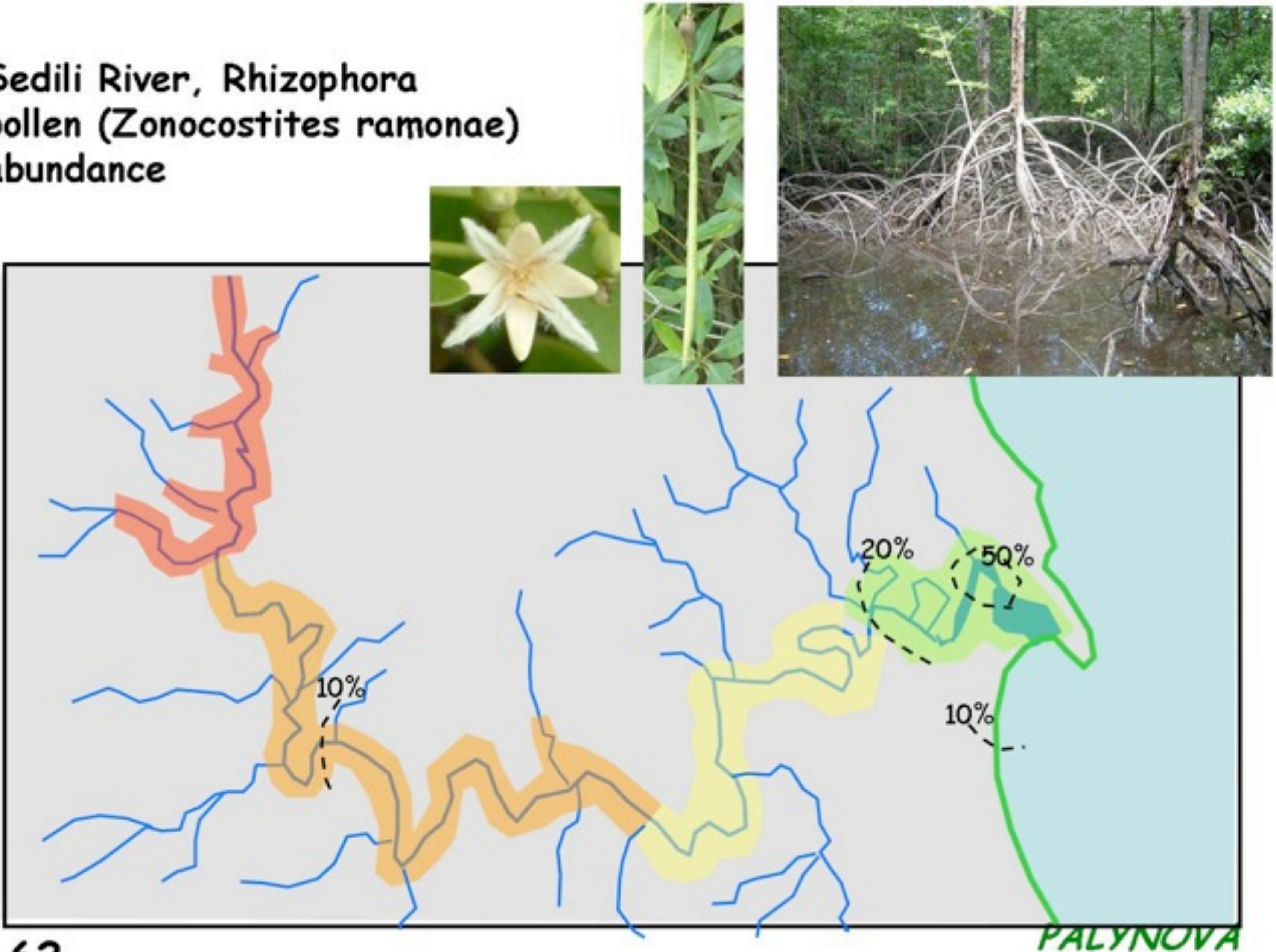
6.60

Foraminifera



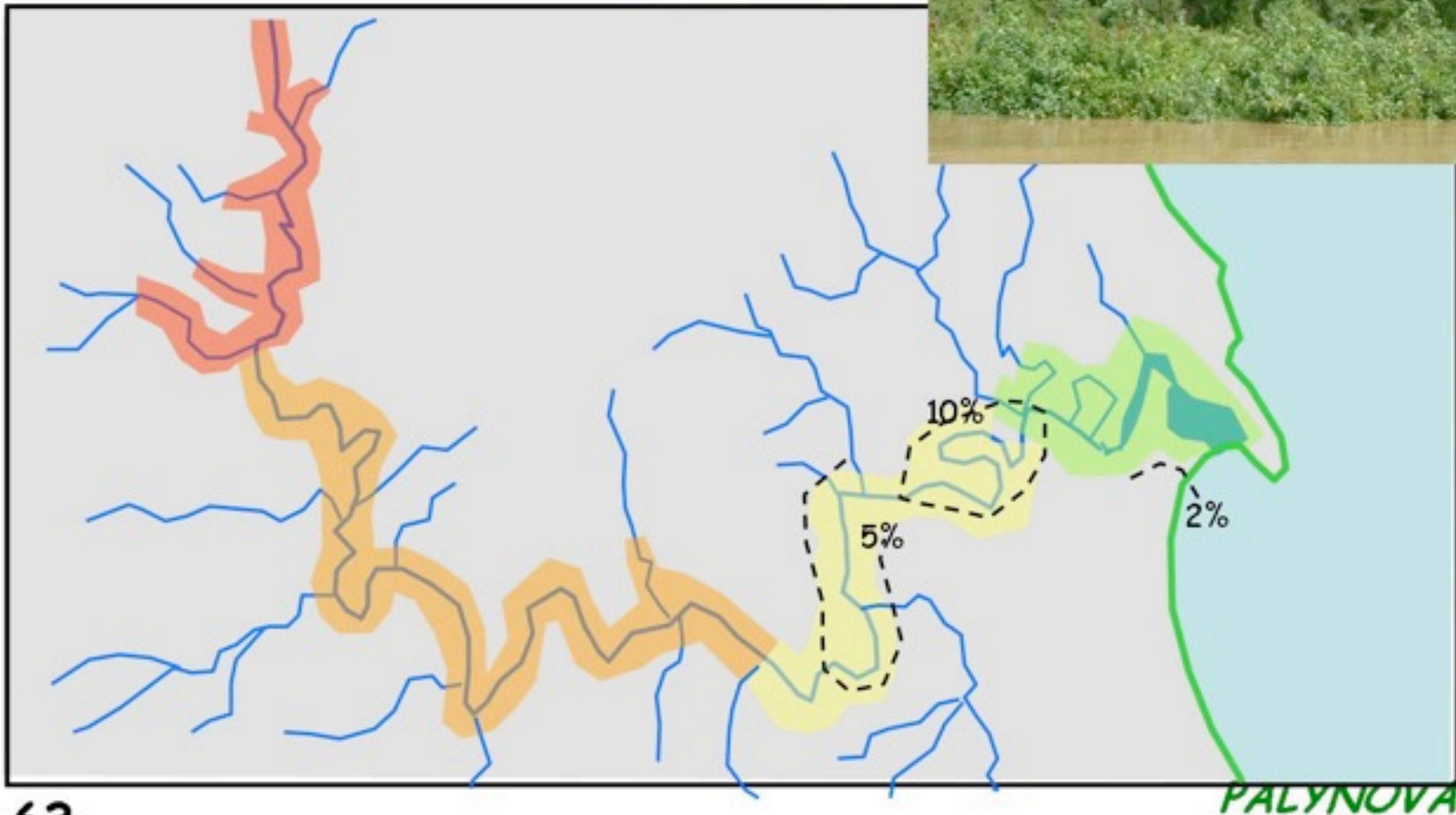
5.61

Sedili River, Rhizophora pollen (Zonocostites ramonae) abundance



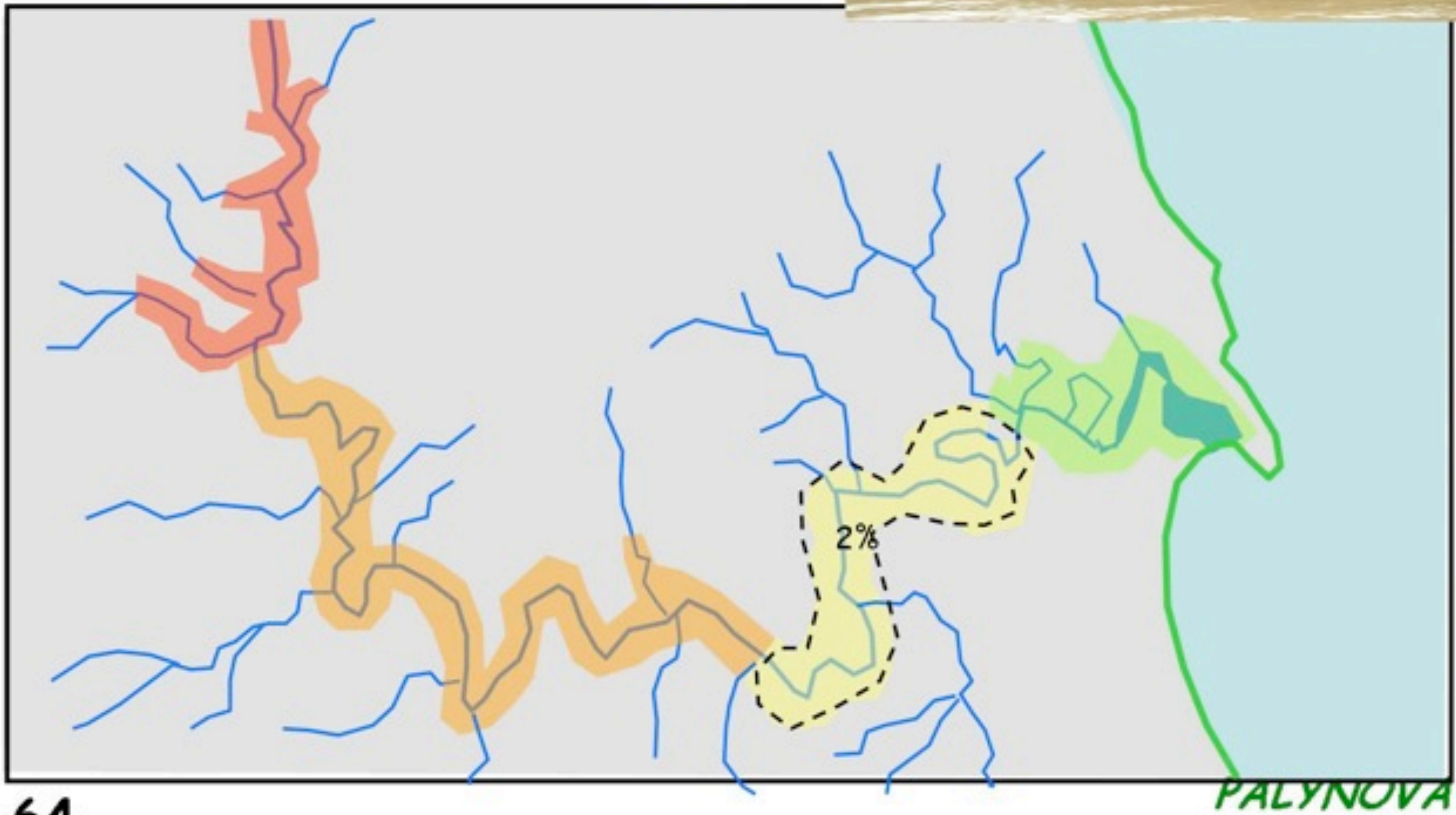
6.62

Sedili River, Sonneratia caseolaris (Florschuetzia levipoli) pollen abundance



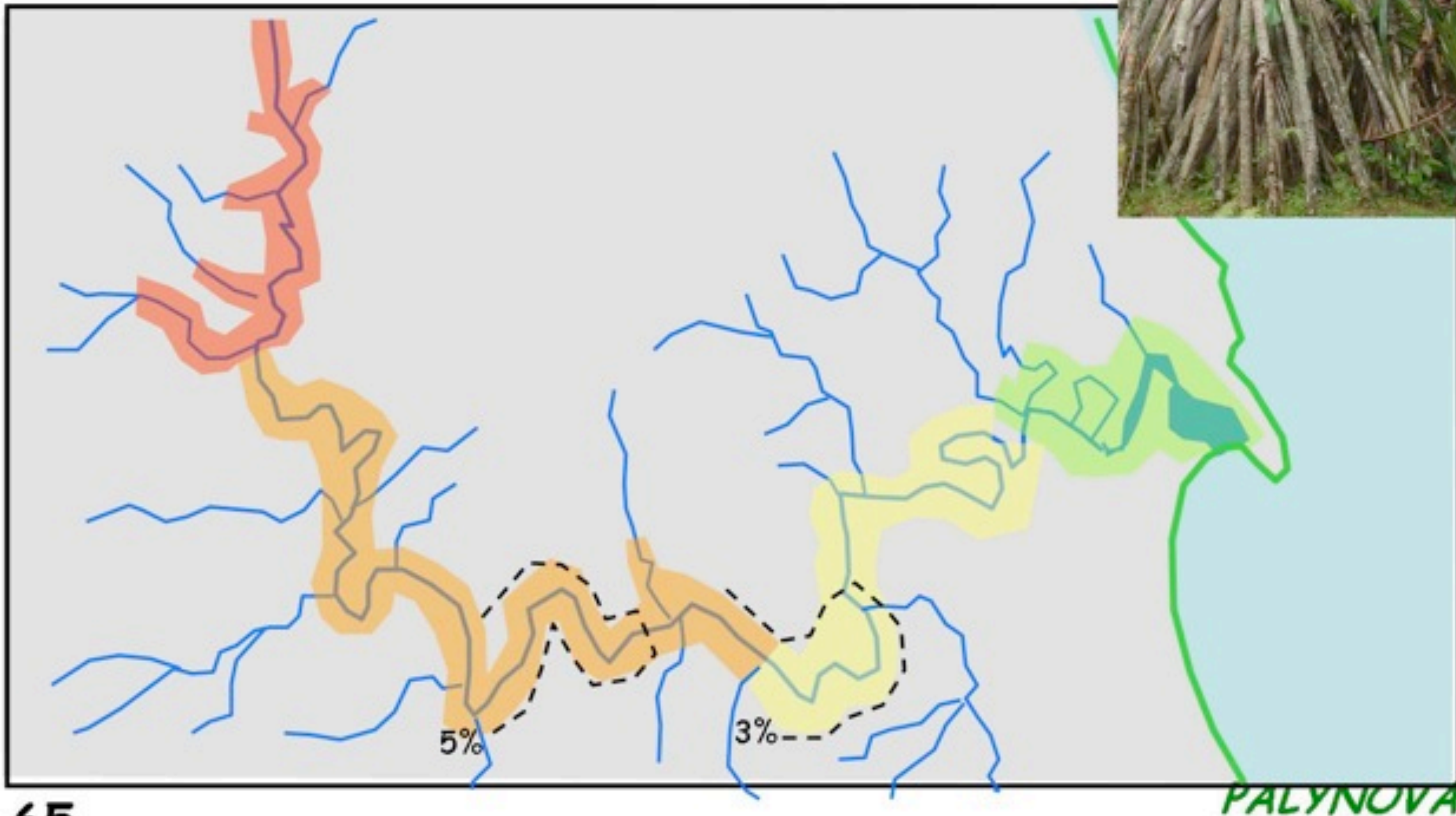
6.63

Sedili River, Nypa Fruticans (Spinizonocostites echinatus) pollen abundance



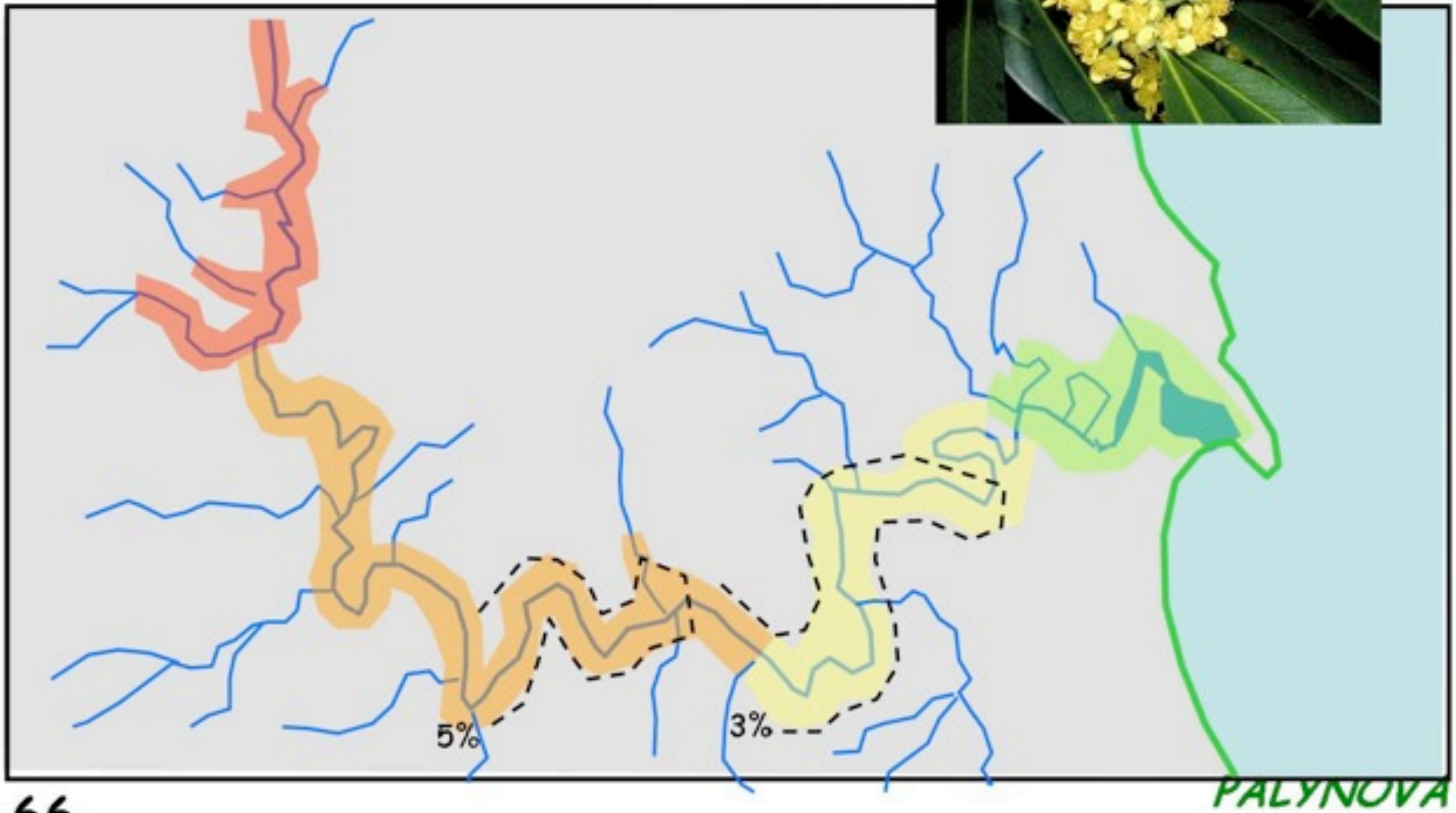
6.64

Sedili River, Pandanus helicopus (Pandaniidites spp) pollen abundance



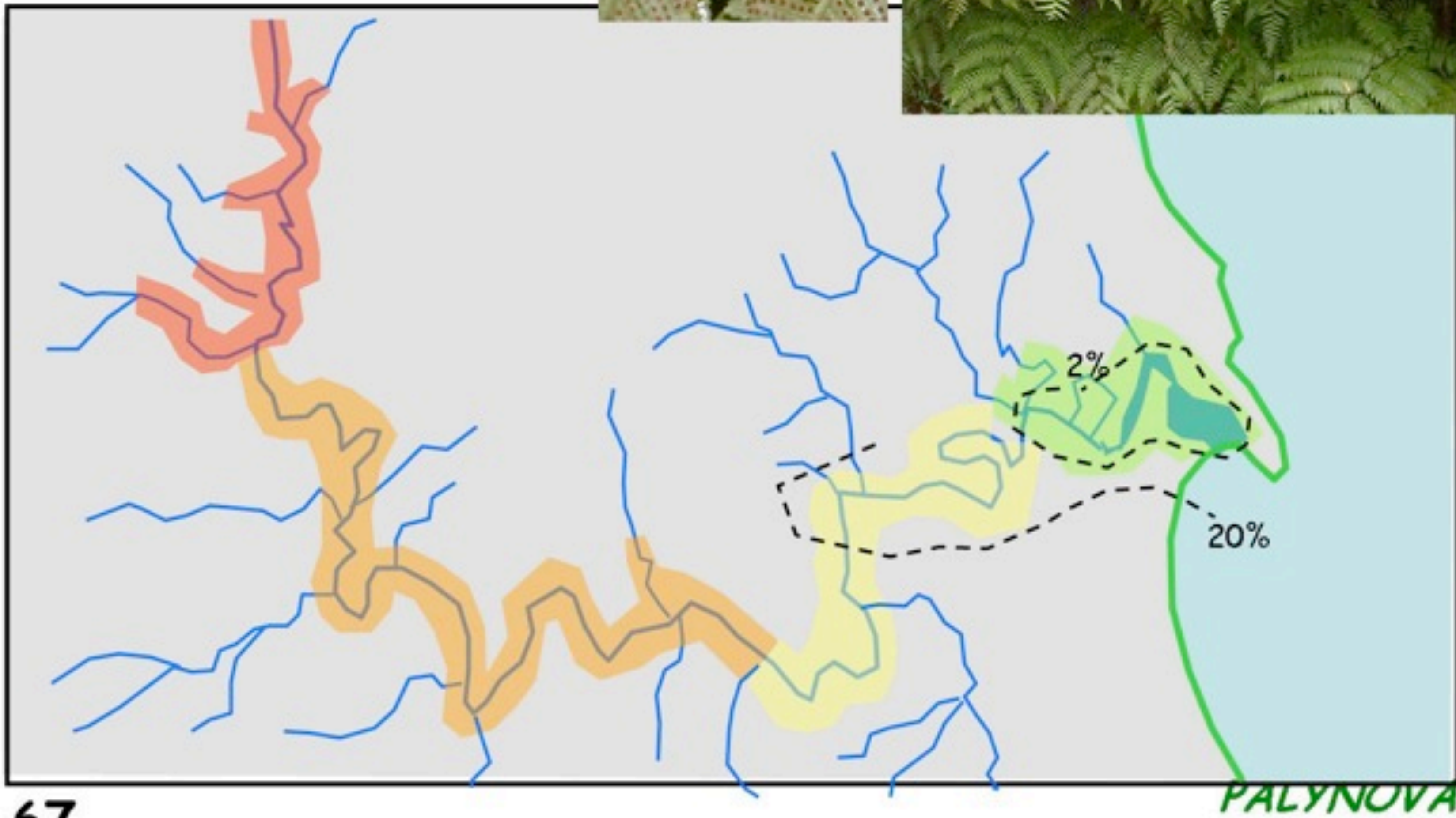
