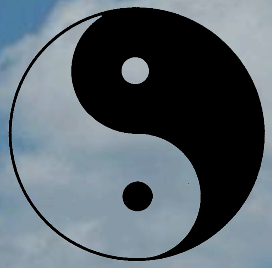
The Yin and Yang of Carbonate Depositional Systems



Gene Rankey

CSL
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What do we know…

- Biotic, physical, chemical influences
- Range of spatial and temporal scales
- Different rates, magnitudes and durations
- Changes through time

…make prediction of landscape/seascape evolution from ‘first principles’ difficult

- sediments

-geomorphic bodies

- stratigraphic record

The results….

“Study of a wide variety of Paleozoic reefs is now revealing hitherto **unexpected levels of ecological complexity**.” -- Wood (1998)

“Every stream [reef, shoal] is **likely to be an individual**…” -- Hynes (1975)

"It's tough to make predictions, especially about the future."– Yogi Berra

Take-Home Messages

Carbonate depositional systems are complex…

…but ‘themes’ persist through space/time

that are ‘independent of the details’

‘Unity of opposites’ results from

- interaction of global and contingent factors

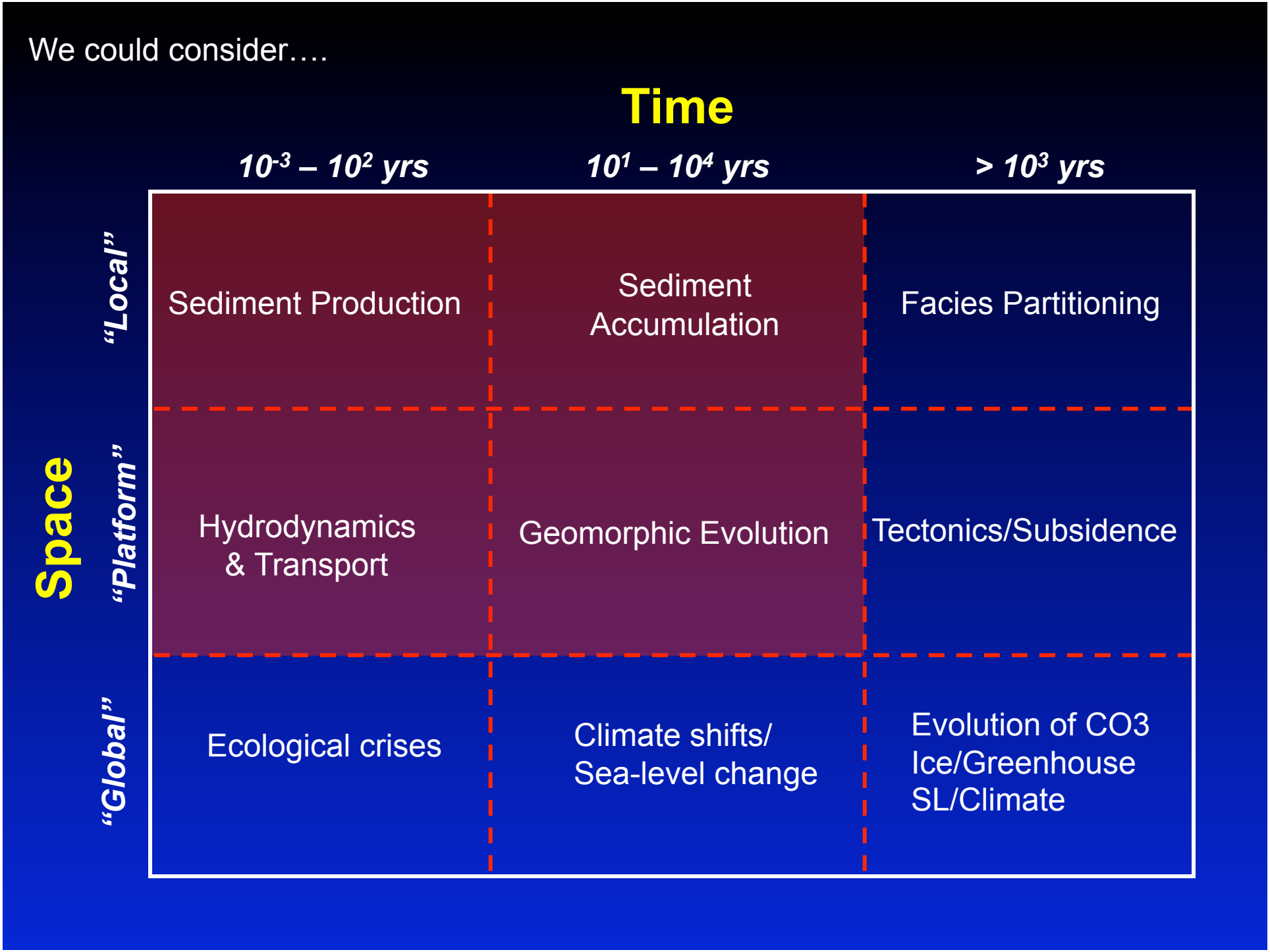
- feedbacks

Every face unique… but common elements

Purposes

- Introduce some perspectives on carbonate depositional systems
- Ask questions
- Open discussions

We could consider….



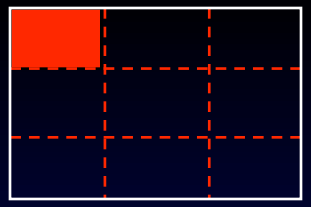
Holocene Systems

- Temporal ‘snapshot’
- Boundary conditions (e.g. bedrock configuration)

- As extend back in time, many unconstrained parameters (evolution, CO_2 levels, hydrodynamics, platform morphology, etc.)

To develop **quantitative predictive models** for **changes through time**…

…need to understand **“how and why” at one point in time**



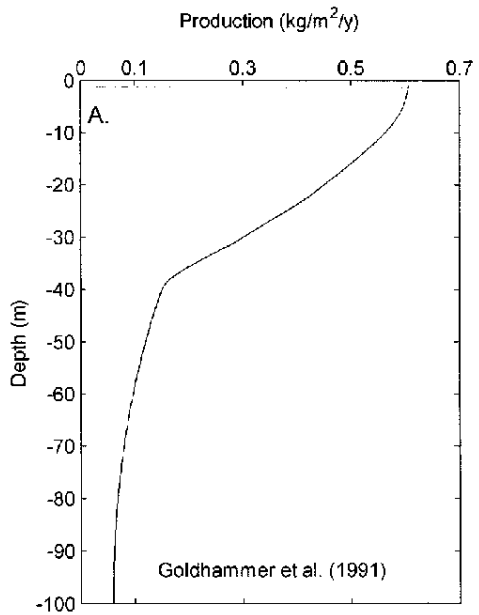
Sediment Production

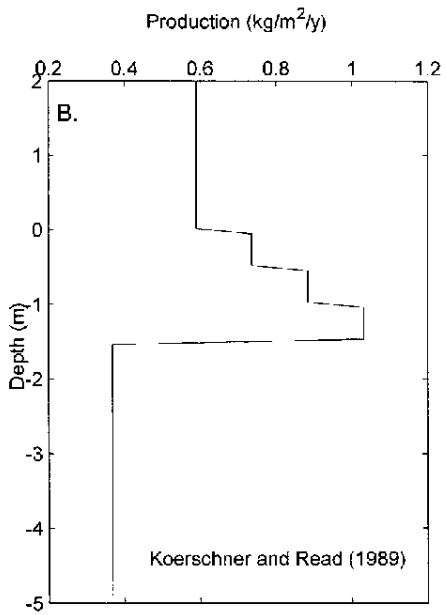
What do we know?

'**Carbonates are born, not made**' – James 1983

'Carbonate sedimentation resembles a powerful Cadillac with a defective carburetor….' – Wilson 1975

Carbonates – Depth Control





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Flourishing green algae
Maximum light &
open circulation

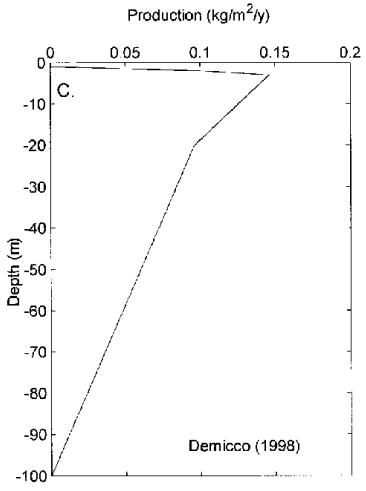
Deth in c

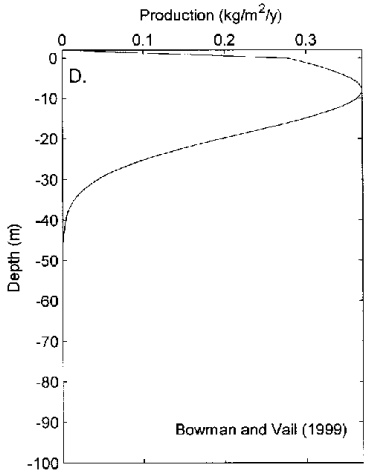
80

100

Lower li
on Beliz

Red algal crusts l
and as deep as 25



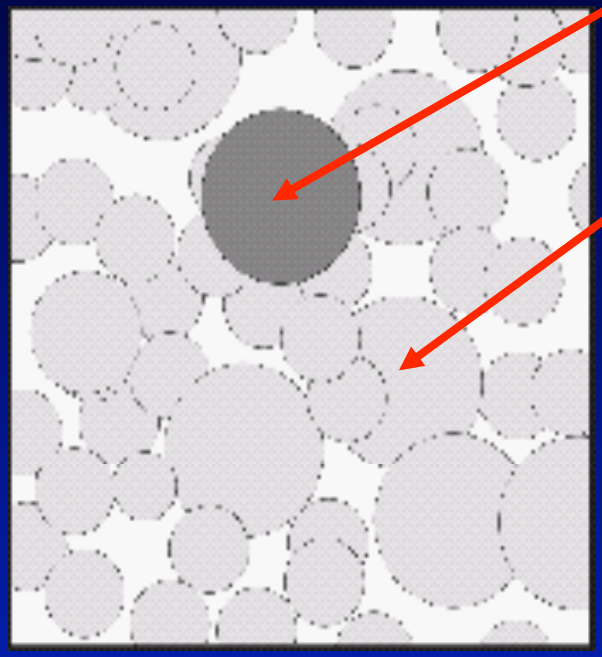


Demicco and Hardie 2002

Spatially variable production

Landward edge of model grid

Current area of active production



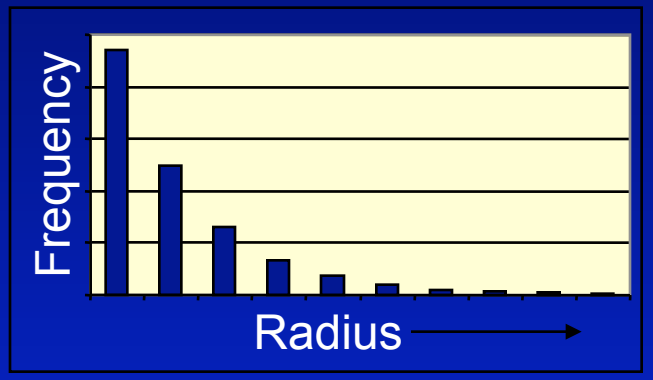
Previous area of production

Seaward edge of model grid

Wilkinson and Drummond models:

$F=333e^{-0.666r}$

Radius r = 4 - 40 km

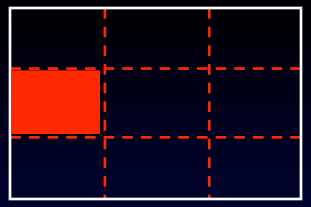


Also leads to temporal variability

Courtesy of Peter Burgess

Sediment Production

- How/where is sediment produced – point source, line source, ‘blanket’? All?
- How do rates vary with different production types?
- How do rates vary among platforms and geological ages? Controls?