6.65

Sedili River, Myrtaceae (from Tristaniopsis) = Myrtaceidites spp pollen abundance



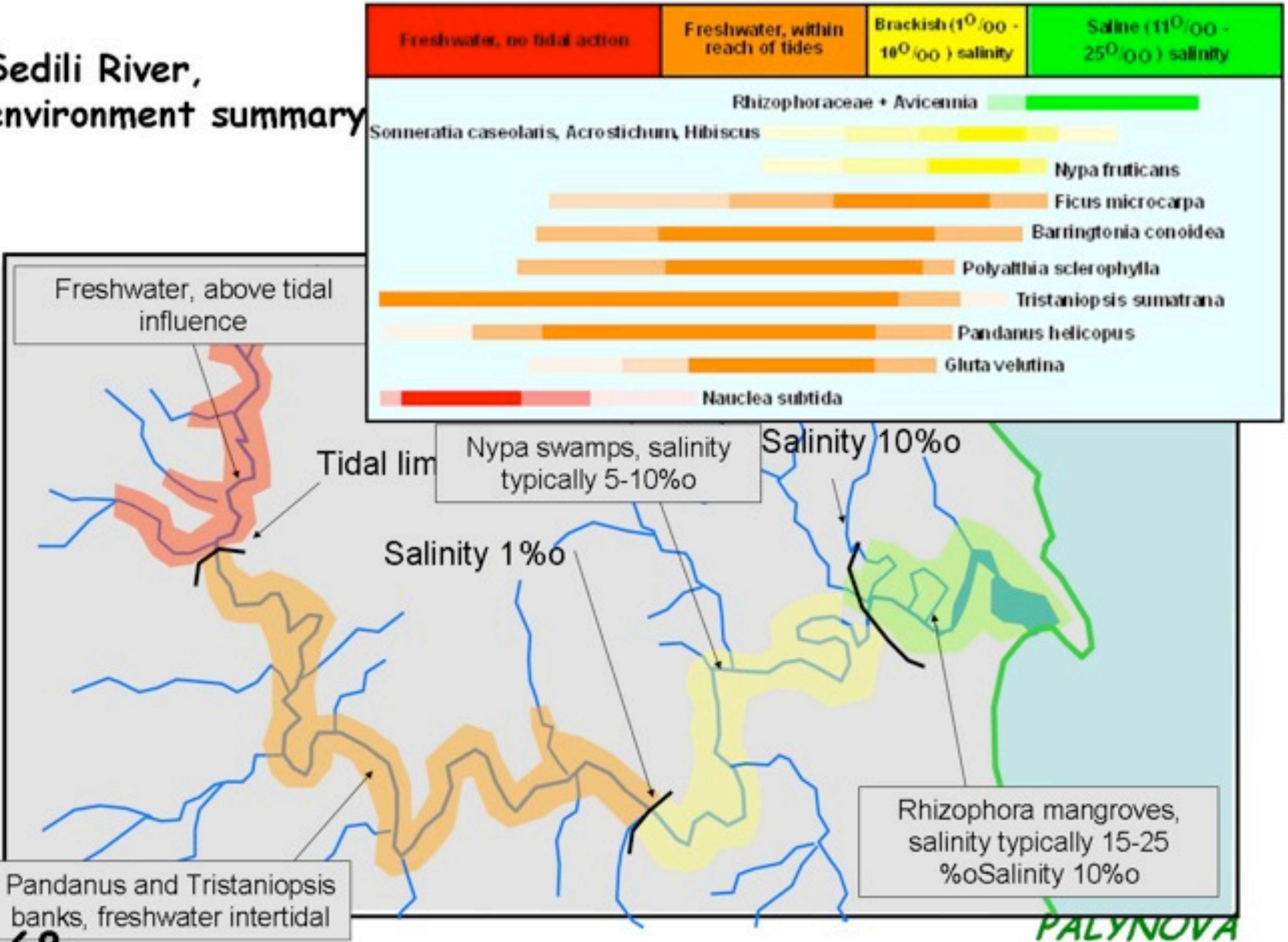
6.66

Sedili River, Smooth fern spores (Laevigatosporites spp abundance



6.67

Sedili River, environment summary



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6.68

Makassar Straits environment interpretation using foraminifera and palynomorphs

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   - Coals

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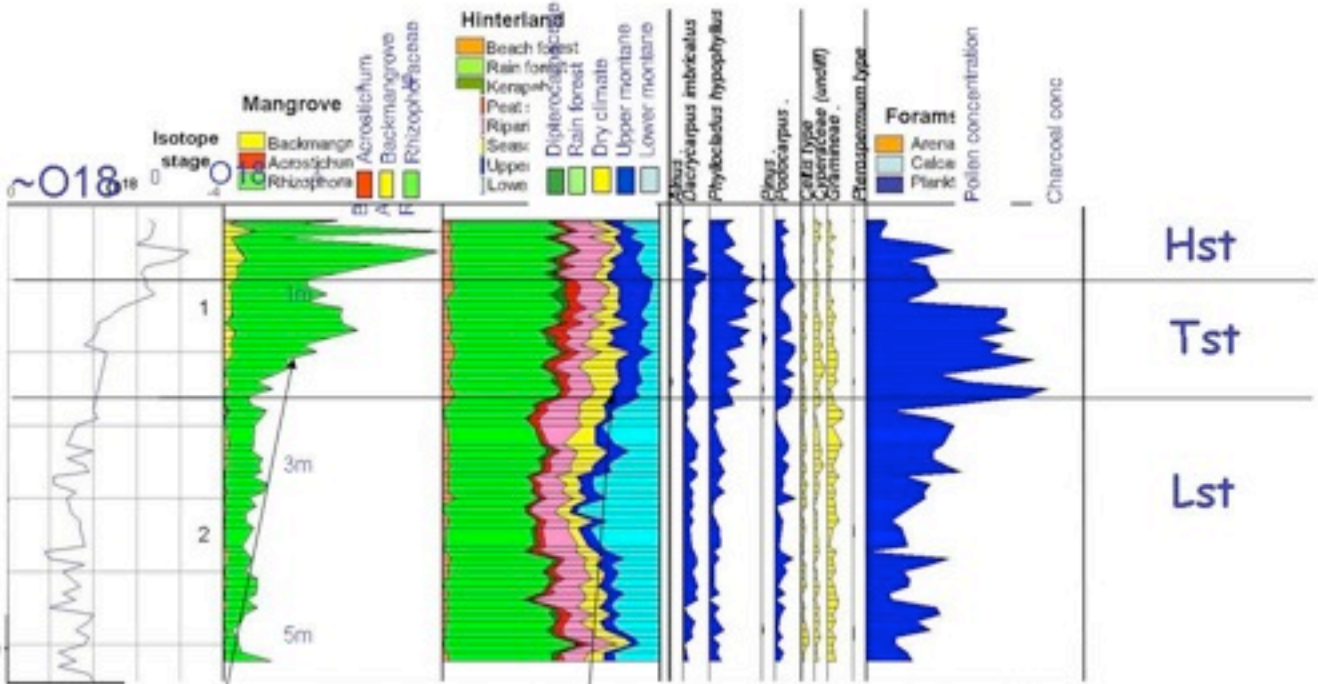
Papalang-10 sea bottom core offshore Mahakam