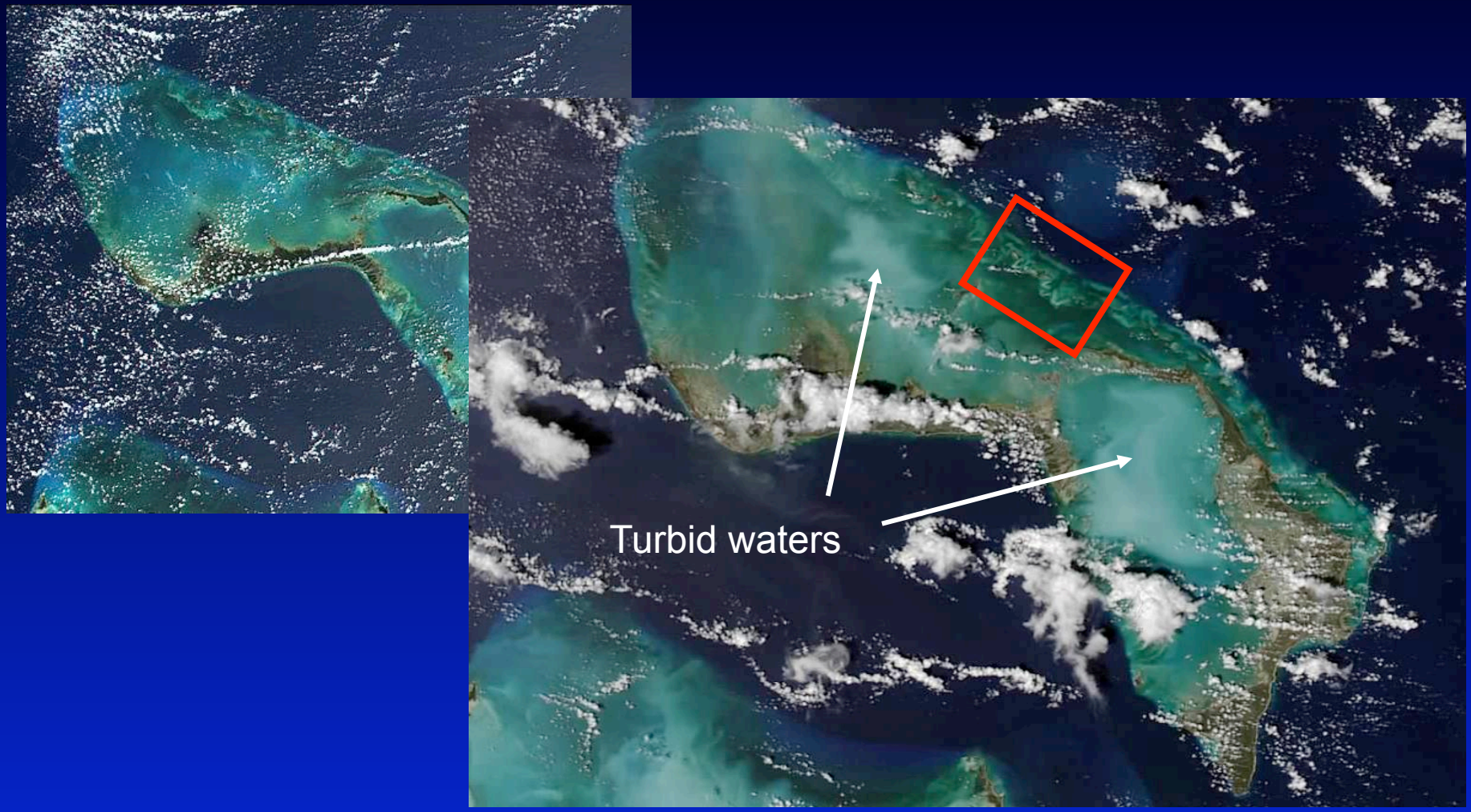
Sediment Transport

What do we know?

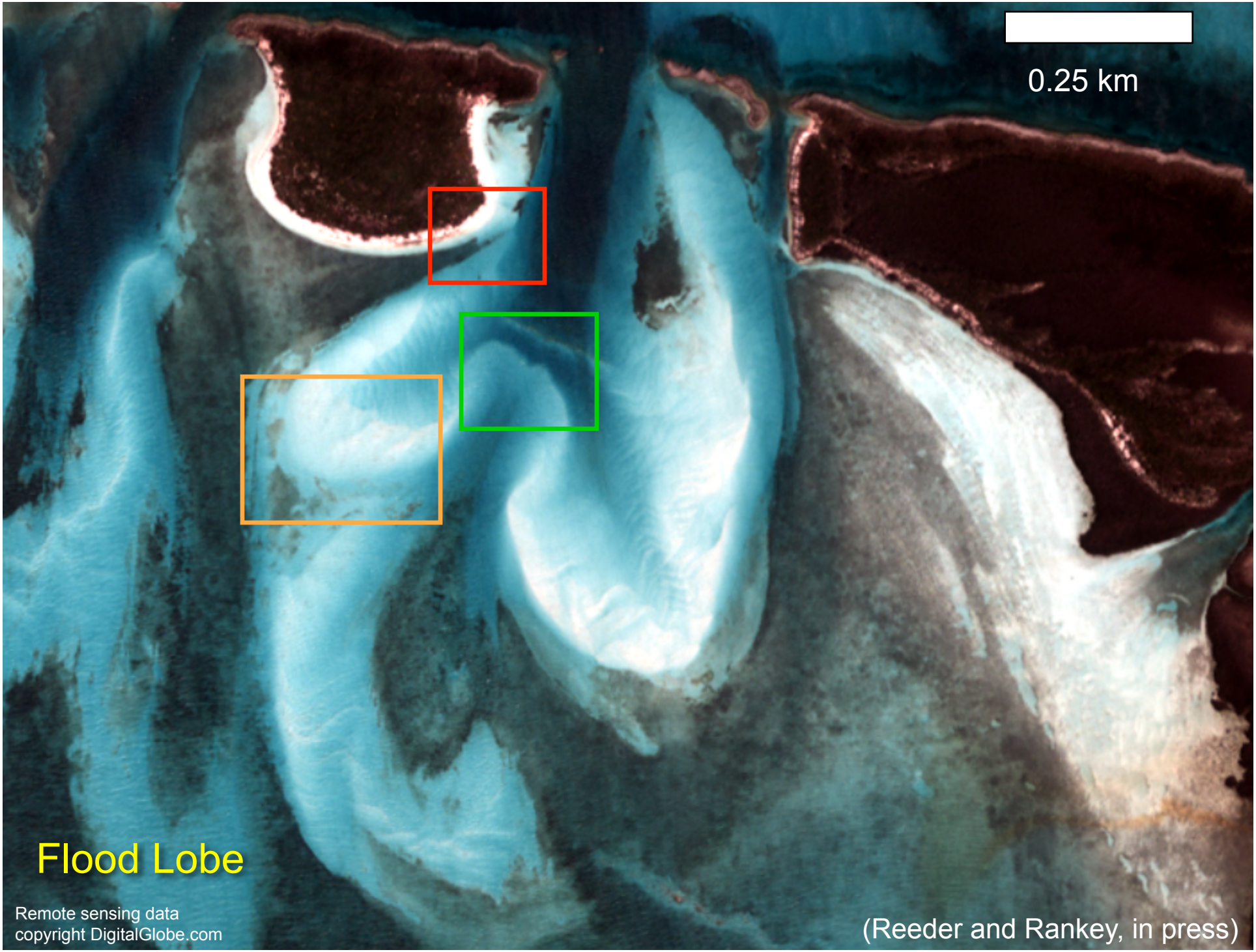
"A large body of literature has suggested that **catastrophic events** are a dominant influence on sedimentation in shallow marine carbonate environments."

-- Wanless et al. (1988)

Influence of Frances on LBB



Frances and Jeanne passed over in a month... if ever we would see changes….


0.25 km
Flood Lobe
Remote sensing data
copyright DigitalGlobe.com
(Reeder and Rankey, in press)

Hydrodynamics

Several potential agents of transport:

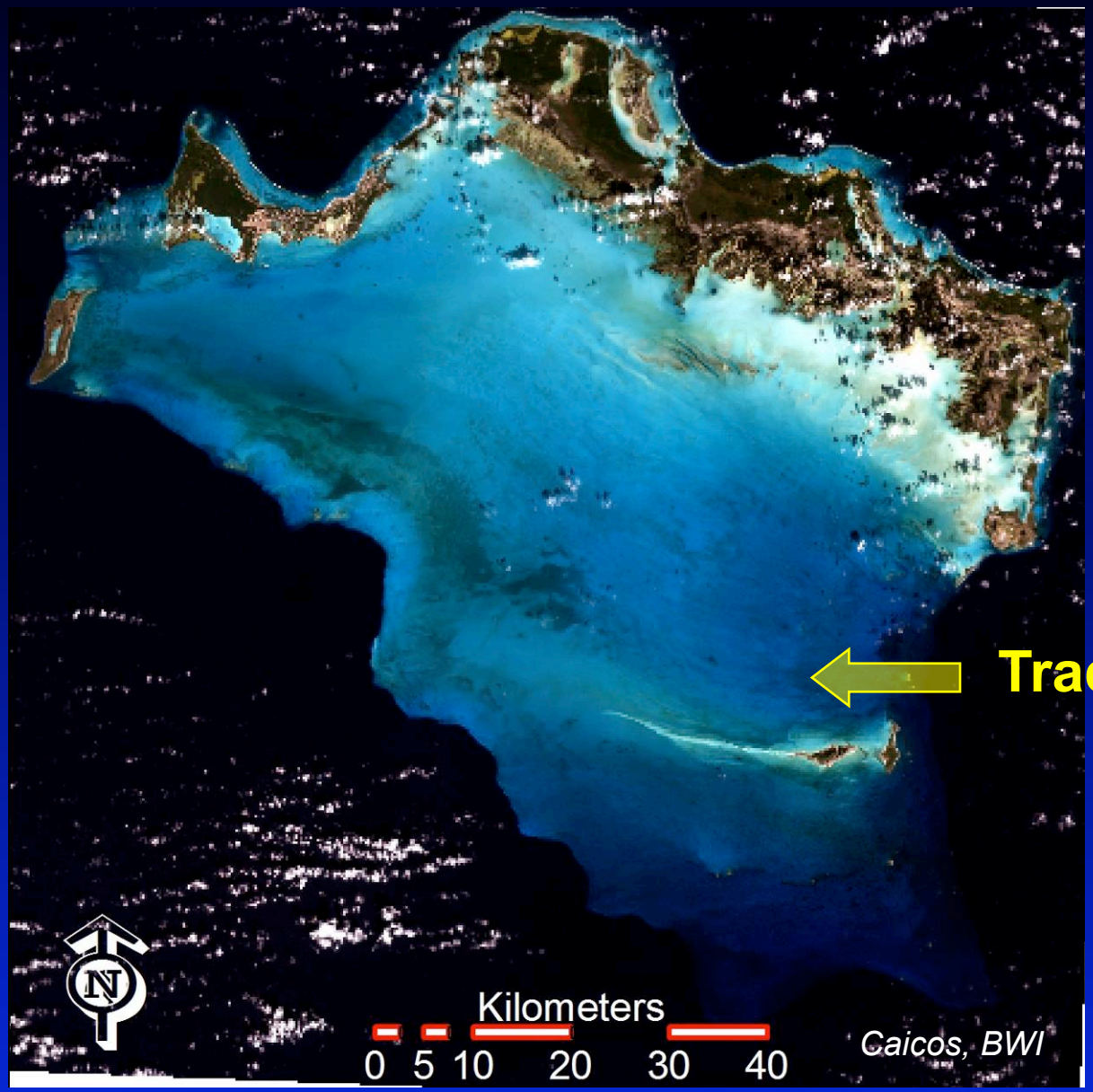
Waves

Tides

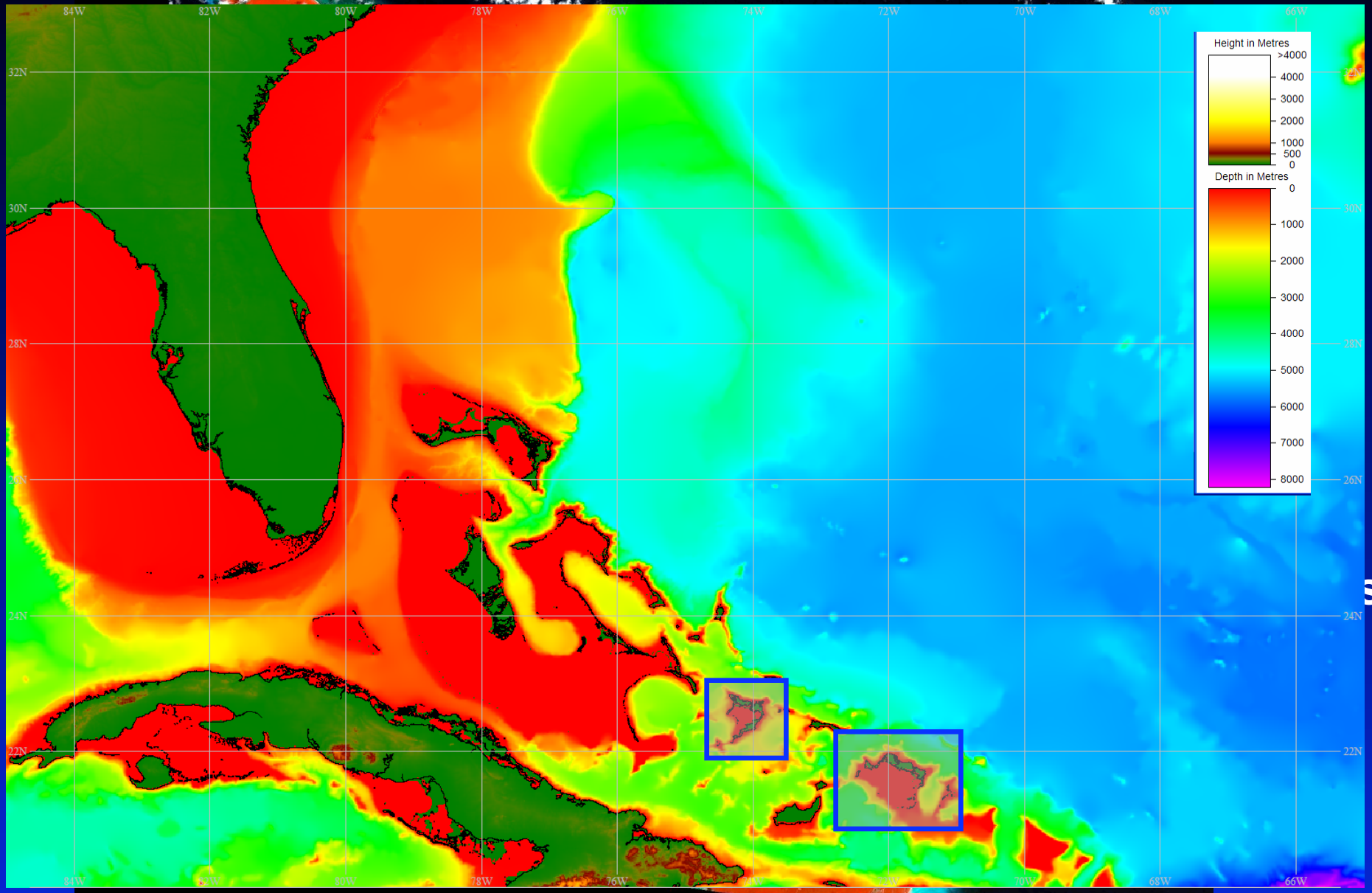
Wind-driven currents

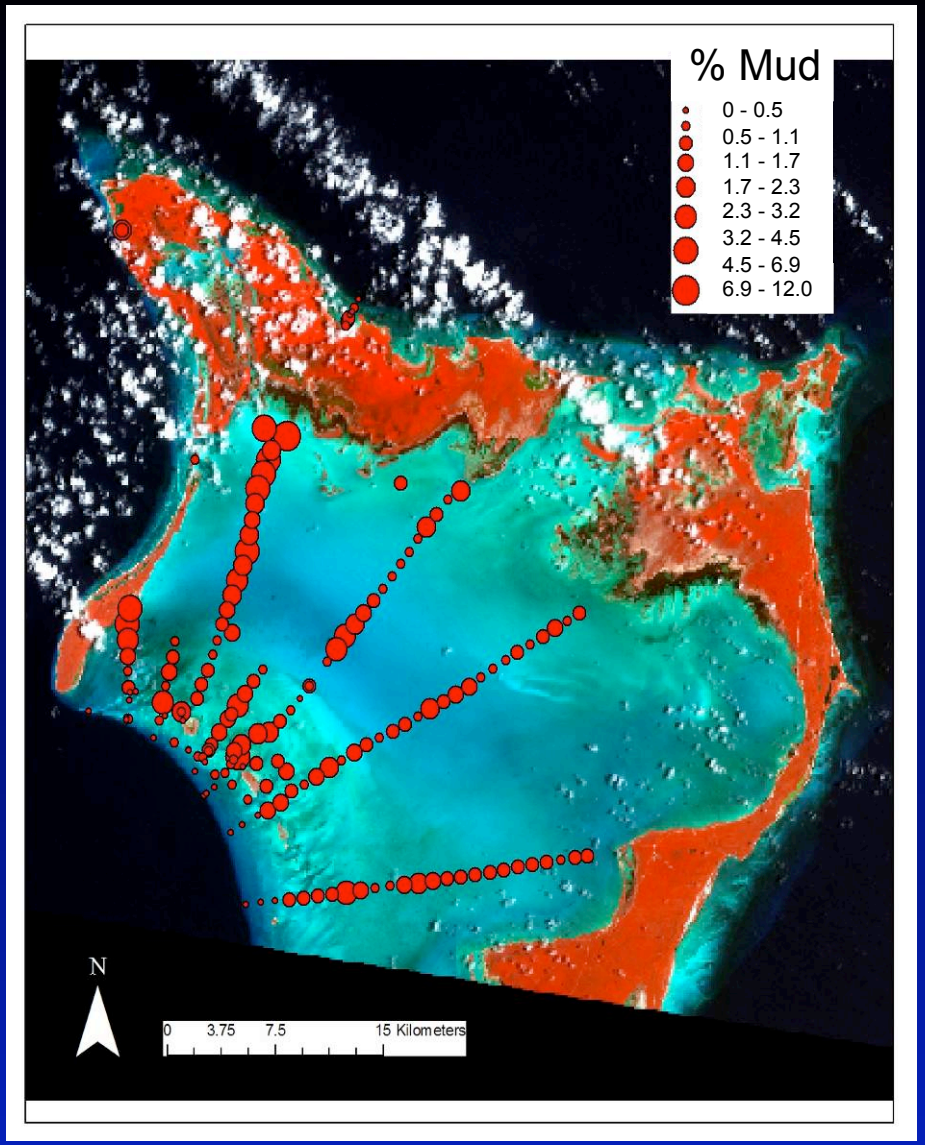
Storms

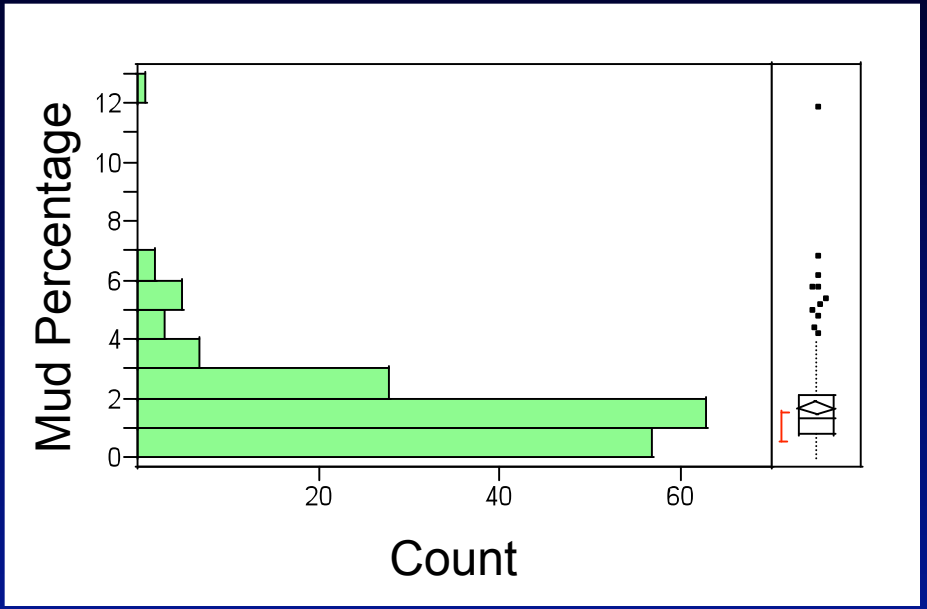
‘Wind/Wave Dominated’ Platforms



Crooked-Acklins Platform







So…not open margin, rather the trade winds…right?

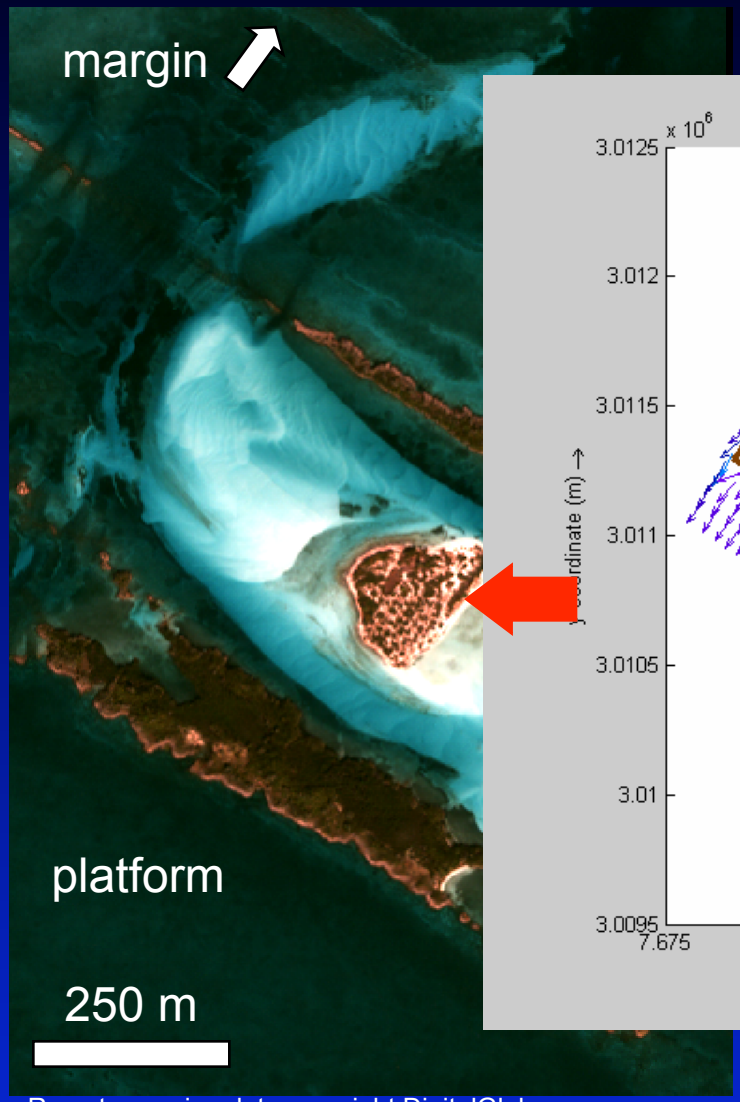
Aitutaki Atoll – Cook Islands
South Pacific Trade Wind Belt