Water depth 2341m

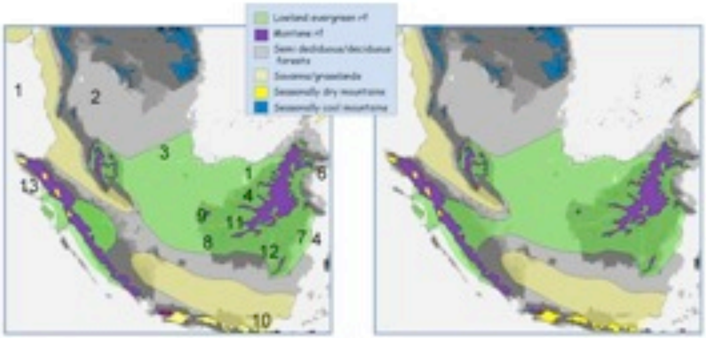
Morley et al 2004

Mangrove pollen acme reflects sharp rise in sea level

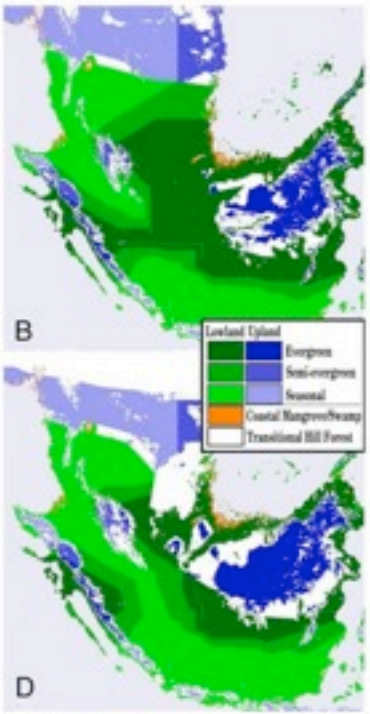
Expansion of cool climate pollen suggests cooler climate/low sea levels

PALYNOVA

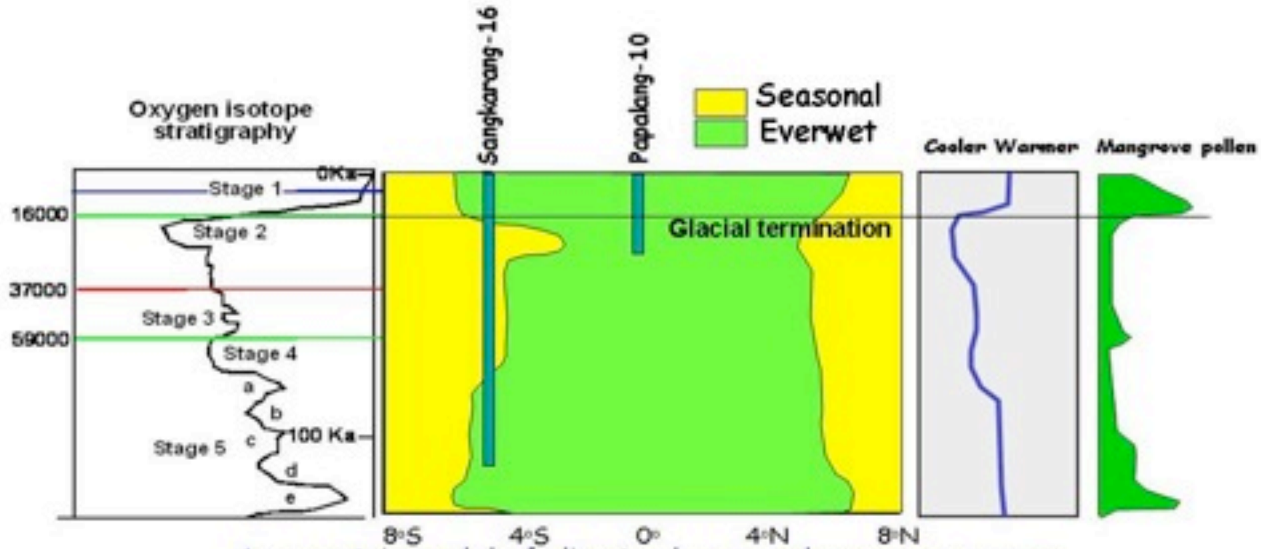
Modelling climate change in E Sunda using historical and GCM data



Cannon, Morley, Bush 2009 historical data



Cannon, Morley, Bush 2009 modelled data



Asymmetric model of climate change and mangrove swamp expansion/contraction for E Sunda through a typical glacio-eustatic sea level cycle

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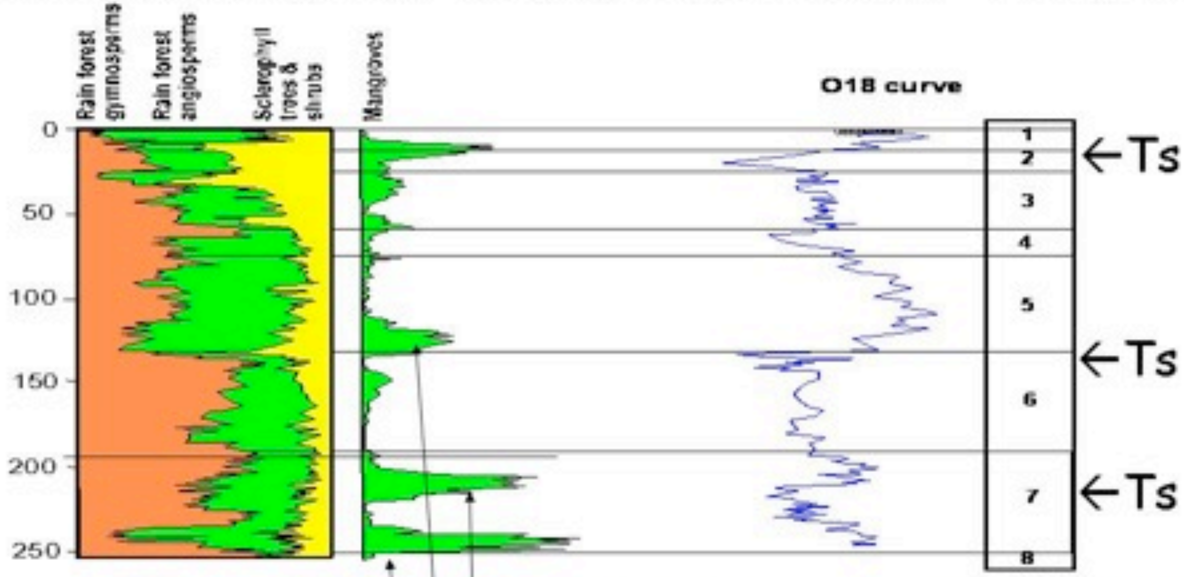
Sea level change and the palynological record - background

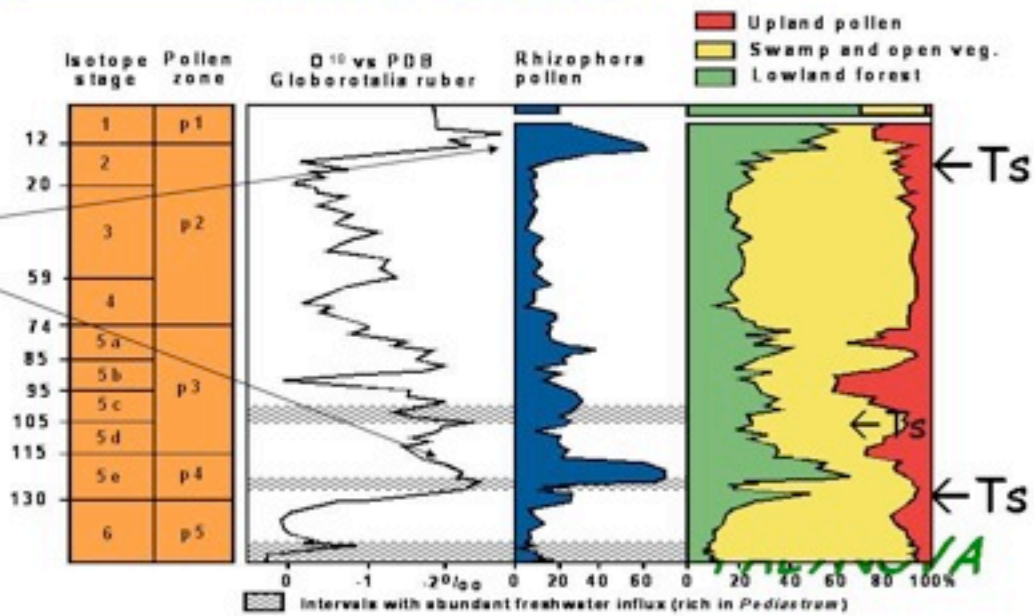
PALYNOVA
in association with
Eksindo Pratama



ODP 820, from offshore NE Australia

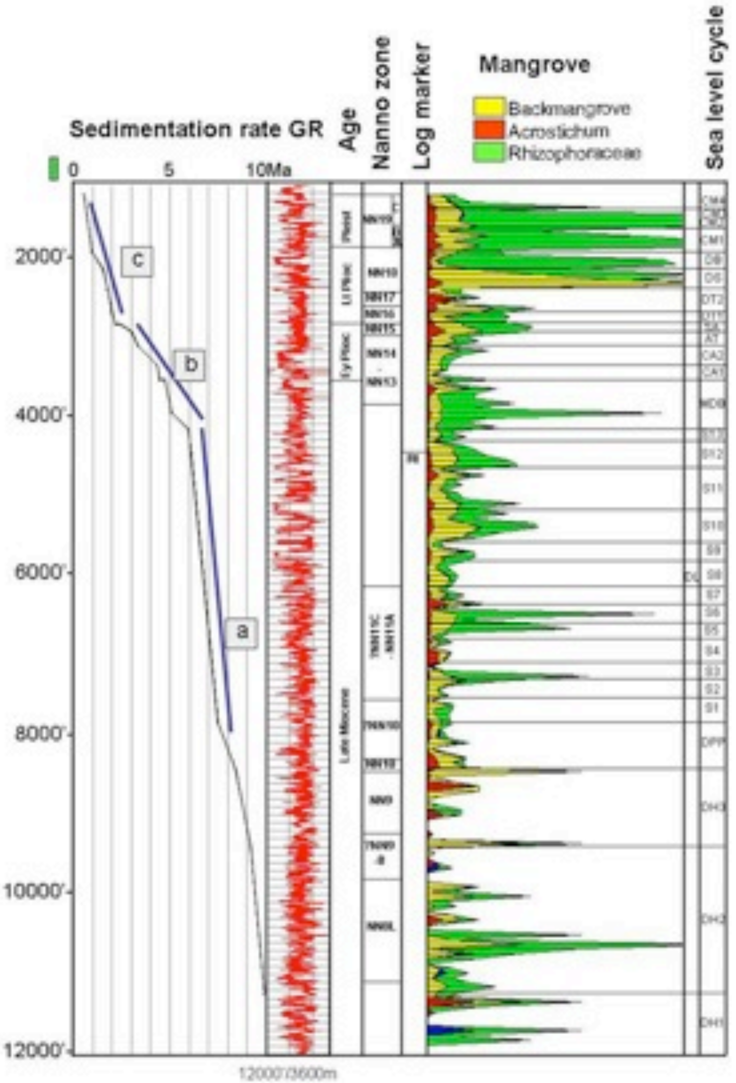
from SW of Niger Delta ←Ts

Note close correlation between phases of sea level rise and acmes of mangrove pollen

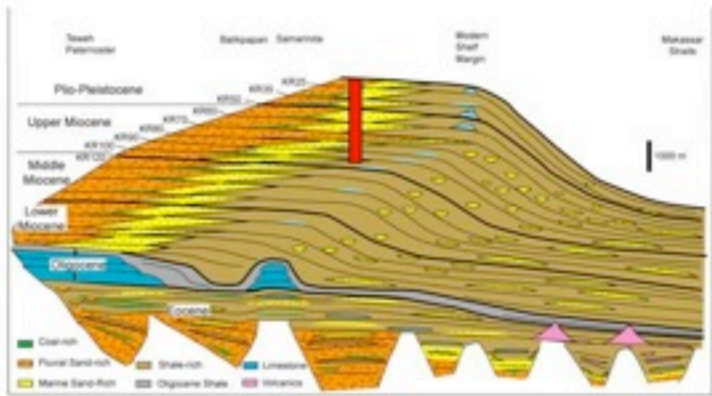


Sea level change and the palynological record

Attaka well, Mahakam Delta (Morley and Morley 2010)