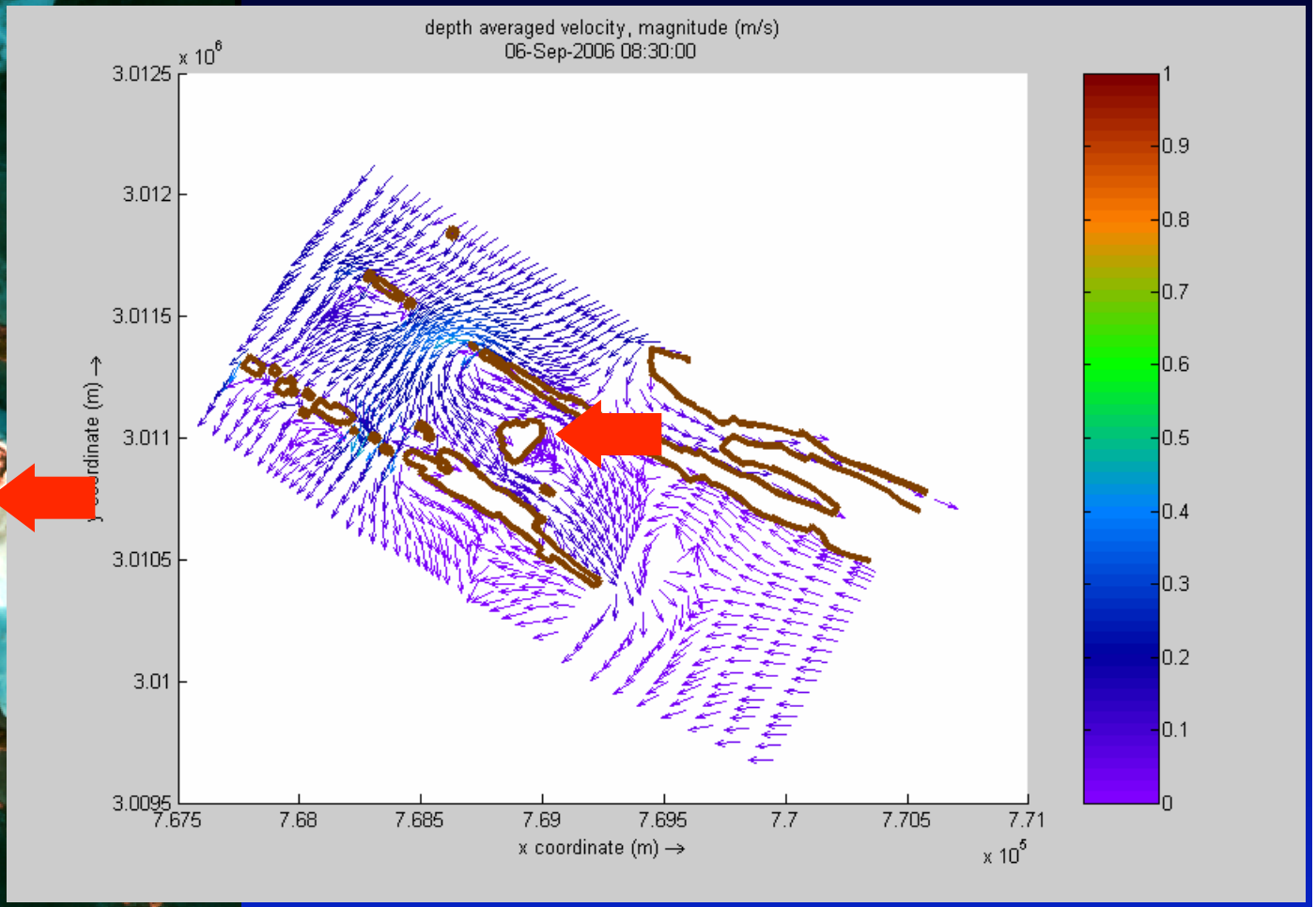
N

0 1,000 2,000 4,000 Meters

0 1,000 2,000 4,000 Meters

Hydrodynamics-Production





Reeder and Rankey 2008

Sediment Transport

- Storms can have an impact…but not always or everywhere

- Wind-waves, tides and currents are important geomorphic agents…but more complicated than our simplistic conceptual models

- Roles of quotidian and event processes

- Feedbacks with production

Once born, "**sand is sand, physics is physics**"
-- Reeder (2007)

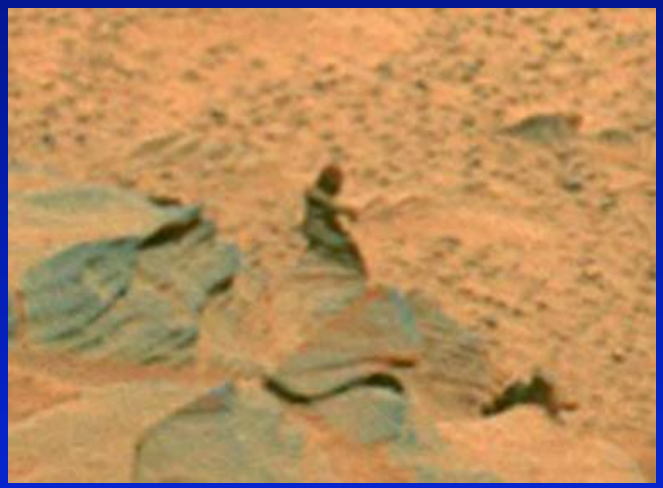
Sediment accumulations

What do we know?

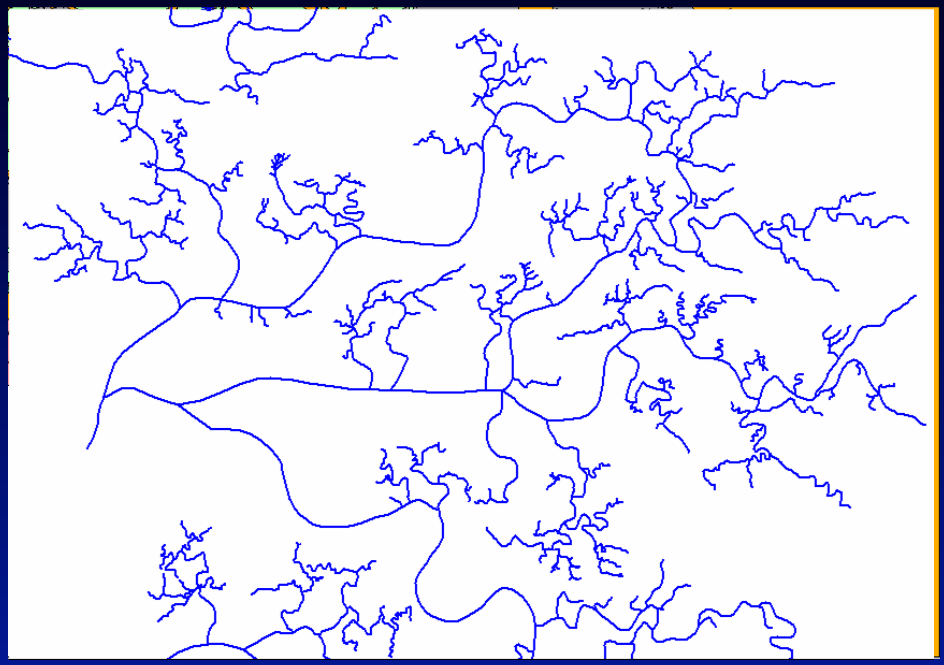
"Topography, areal geography, and hydrography … are reflected in the grain size and…constituent particles … being deposited" – Ginsburg (1956)

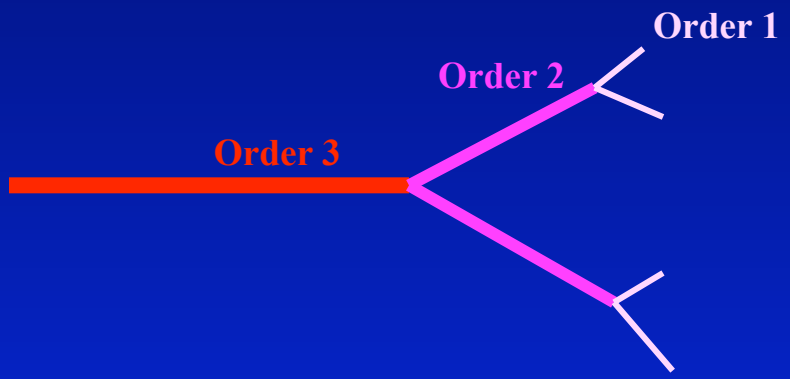
Commonly cited result: the "Facies Mosaic"

BFRO
THE BIGFOOT FIELD RESEARCHERS ORGANIZATION



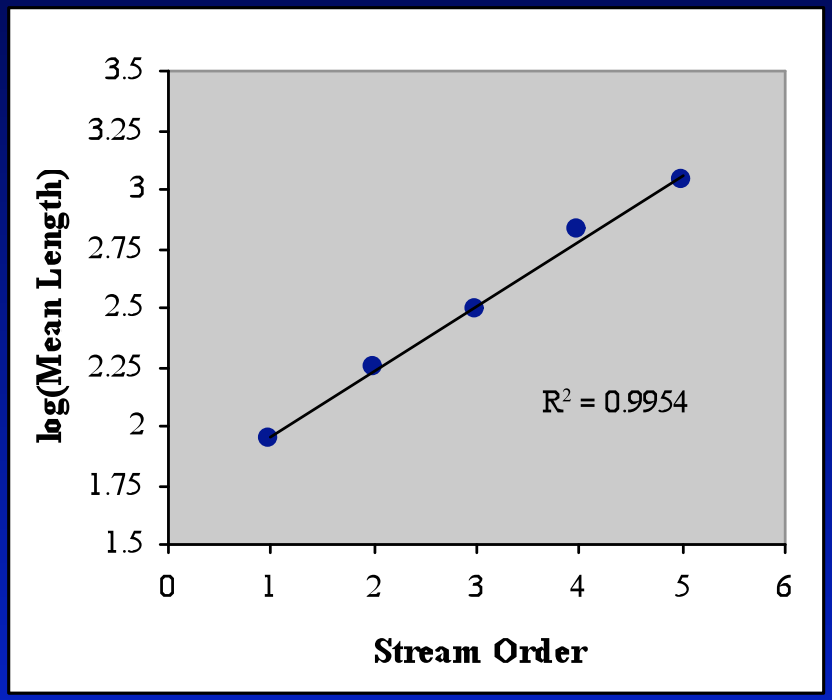
Facies Mosaic



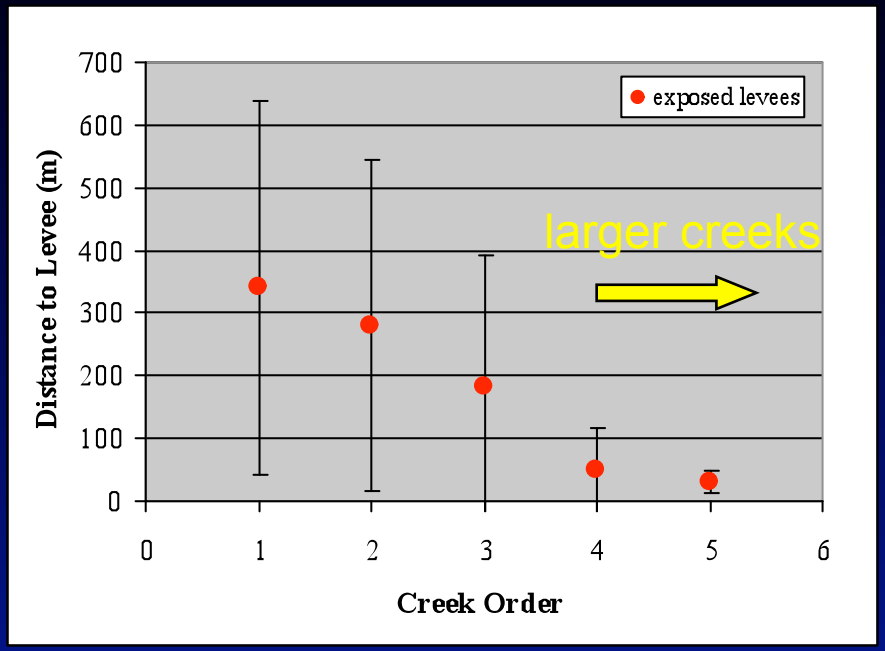


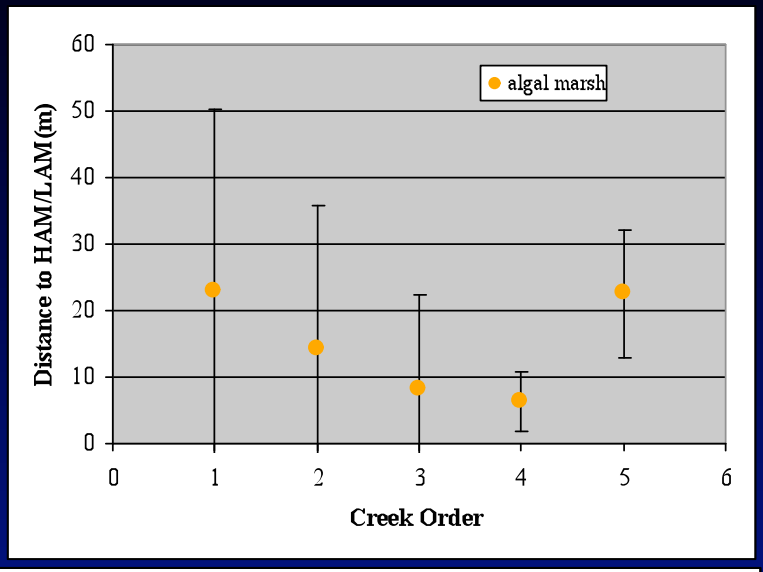
Tidal Creek Networks

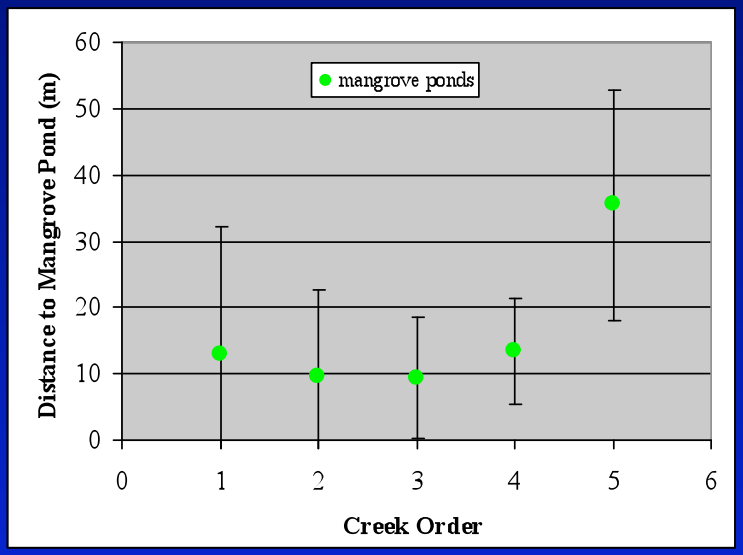
- Hack (1957) noted patterns in numbers and lengths of fluvial channels….
- Similar patterns present in tidal flat creeks