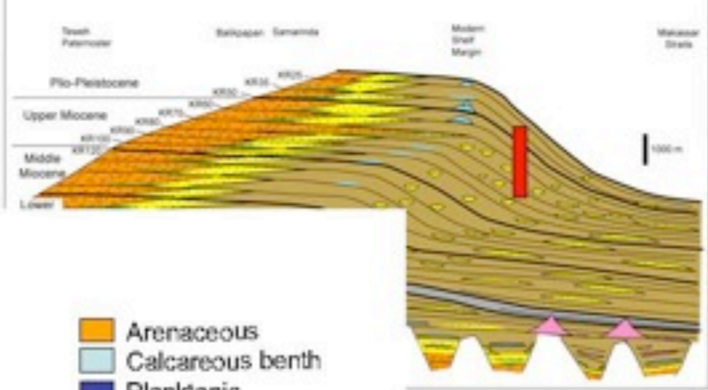


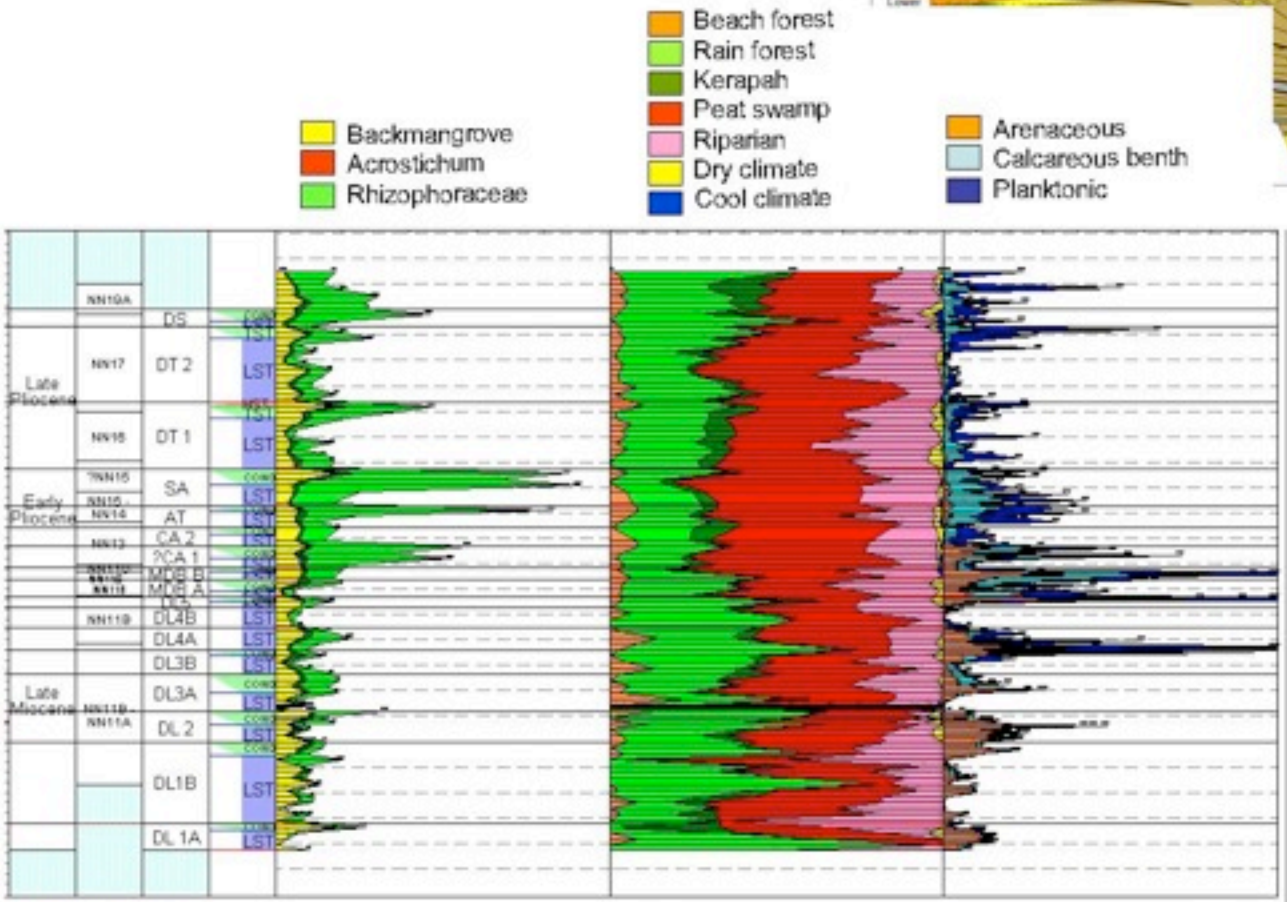
Mangrove pollen acmes approximately reflect frequency and extent of rapid sea level rises over Late Miocene to Pleist



Sea level change and the palynological record

Mahakam Slope well





0 300%

Mangrove pollen acmes are very well represented in slope deposits offshore

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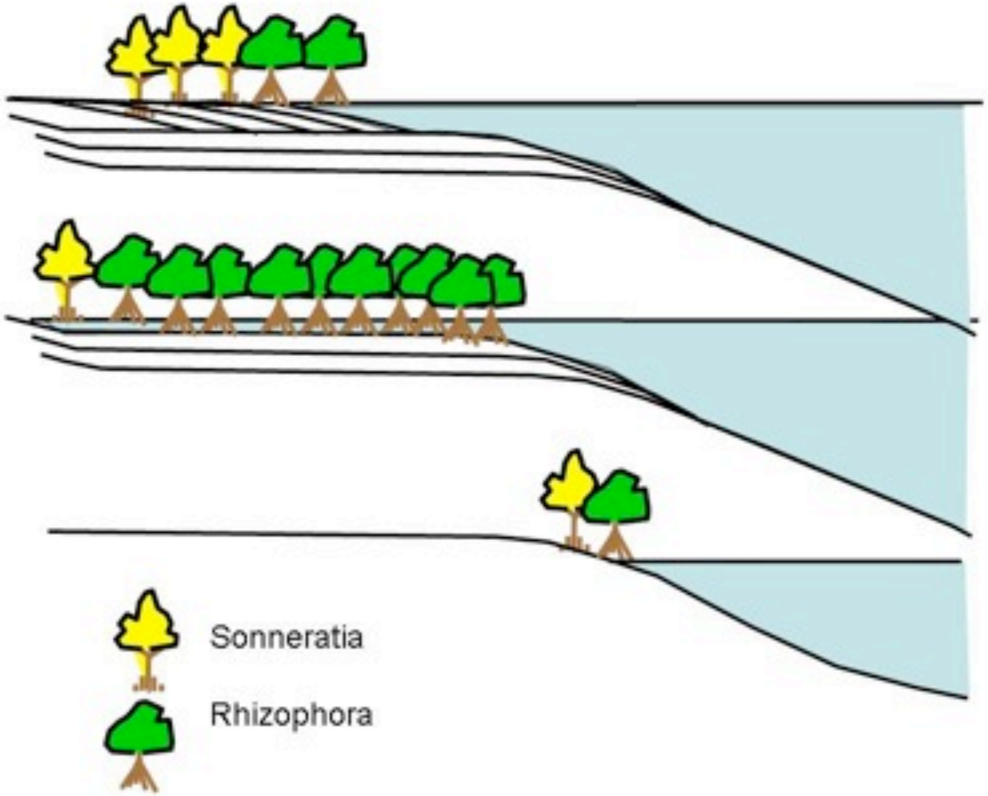
Mangroves

From the base Early Miocene *Rhizophora* swamps have been closely tied to sea level cycles, becoming most widespread during periods of rapid sea level rise, such as immediately following glacial terminations

High, stable sea level with prograding delta

Aggradational phase, Rhizophora mangroves expand in relation to rapidly rising sea levels

Low sea level, mangroves restricted to limited areas below shelf break



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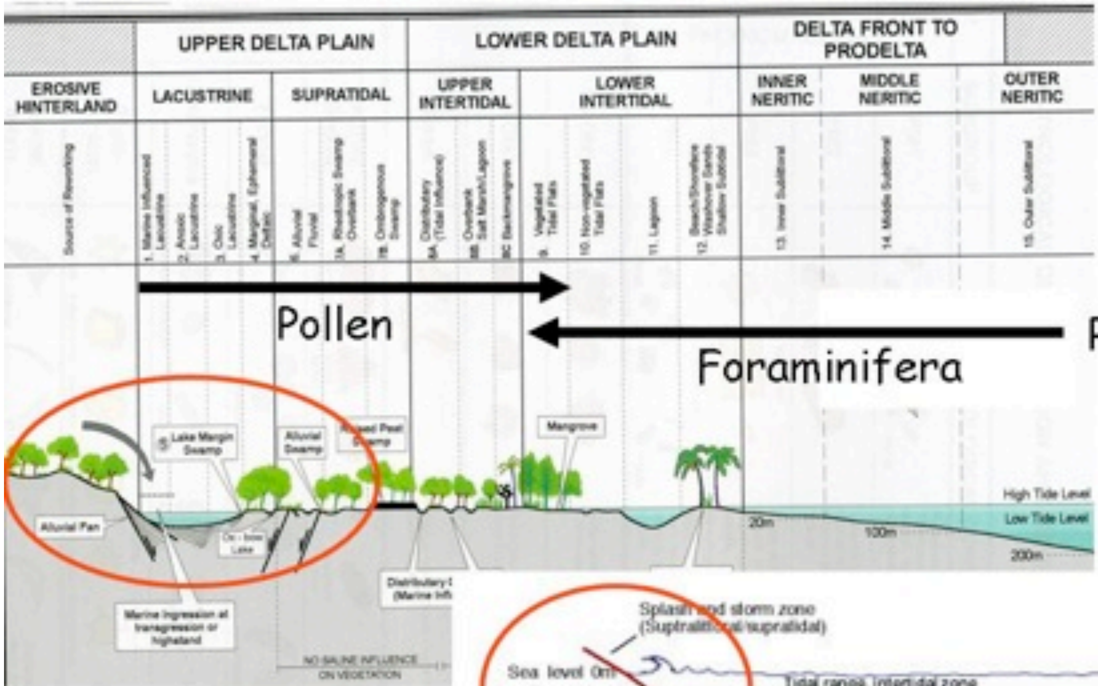
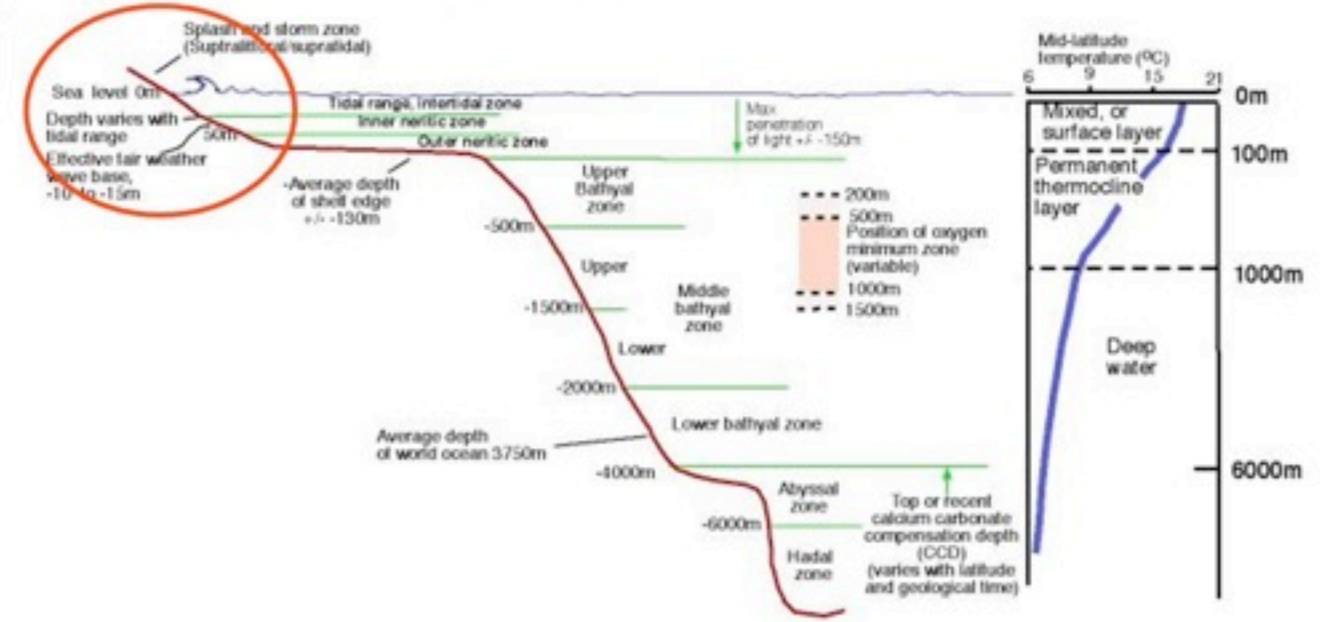
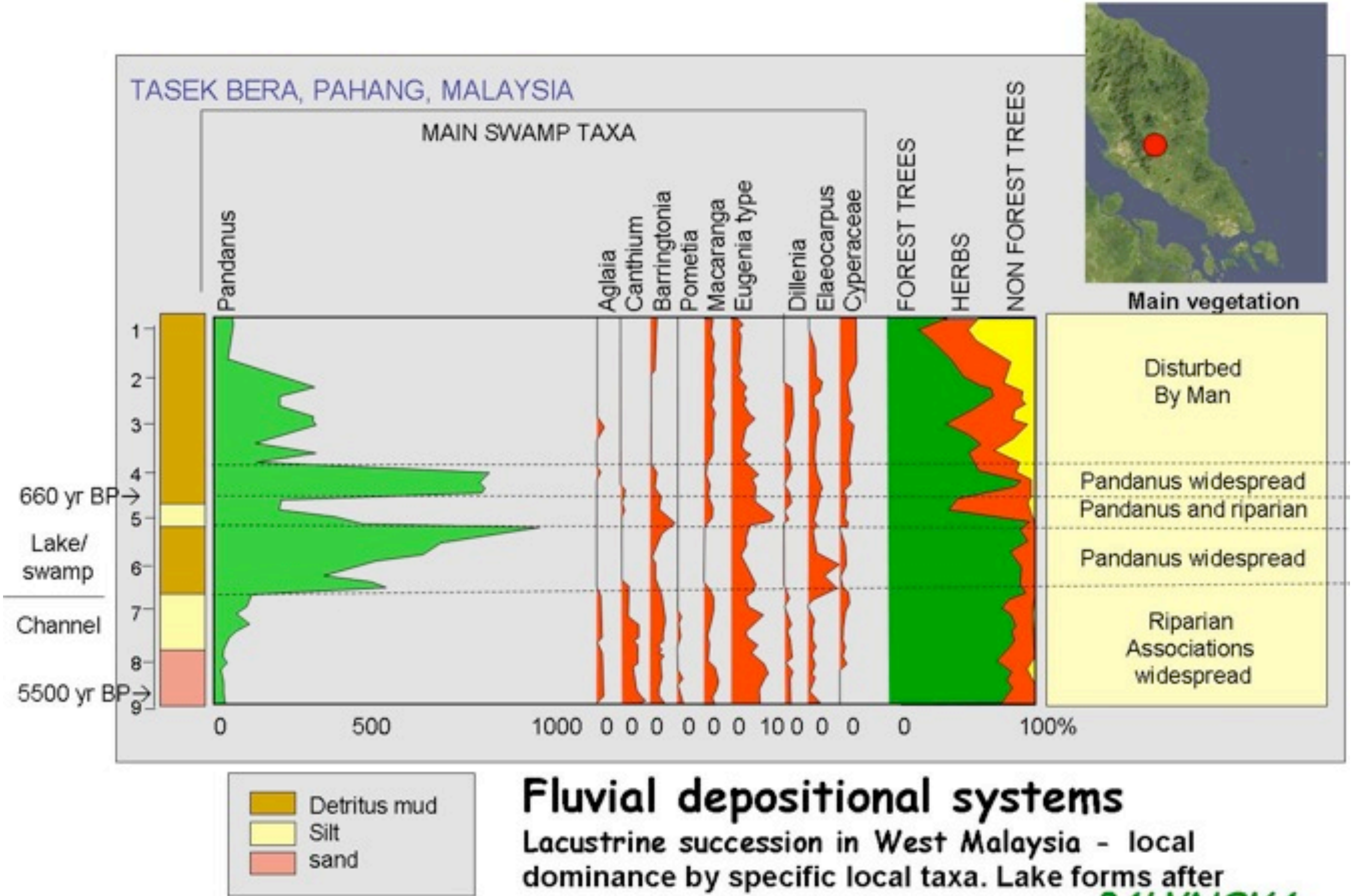
Fluvial depositional systems





6.69



Fluvial depositional systems

Lacustrine succession in West Malaysia - local dominance by specific local taxa. Lake forms after channel abandonment