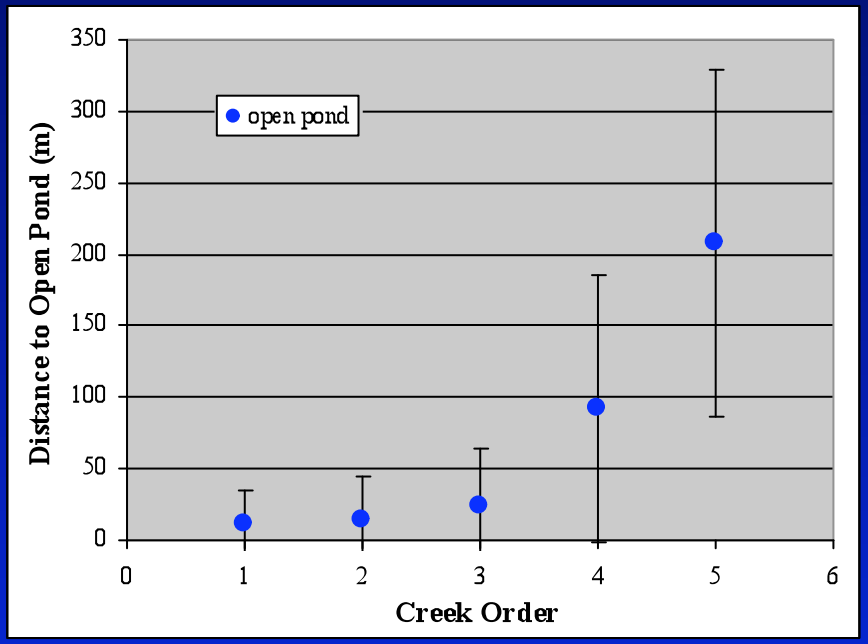


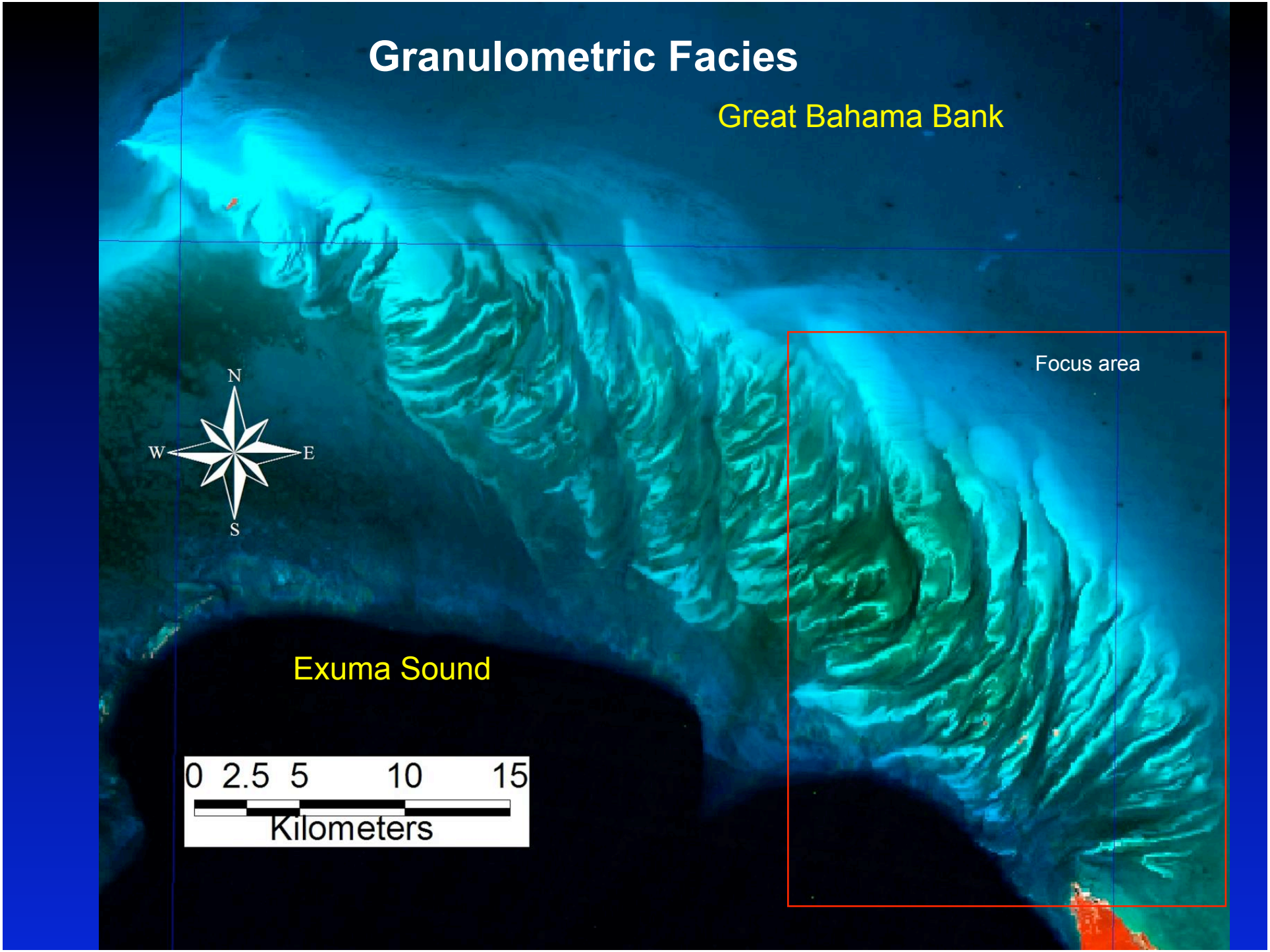
Quantitative Facies Distribution

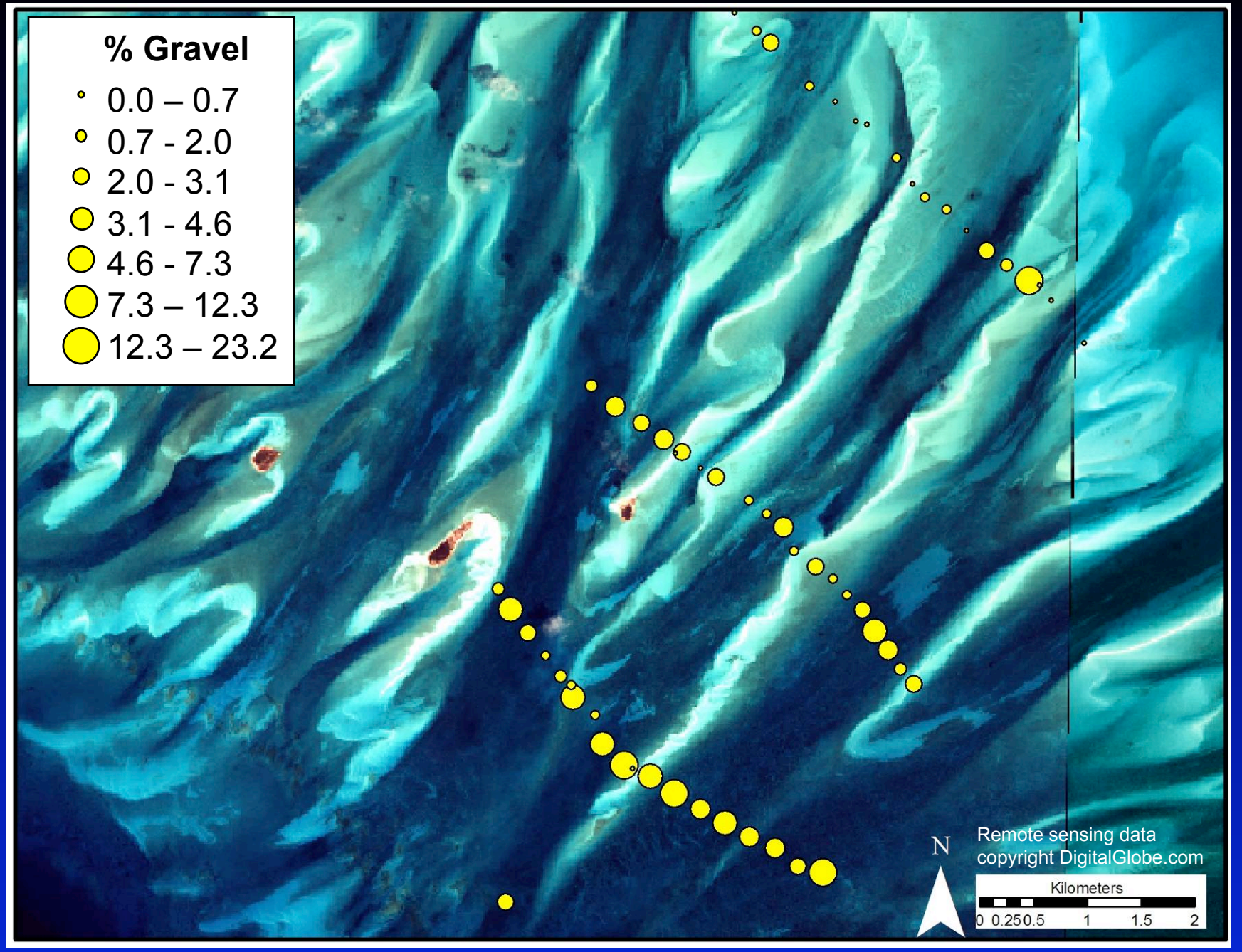




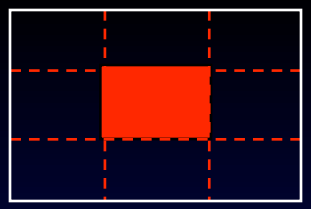




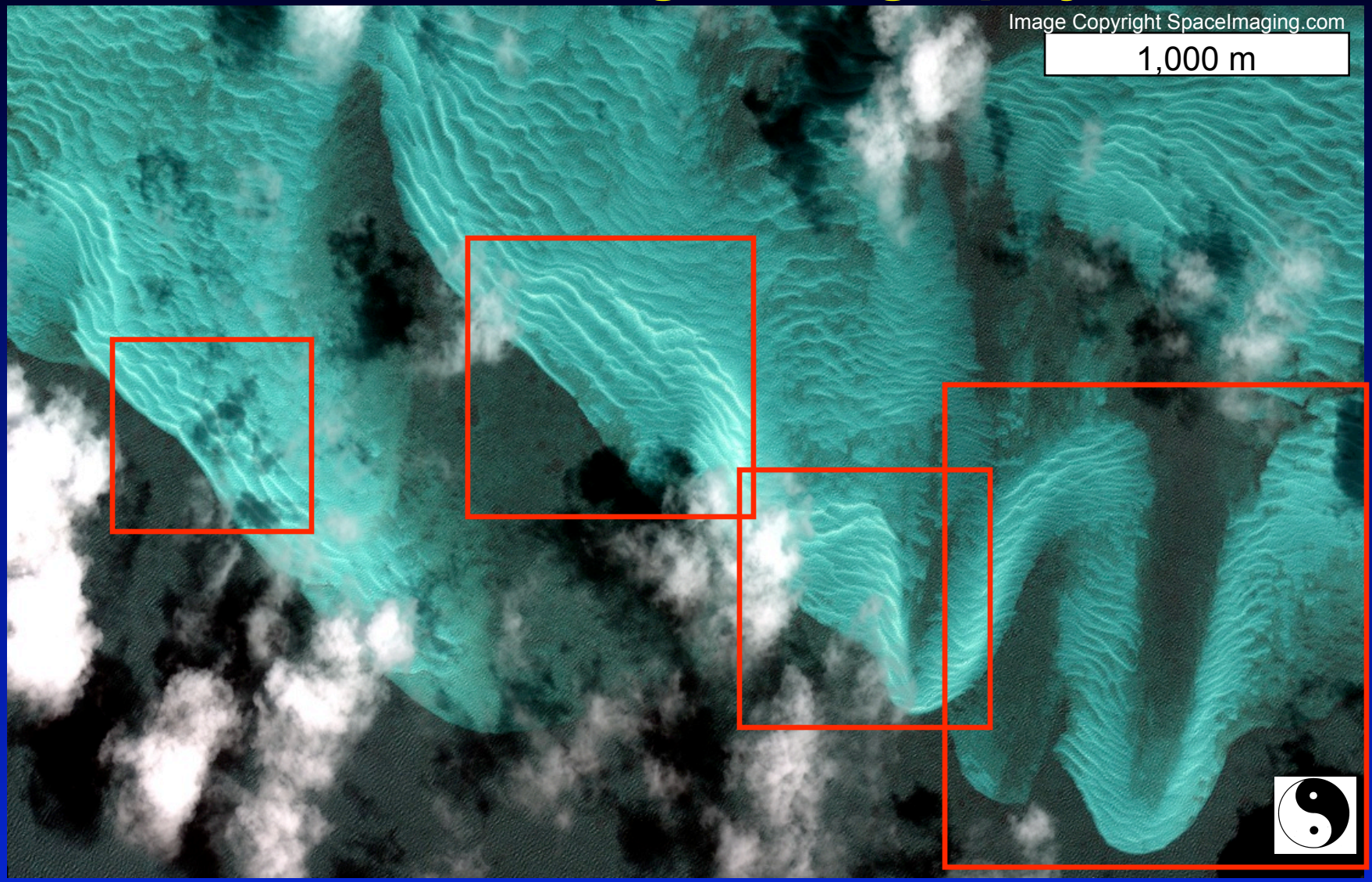

Granulometric Facies
Great Bahama Bank
Focus area
N
W
E
S
Exuma Sound
0 2.5 5 10 15
Kilometers


% Gravel
0.0 – 0.7
0.7 - 2.0
2.0 - 3.1
3.1 - 4.6
4.6 - 7.3
7.3 – 12.3
12.3 – 23.2
N
Remote sensing data
copyright DigitalGlobe.com
Kilometers
0 0.25 0.5 1 1.5 2


BIGFOOT
Firestone



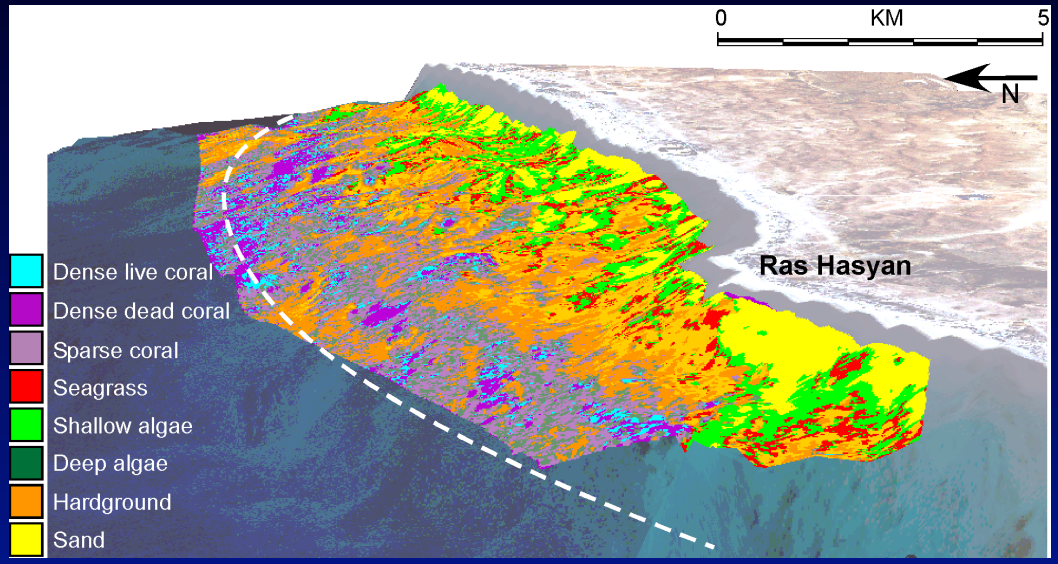
Geomorphic Evolution:
Constructing Stratigraphy

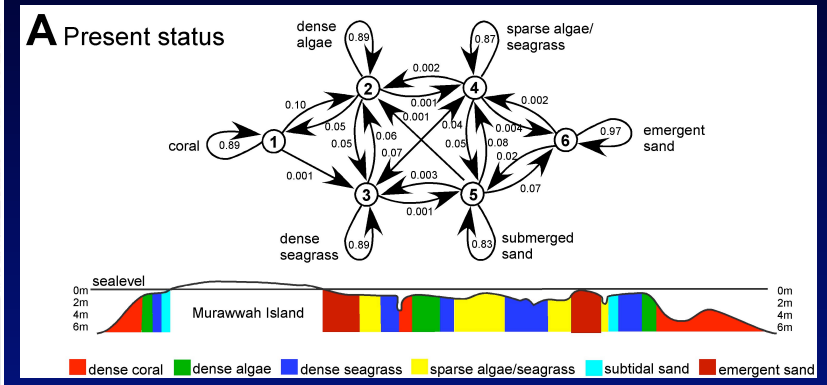


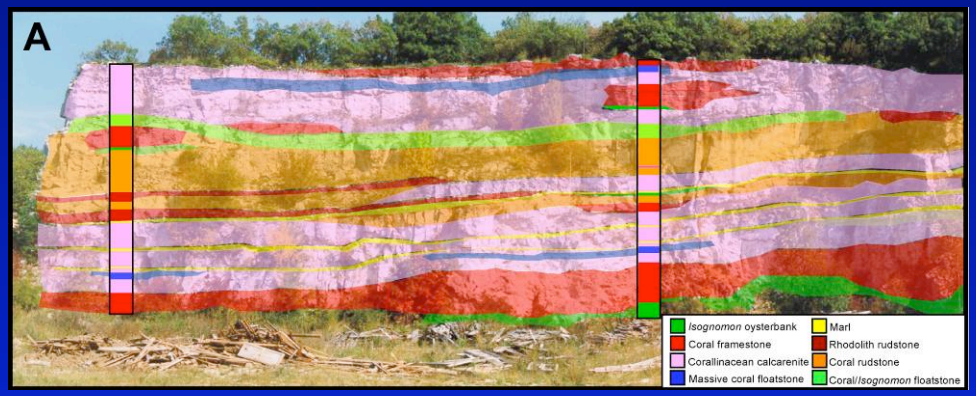
Rankey et al., 2006 – conceptual model

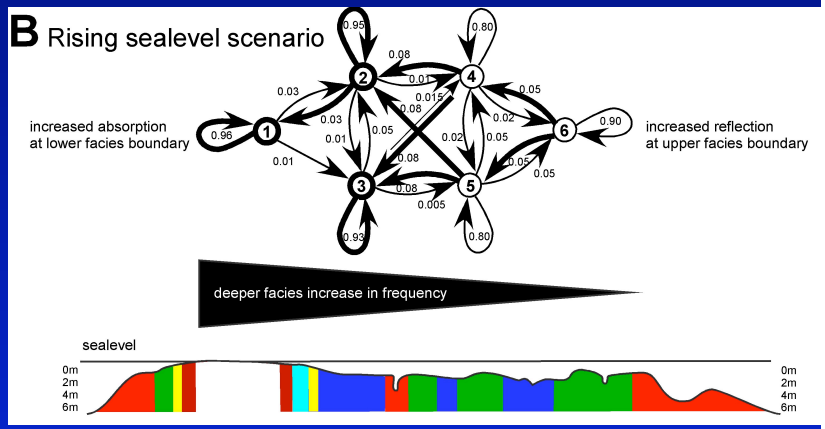
Geomorphic Evolution:

Constructing Stratigraphy









Courtesy of Bernhard Riegl

Geomorphic Evolution:
Constructing Stratigraphy

- What are the **rates of geomorphic change**? How and why do they vary?
- What aspects of sediments are preserved ('**facies taphonomy**')?
- What are **criteria** diagnostic of different geomorphic forms?
- What parts of geomorphologic forms are preserved ('**body taphonomy**')?
- What is **predictable**?

Geomorph patterns = $\sum_{t=0}^{\text{present}}$ Fluid motion ⟷ Bathymetry

Fluid motion ↕ Sediment dynamics

Fluid motion ⤫ Biophysical processes

Bathymetry ↕ Biophysical processes

Sediment dynamics ⟷ Biophysical processes

We can study these in the **present**

Things are more like they are now than they have ever been.