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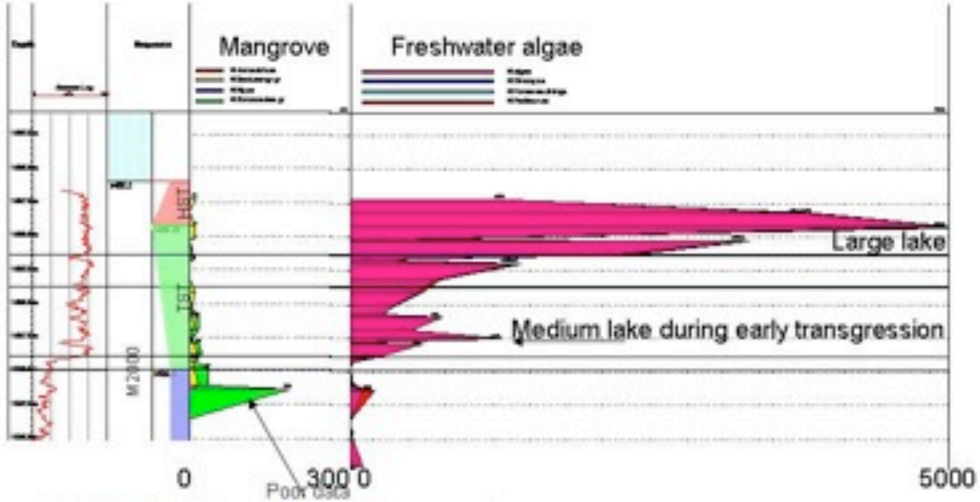
6.70

6 Lower fluvio-lacustrine depositional systems, lake size

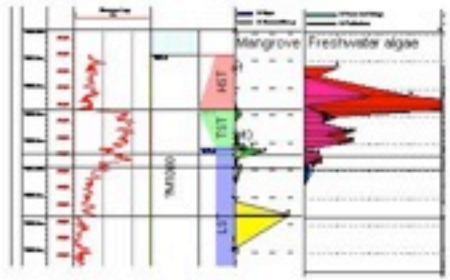
Large lake, minimal marginal swamp suggesting young, mountainous terrain

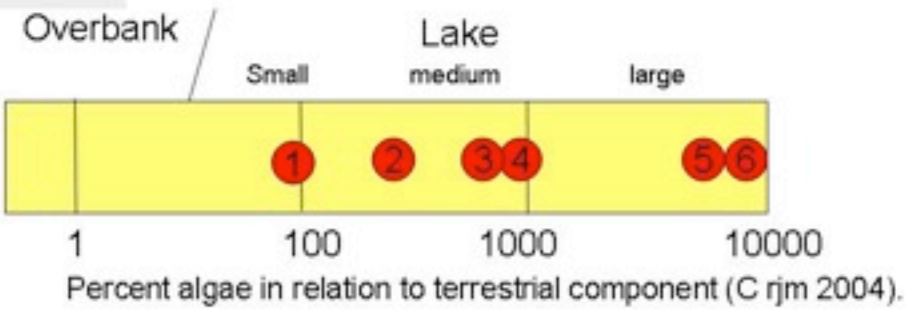
Lacustrine interval contains superabundant freshwater algae suggesting a very large lake.



Small to medium lake, minimal marginal swamp suggesting young, mountainous terrain,

Lacustrine interval contains abundant freshwater algae suggesting a medium sized lake.





6.75

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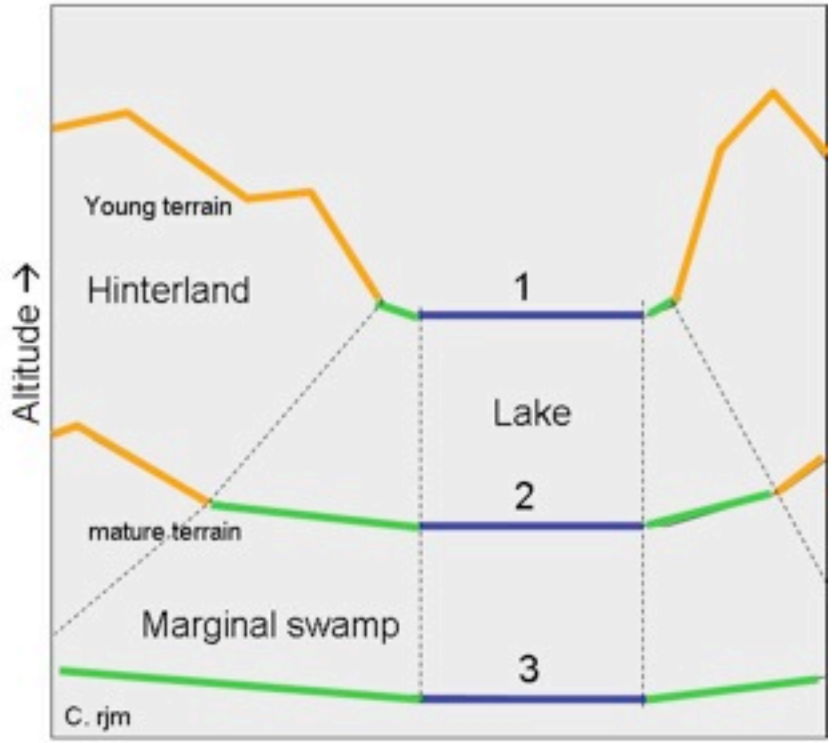
6 Lower fluvio-lacustrine depositional systems, lake geomorphology

Lake geomorphology is indicated by examining the character of lake margin palynomorph signals, such as the abundance and diversity of marginal mangrove and freshwater swamp pollen, with the abundance and diversity of pollen from *terra firma* vegetation. Lakes with narrow marginal swamps, implying young terrain with steep slopes, is suggested when the swamp pollen component is small, but with a well developed marginal swamp, most of the pollen will probably be derived from the marginal swamp and very little from the hinterland.



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Makassar Straits environment interpretation using foraminifera and palynomorphs

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Ecology and palaeoecology of Southeast Asian peats and coals

-Main peat types

-'Basinal peats

-Kerapah peats

-Mangrove peats

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-Main peat types
-Basinal peats

-Main peat types
-Basinal peats

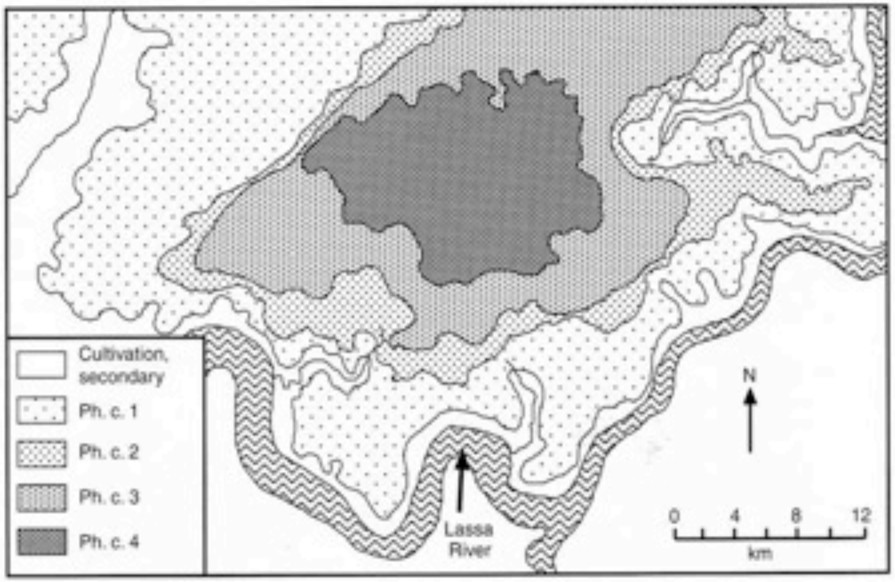
-Mostly occur in coastal settings behind mangrove swamps, on variety of soil types

-Typically intergrade with mixed dipterocarp forest

-Typically domed, beginning as topotrophic mires, developing into ombrotrophic mires, need low nutrients

-Show concentric zonation, divided into 'Phasic' communities, reflected by floristics, physiognomy, peat thickness and nutrients

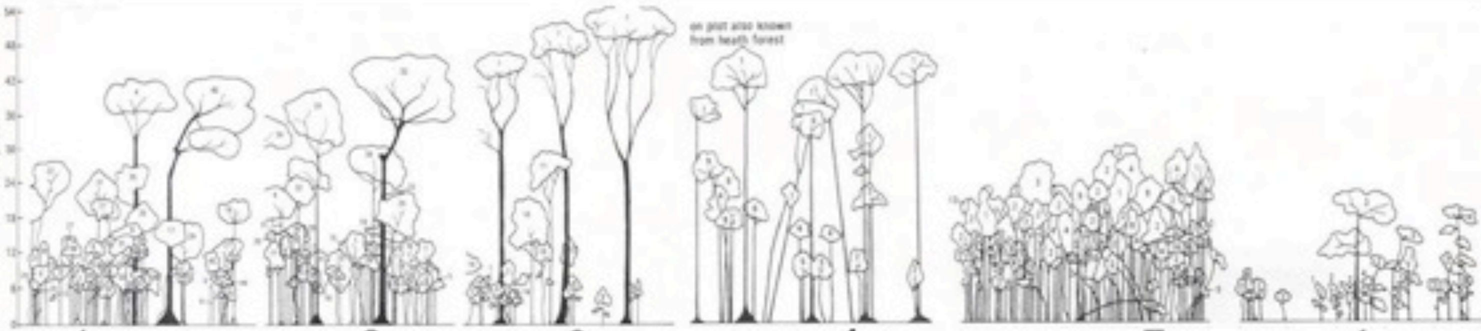
-Phasic community 1 similar to Mixed Dipterocarp Forest, Ph 6 to stunted Kerangas



Lassa forest reserve, Sarawak

-Relatively low diversity (about 300 tree spp in Sarawak)

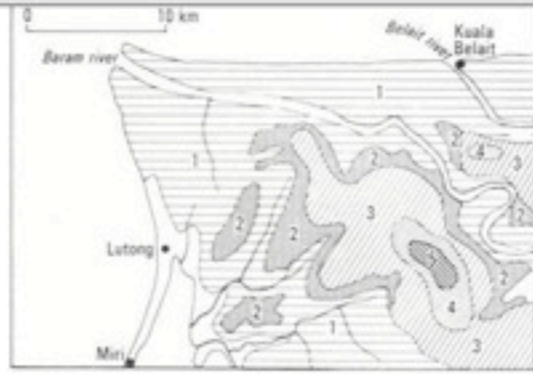
-Peats reach up to 20m in thickness



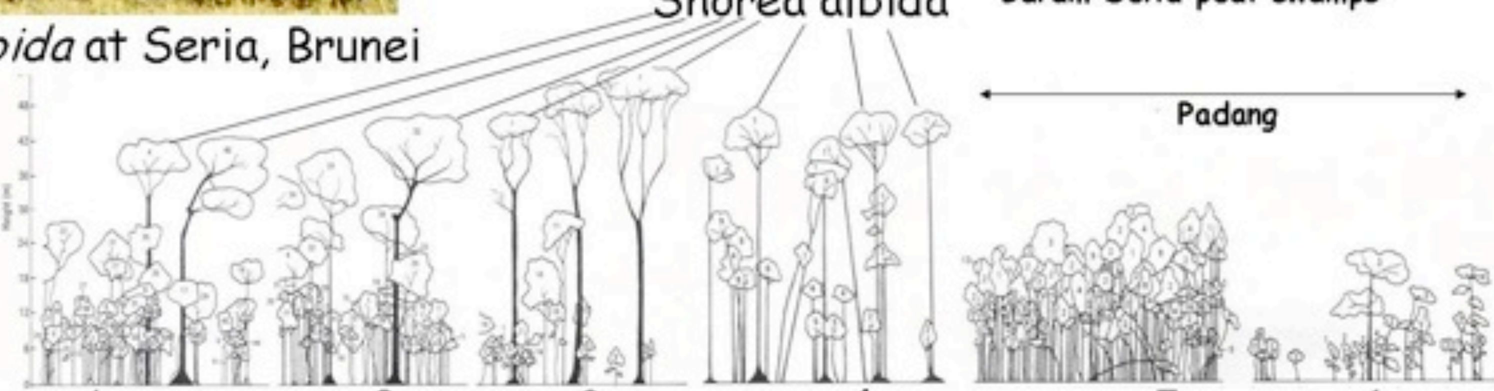
Peat swamp types on Baram 1 2 3 4 5 6

The strongly domed Sarawak peats are widely used as an analog for all domed peats. However, they are exceptional, in that Phasic communities 2-4 are dominated by one local species, *Shorea albida*. Elsewhere this is missing and few analog species are known. Elsewhere doming is less, with two main communities: Ph 1 (Mixed swamp forest) and 'Padang'

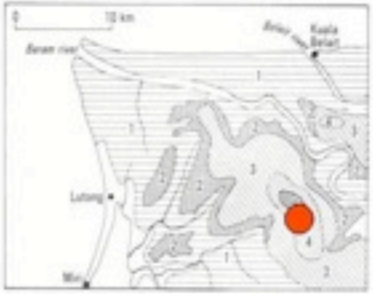
Shorea albida at Seria, Brunei

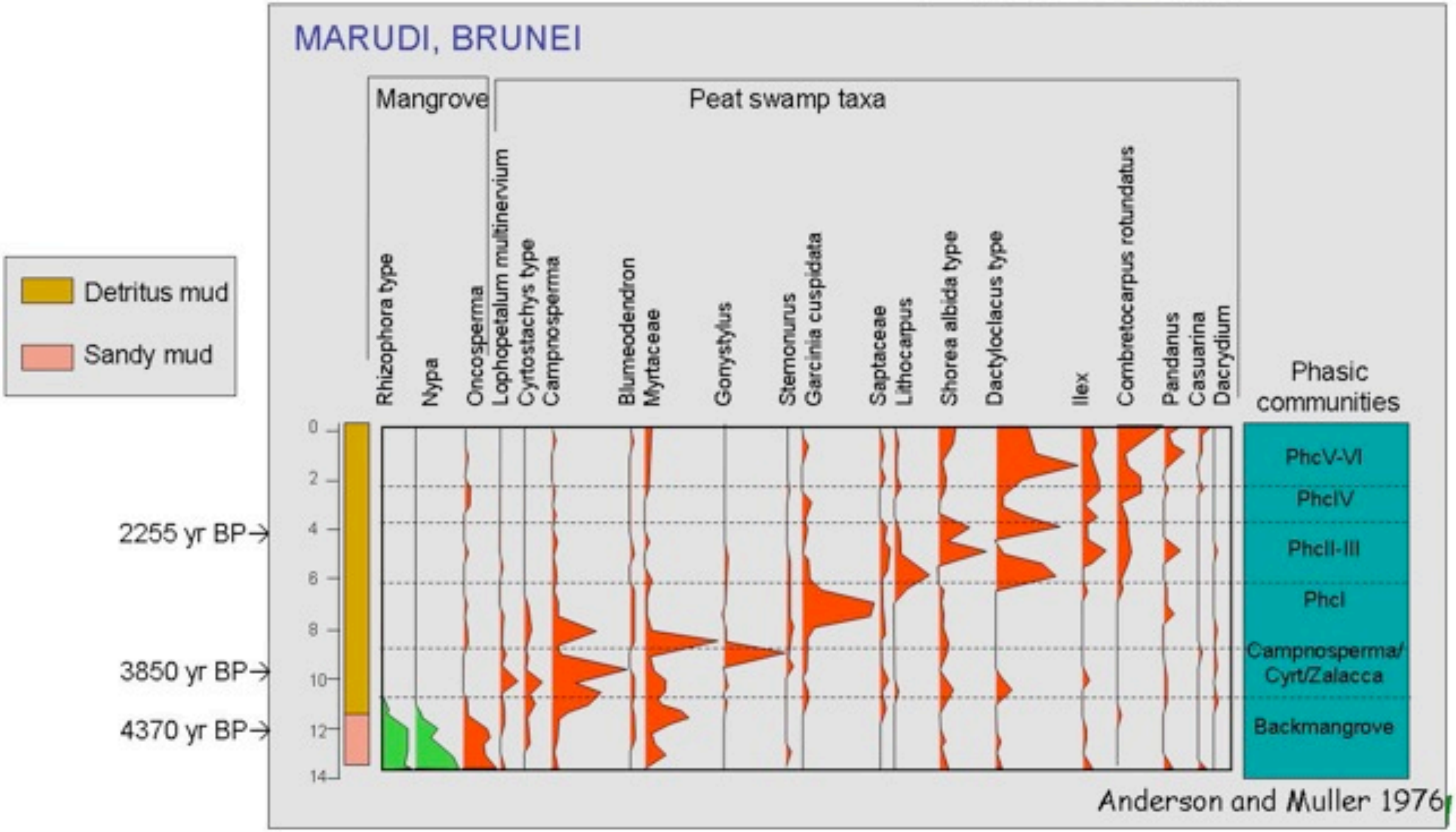


Baram Delta peat swamps



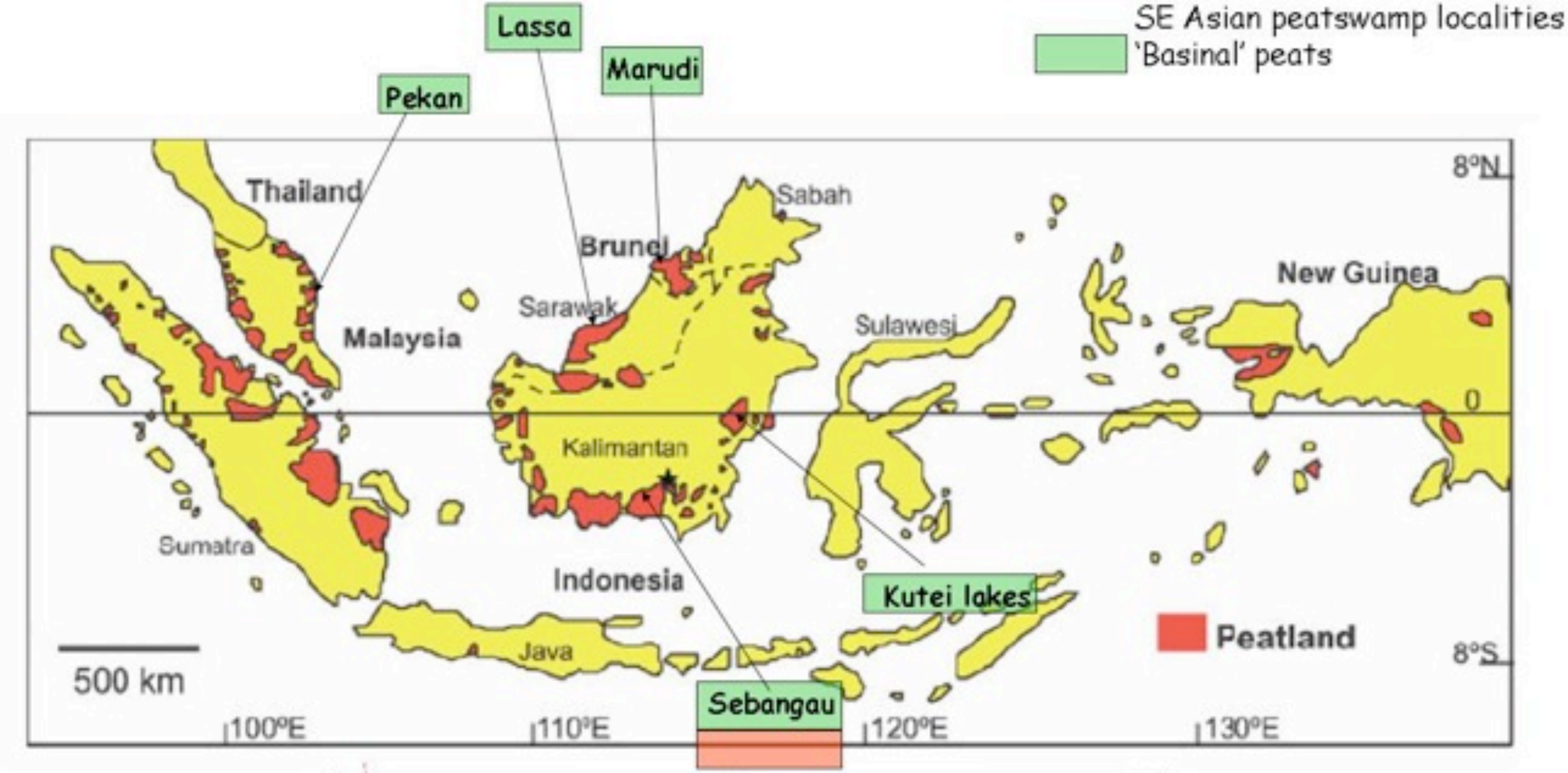
'Basinal peats show the same succession seen from shallow to deep peat to have developed in temporal succession over 4500 years since sea levels stabilised during the mid Holocene

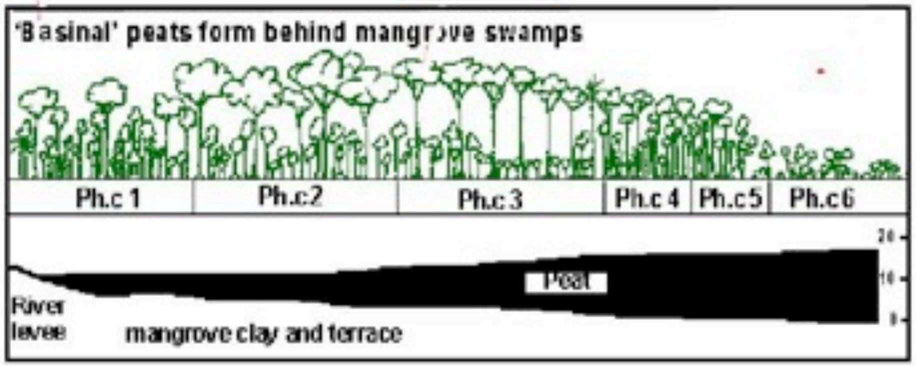




Friday, 7 October 2011

Basinal peats are the dominant peat type in Sunda Region





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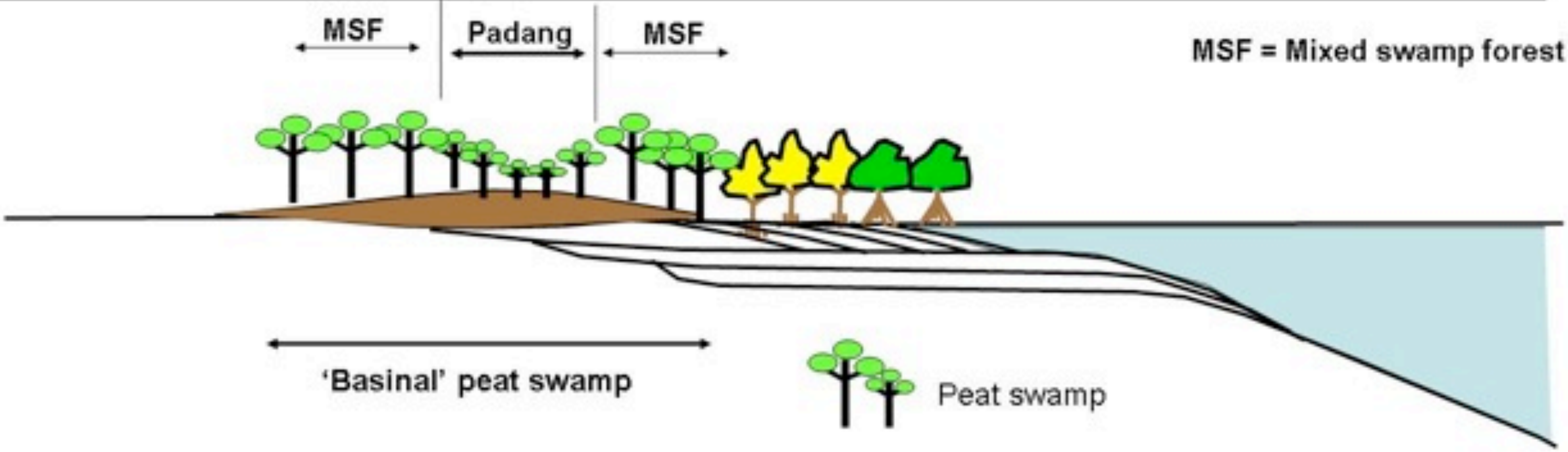
'Basinal' peat swamps summary

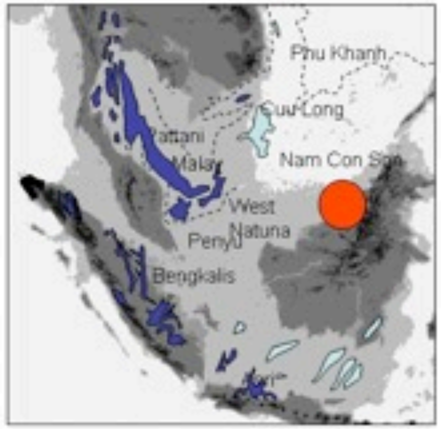
'Basinal' peats are essentially tied to sea level and commence as topotrophic peats building up behind mangrove swamps at times of stable sea level. If they develop over long time periods they may build up into the typical 'domed' peats of Sarawak/Brunei, but the Sarawak peat swamps are anomalous in that elsewhere doming is reduced since the main peat-forming species, Shorea albida, is missing outside northern Borneo.

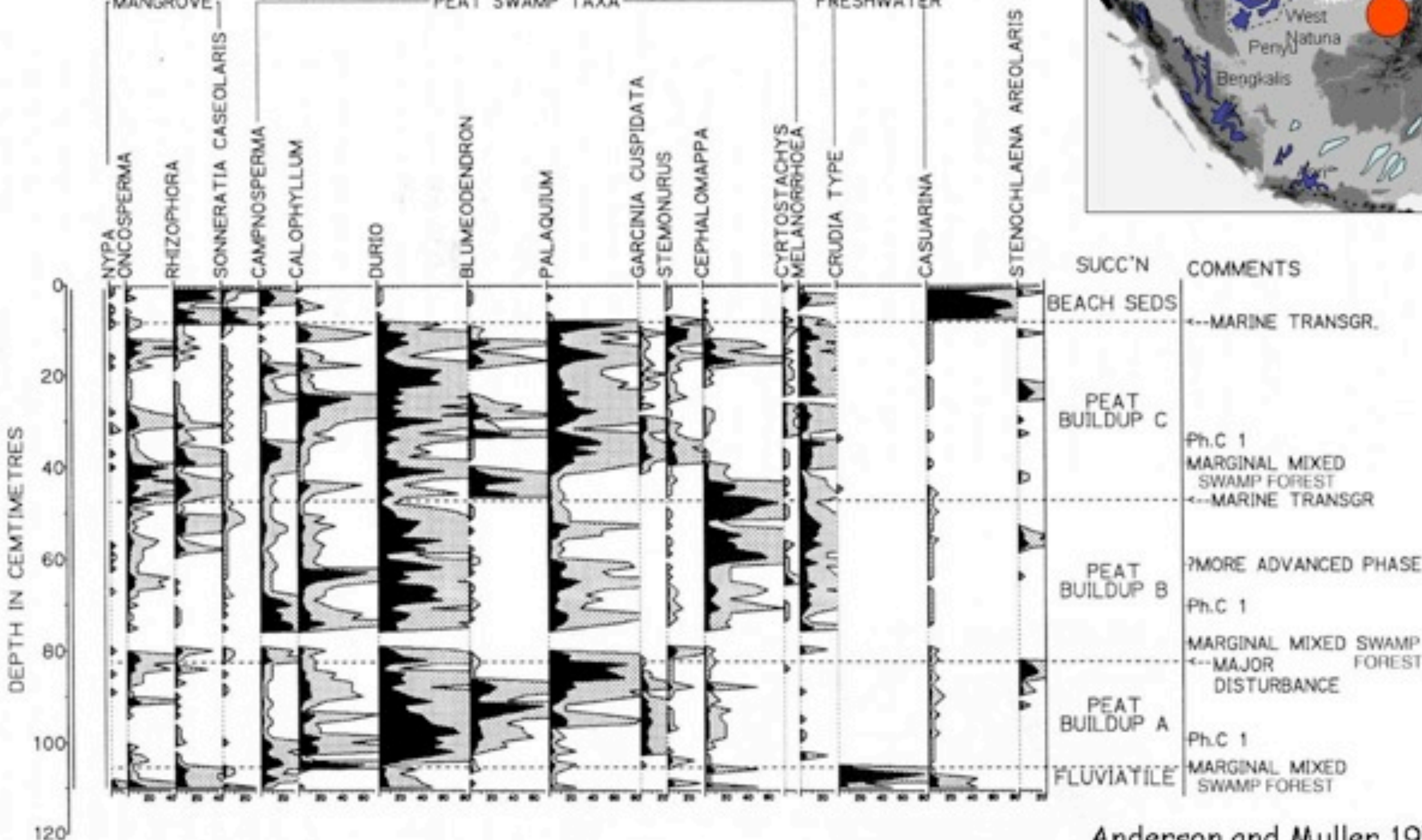
They principally form during periods of high or stable sea levels in areas of everwet climate