–Gerald R. Ford (1913 – 2006)

External influences at each t_n = $\sum_{t=0}^{t_n}$

- Waves-winds-tides
- Storms
- Sediment producers
- Climate
- Sea-level trends

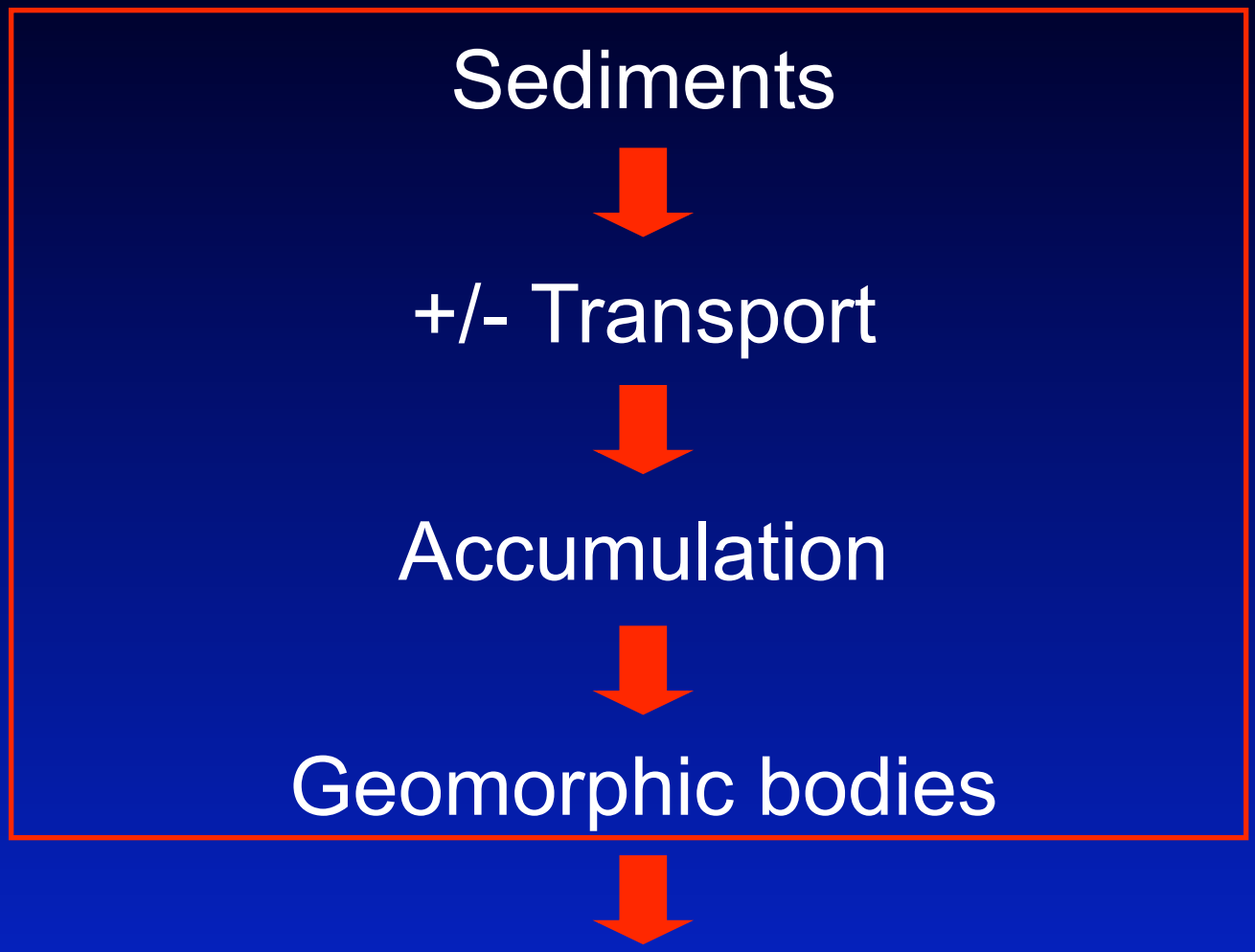
External influences at t_0 = pre-existing topography, climate, rate of SL change, etc.

Mix of global and contingent factors

Most of which cannot be known

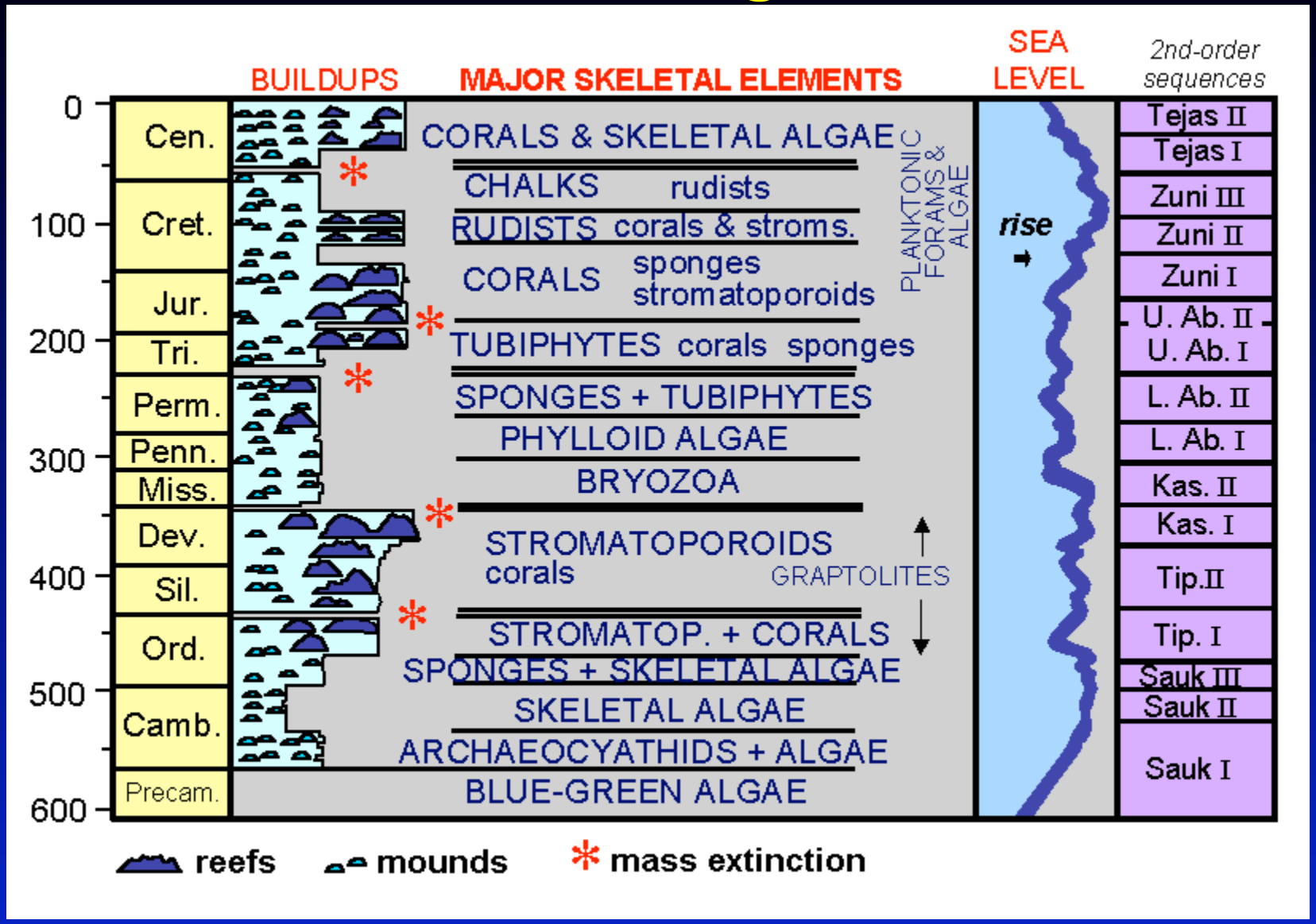
Models – more factors, more 'local'

Lots of unknowns….



Hopeless?

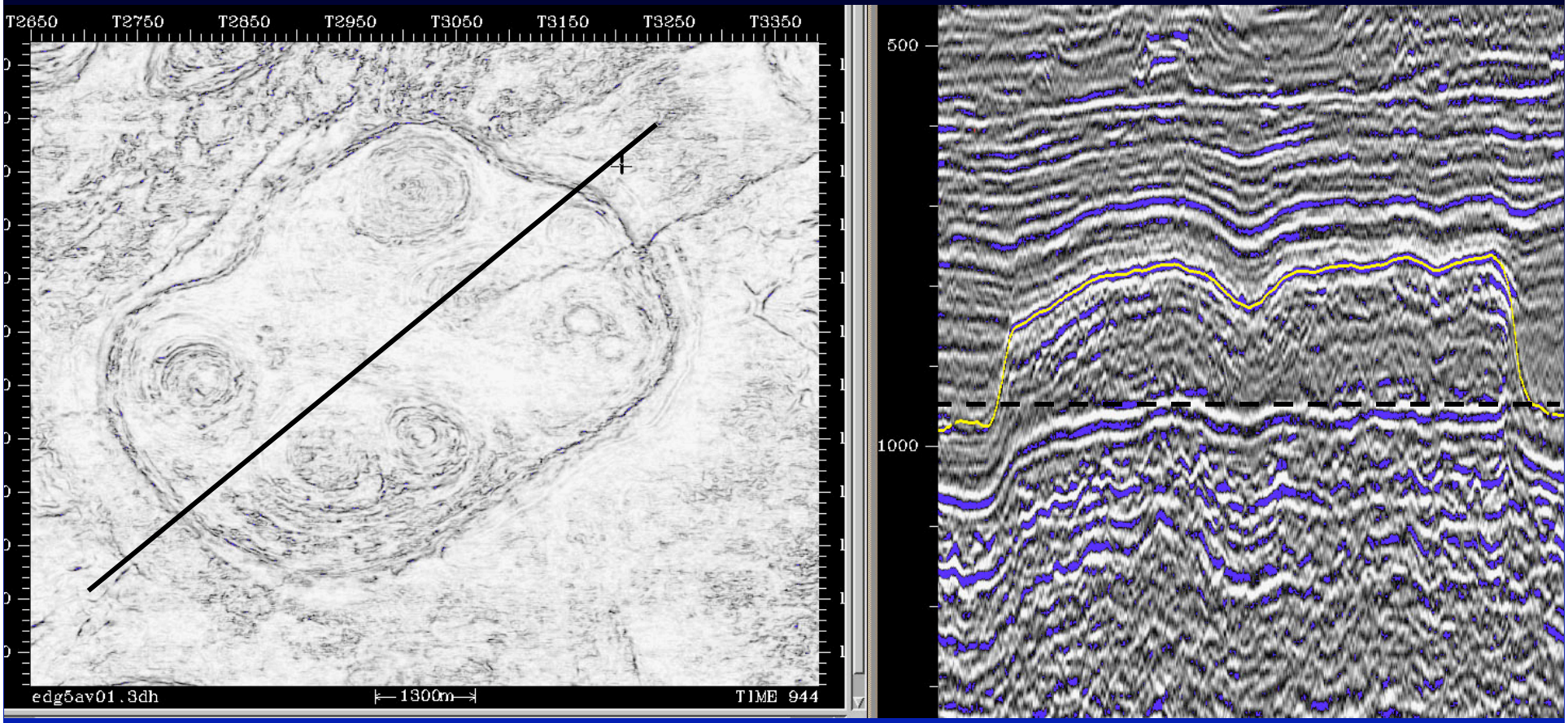
Reef-Building Biota



Is this a fundamental control on reef morphology?