Miocene coal

Berakas coal, Brunei, Basinal peat

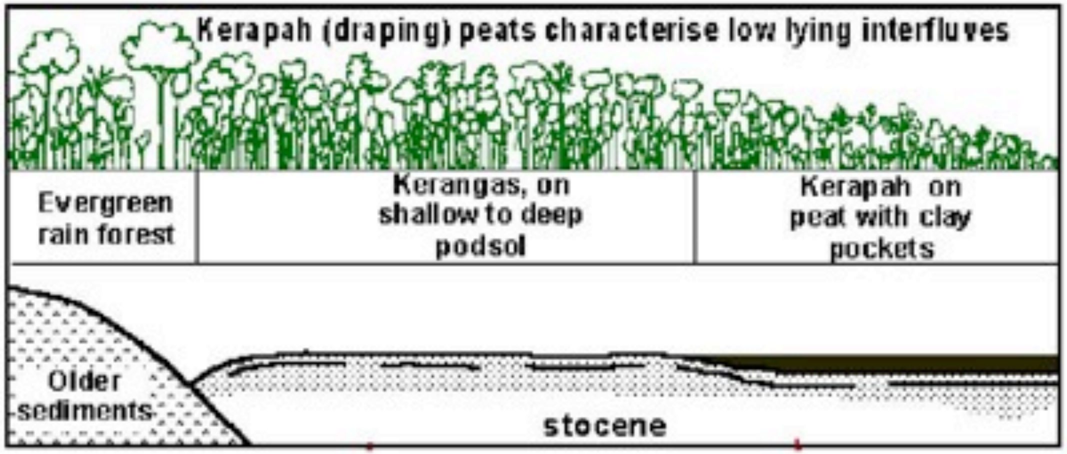




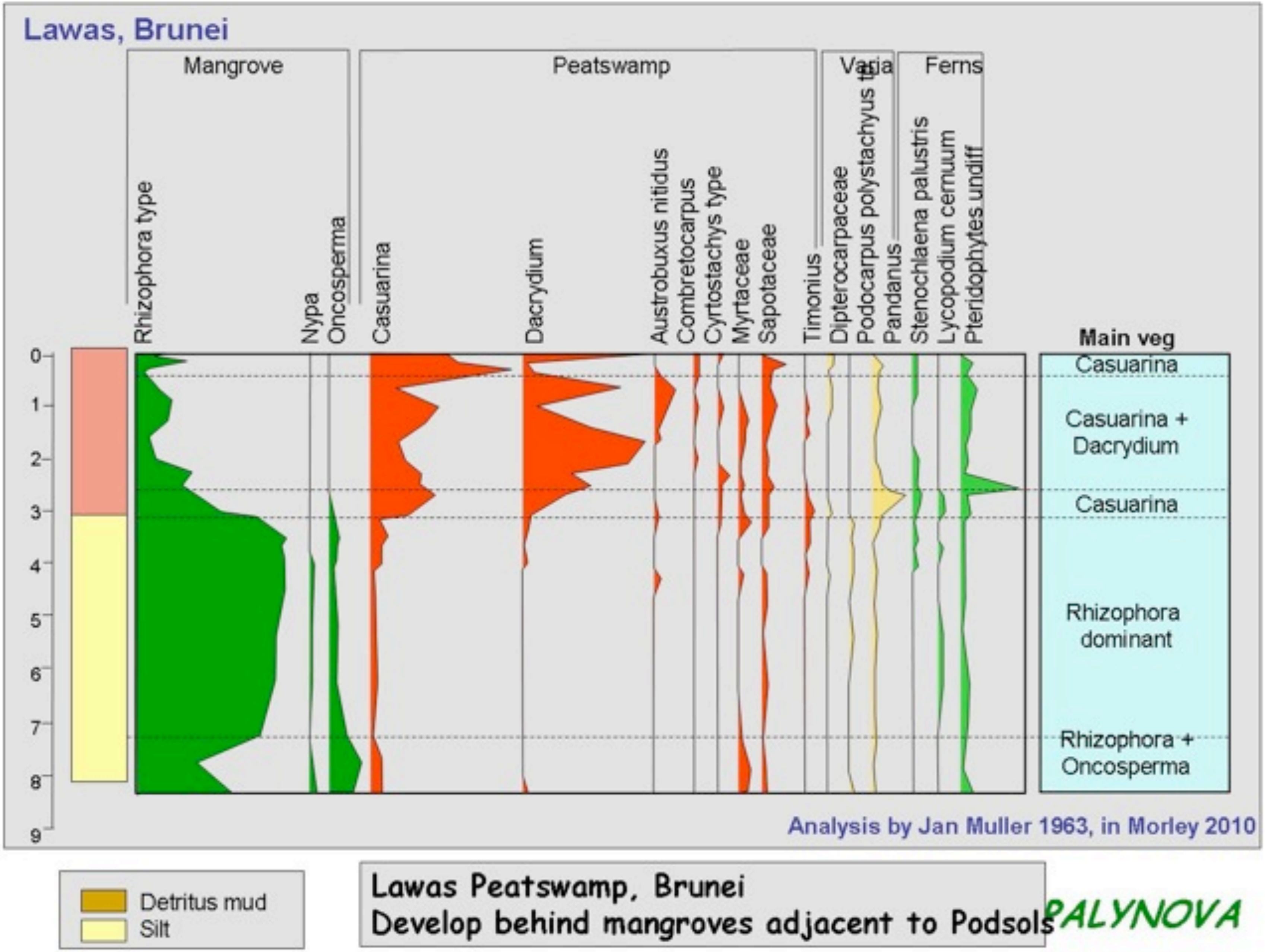
Anderson and Muller 1976

Main peat types
-Kerapah peats

-Mostly occur on podsolic soils especially where there is an iron or humic pan inhibiting movement of ground water
-Thus associated with Kerangas rain forests
-These are true ombrotrophic mires, and may drape irregular topography
-May show doming and concentric zonation but not so pronounced as Basinal peats
-'Kerapah' means 'wet end of Kerangas' in Sarawak
-Develop on poorly drained terraces and interfluves poor in nutrients
--Generaly associated with 'small leaved' Kerangas spp especially Casuarina (Gymnostoma) and Dacrydium
-Poorly developed today, greatest thickness 2-3m in Sarawak, 6m in S Kalimantan
- Were much more extensive in past, High diversity



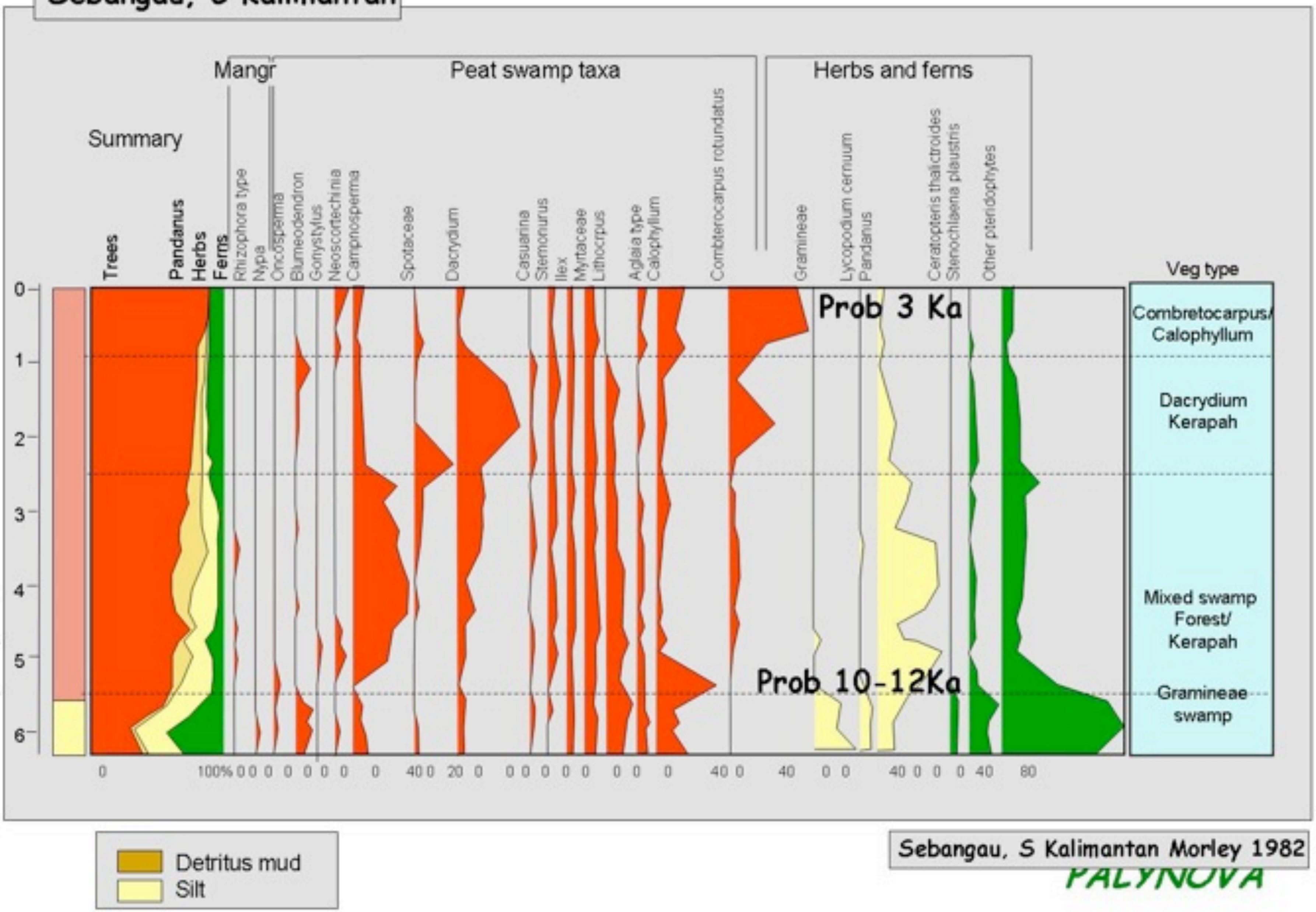
'ALYNOVA



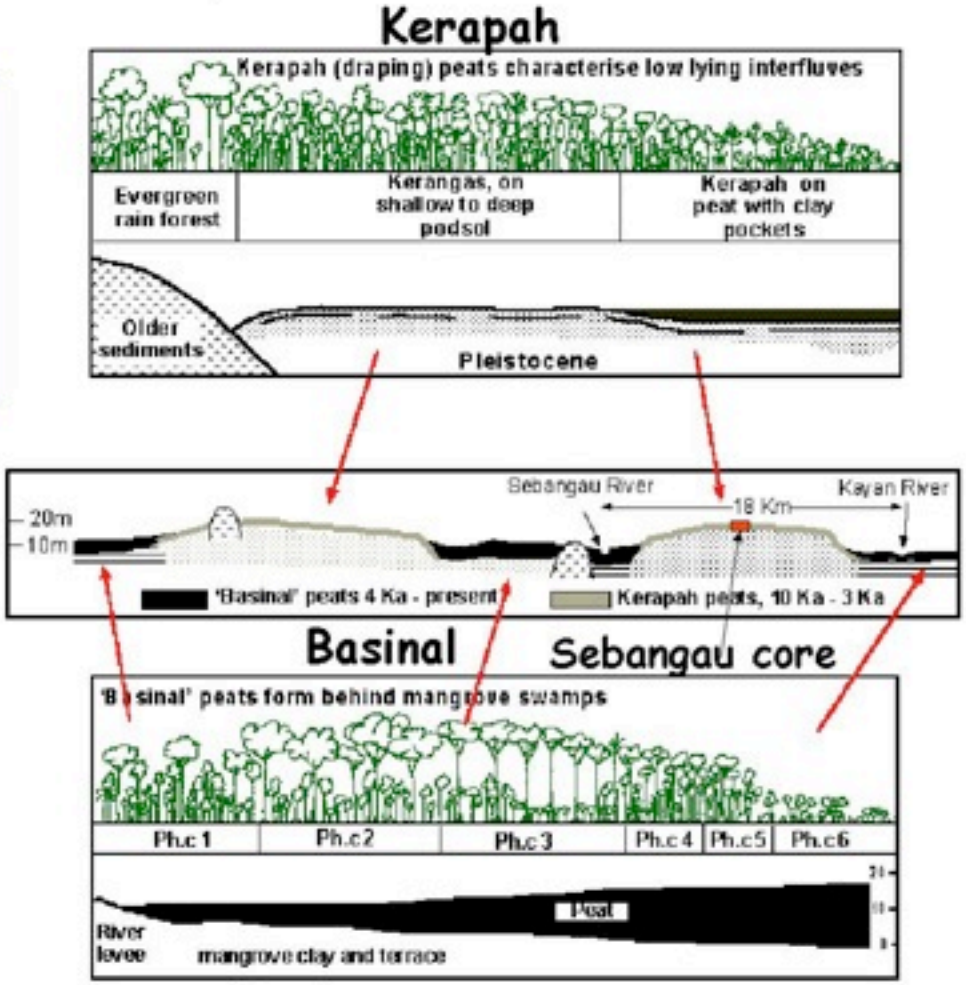
Lawas Peatswamp, Brunei
Develop behind mangroves adjacent to Podsols

PALYNOVA

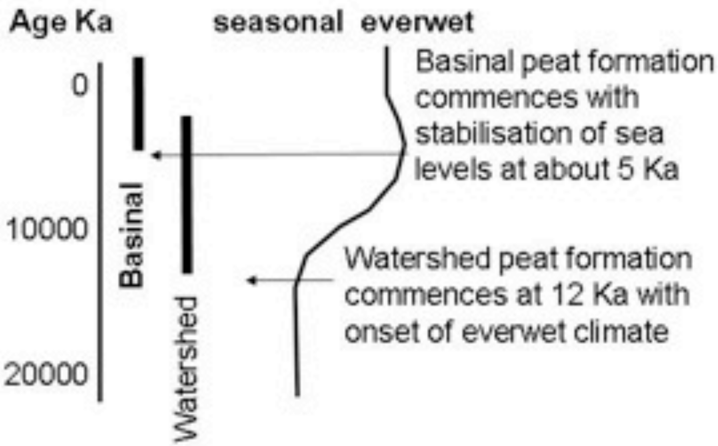
Sebangau, C Kalimantan



In Sebangau, S Kalimantan, both peat types occur together and intergrade



Sebangau



Different periods of peat swamp formation in Sebangau area of S Kalimantan

C. Shell 2008

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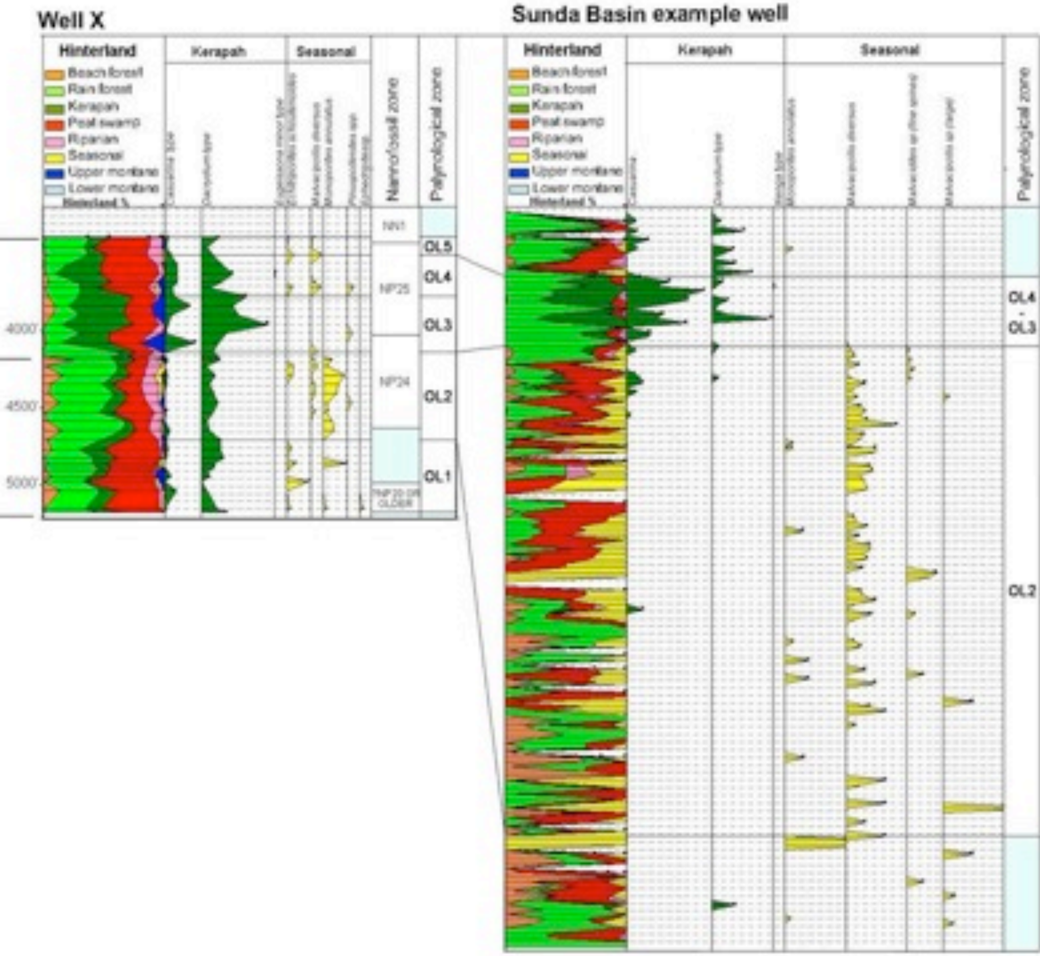
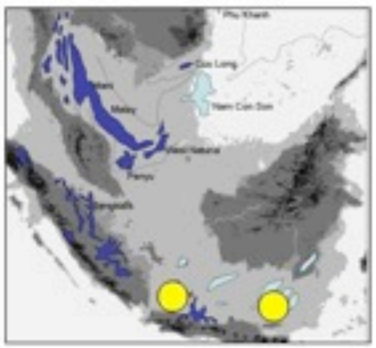
Oligocene coal

Kerapah swamps

Lt Oligocene

Ey Oligocene





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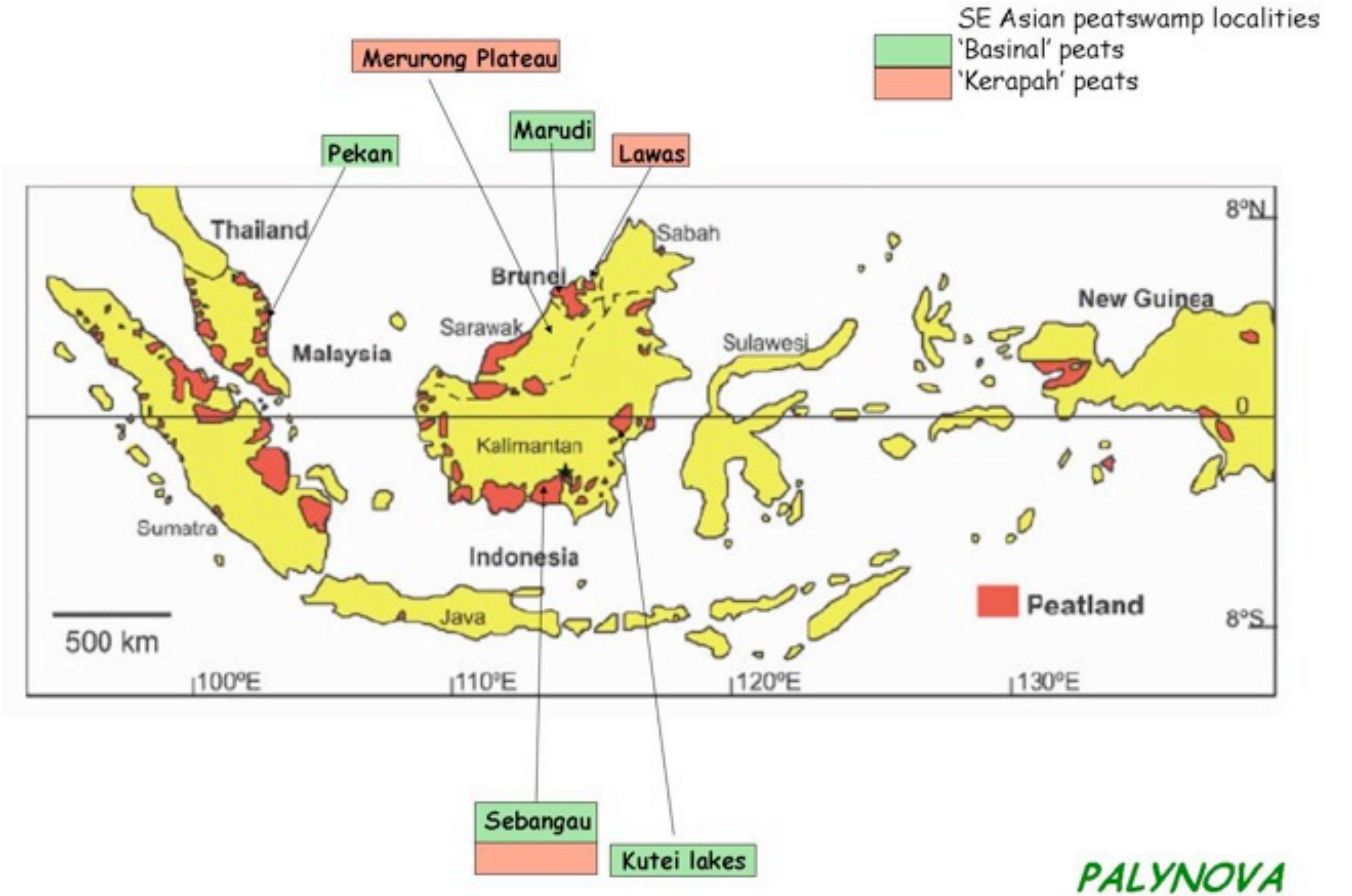
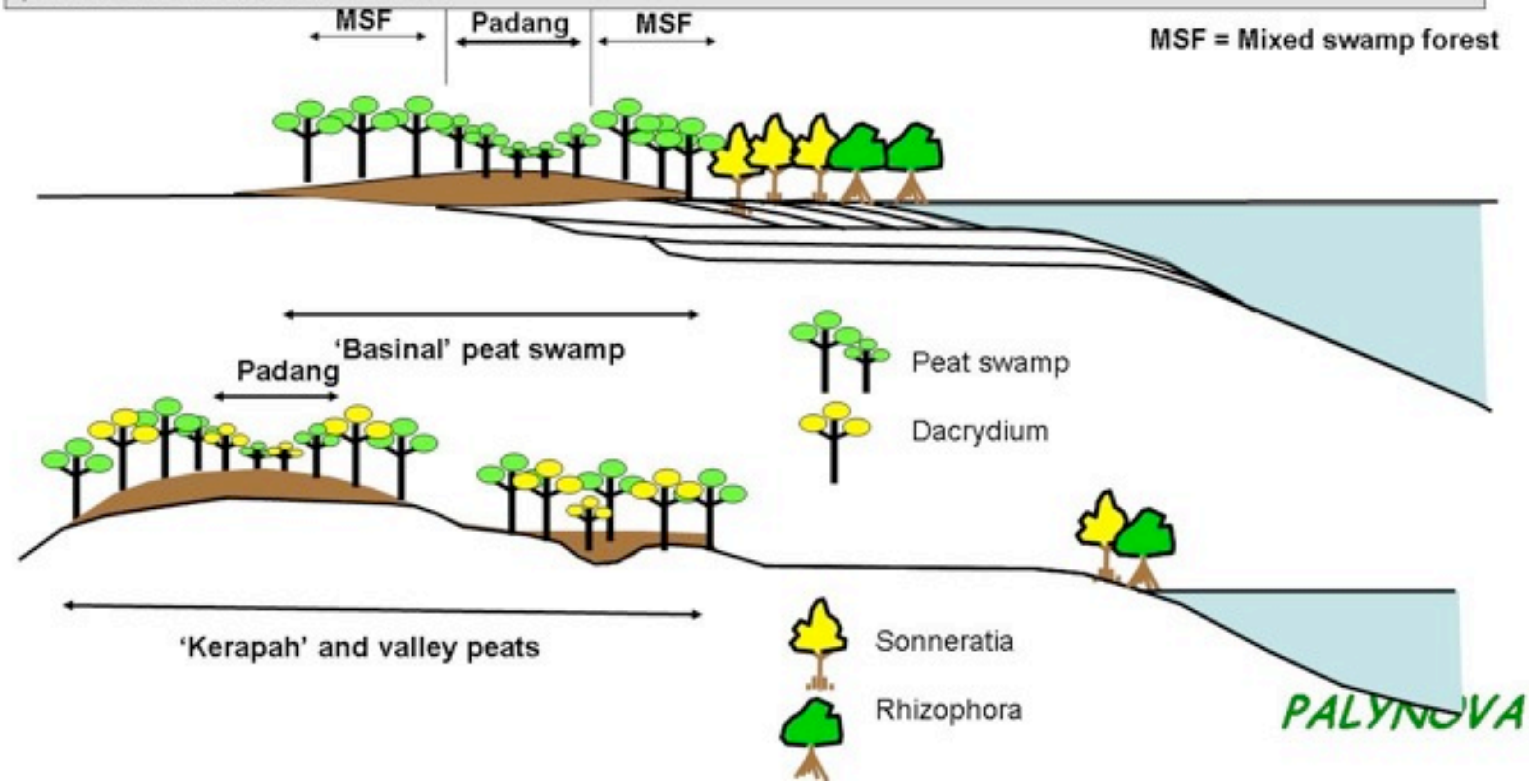
Basinal and Kerapah peats in Sunda Region



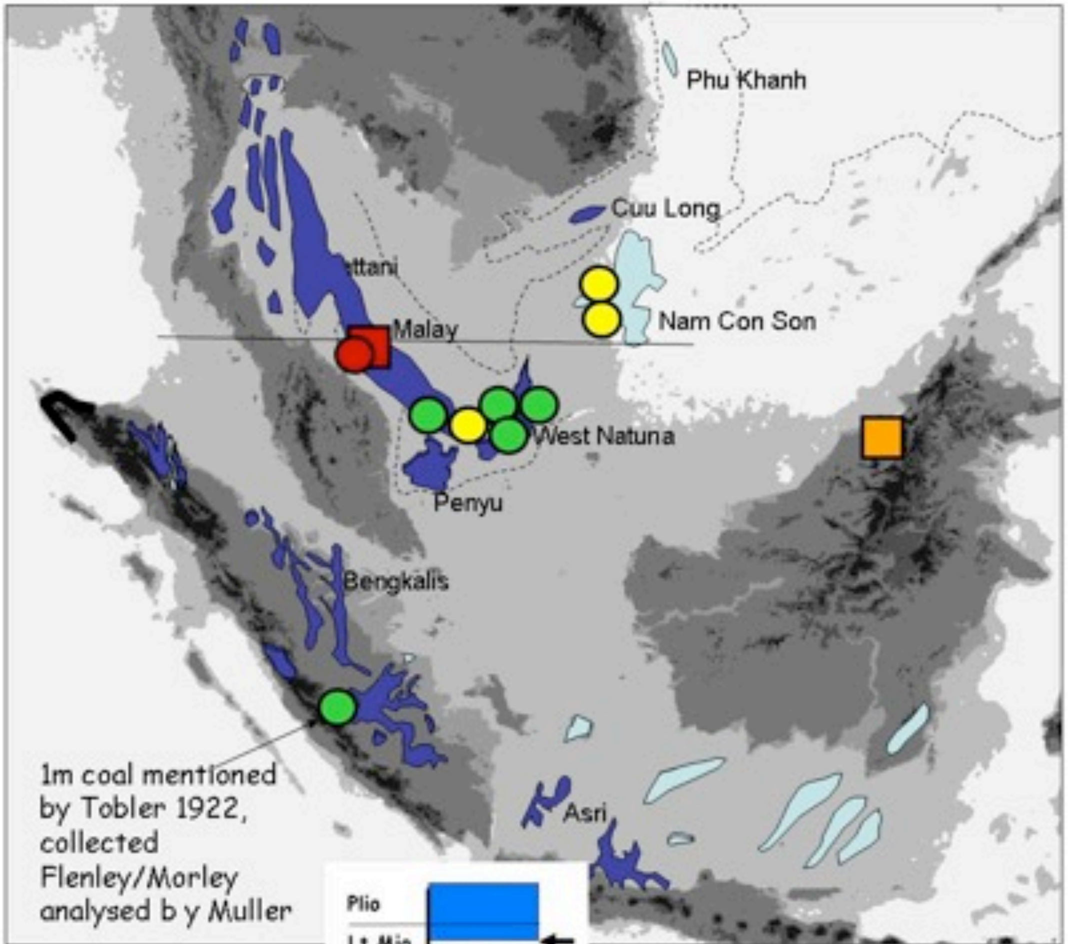
'Basinal' and 'Kerapah' peat swamps summary

'Basinal' peats are essentially tied to sea level and commence as topotrophic peats building up behind mangrove swamps at times of stable sea level. If they develop over long time periods they may build up into the typical 'domed' peats of Sarawak/Brunei, but the Sarawak peat swamps are anomalous in that elsewhere doming is reduced since the main peat-forming species, Shorea albida, is missing outside northern Borneo. They principally form during periods of high or stable sea levels in areas of everwet climate

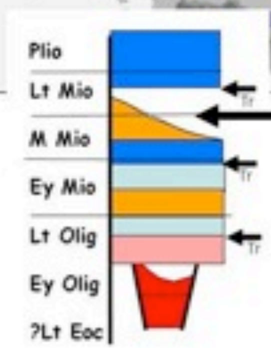
Kerapah peats are true ombrotrophic peats and are not tied to sea level, occurring on topographic lows lacking mineral influx, on interfluves and watersheds. They can form at any time during a sea level cycle provided the climate is everwet



Other peat forming associations

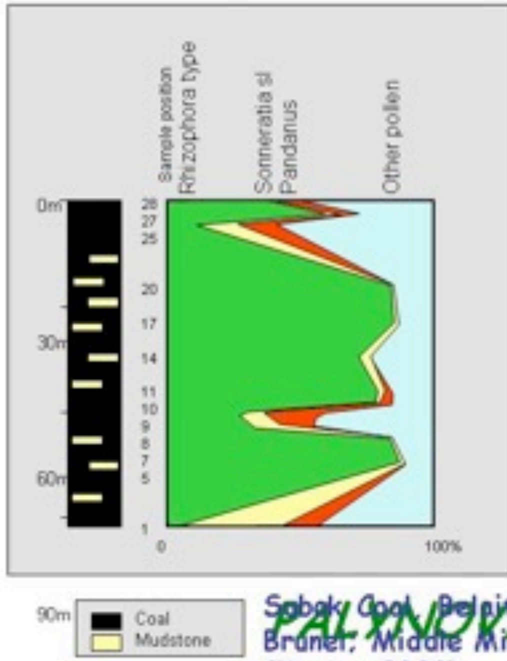


Mangrove Peats (Rhizophora Sonneratia)	rattan swamps	
■ (red)	● (red)	Late Miocene
■ (orange)	● (orange)	Middle Miocene
	● (green)	Early Miocene
	● (yellow)	Oligocene



Major marine coal at end M Mioc

Also Brownlowia Nypa



Sabak Coal, Belait Fm, Brunei, Middle Miocene (Morley 2000)

End

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