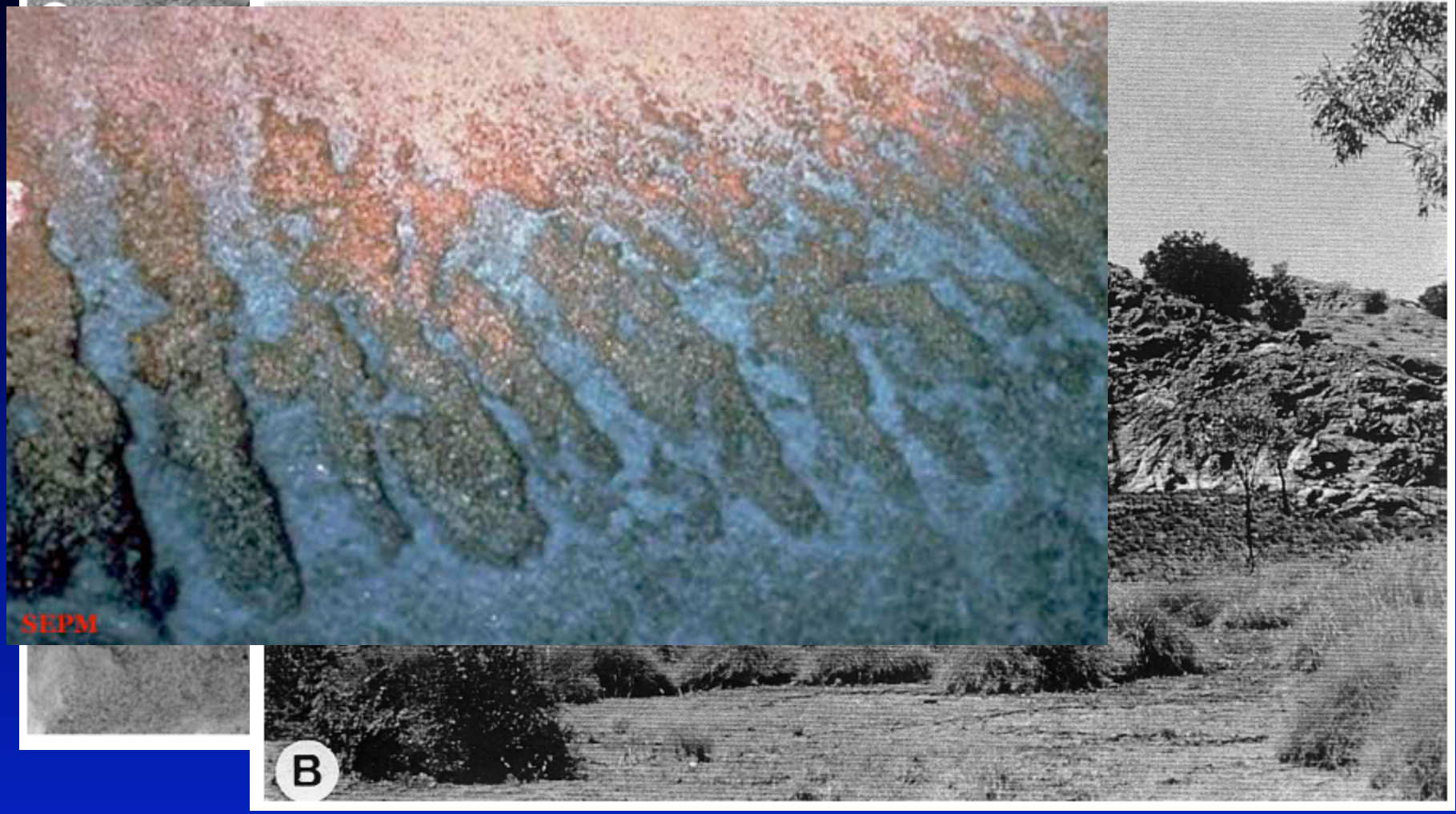
(From James, 1983)

Patch Reefs



Age/Organisms?

Spurs and Grooves



Devonian coral-stromatoporoid-mud-cement reefs

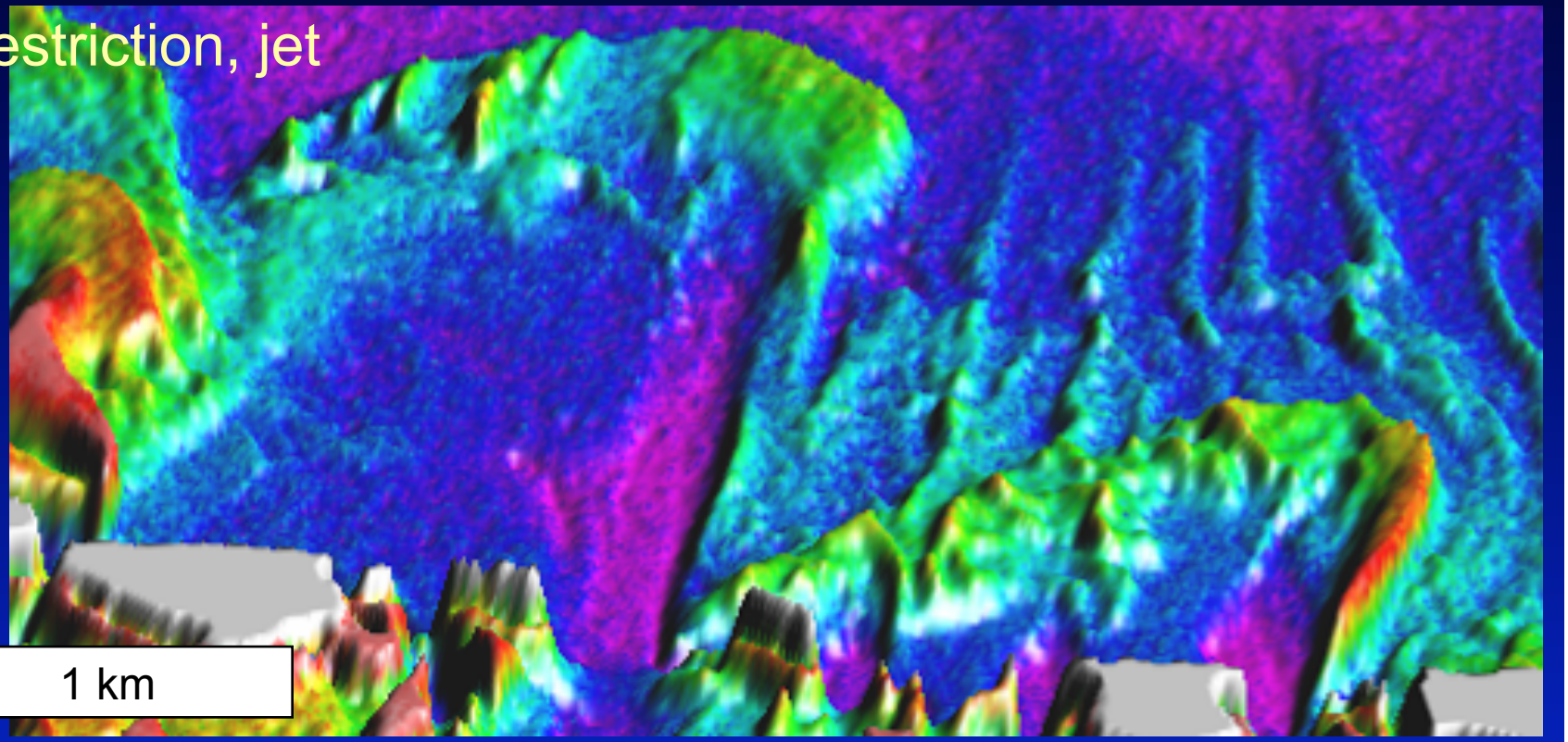
(Wood and Oppenheimer 2000).

Age/Organisms?

In formation of this geomorphic shape, doesn't matter…

Tidal Deltas

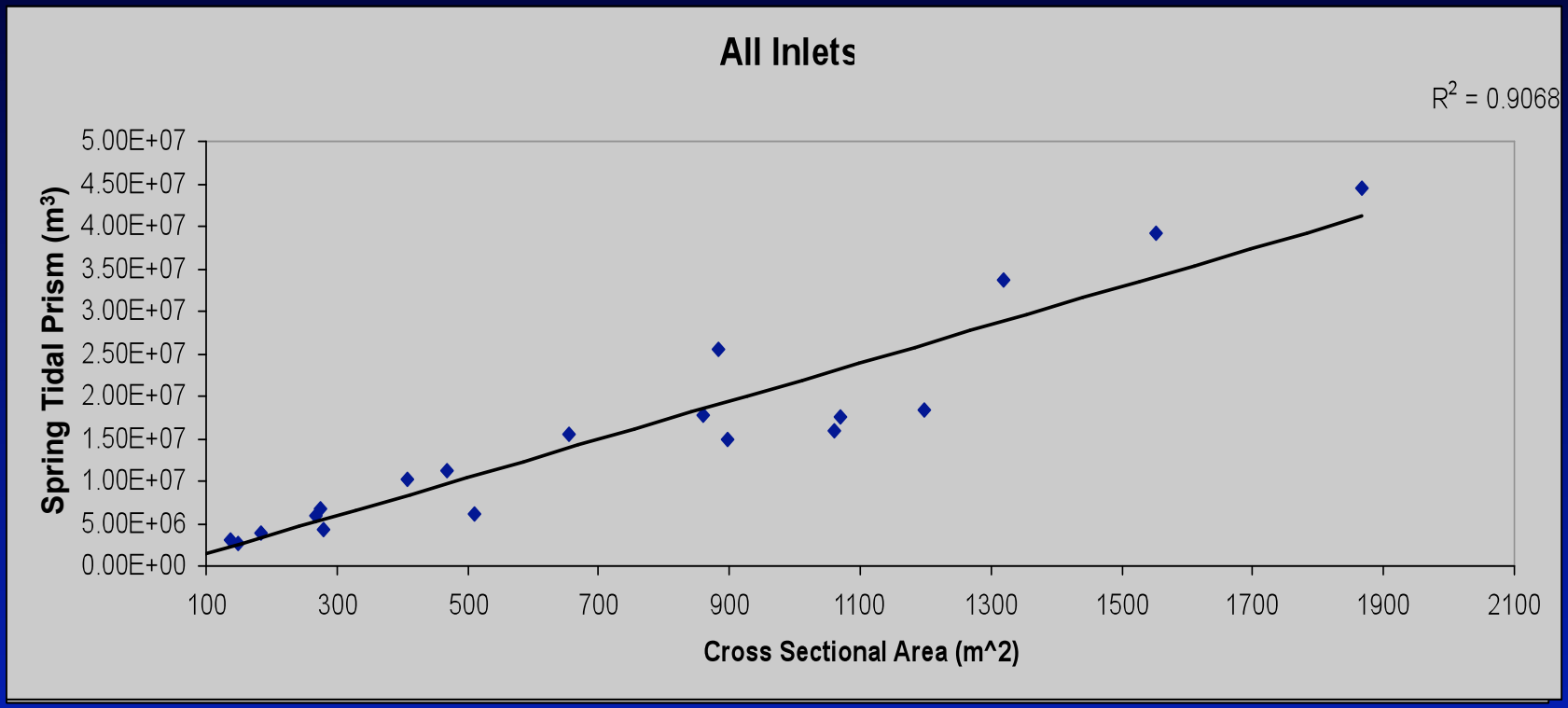
Longshore transport
Role of beaches in sed. flux
Inlet restriction, jet



Data courtesy Rodrigo Garza

Carbonate or clastic?
In formation of this geomorphic shape, doesn't matter…

Tidal Delta Hydrology



Reeder 2007

Review

- Earth's surface is diverse – patterns and processes
- Stratigraphic heterogeneity suggests similar diversity in past
- Yet, many (but not all) very different systems evolve to create similar geomorphic forms 
- These forms are not dependent on 'details'

"Nature is a mutable cloud,
which is always and never the same…."
- Ralph Waldo Emerson

Why might details not matter?

Feedbacks: Essential in landform genesis

Spurs and grooves
Tidal deltas and bars
Creek networks

At some scales, dynamics NOT dependent **solely** on details (organisms, types of sediment, nature of flow - contingencies)

Models can play paramount role in:

- Illuminating roles of contingent vs. global factors
- Explicitly **testing** conceptual models
- Asking questions – what info is necessary to build the **simplest model**?
- Ascertaining the implications for **prediction** and **understanding**
  - Do ‘themes’ = Predictability? Portability?
  - What is ‘knowable’?

Take-Home Messages

Carbonate depositional systems are complex…

…but ‘themes’ persist through space/time

‘Unity of opposites’ results from
- interaction of global and contingent factors
- feedbacks

Characterization and Prediction

Kids (& carbonates):
Shaped by contingent and global factors
Difficult to predict…
…'Easy' to recognize looking back

diagenesis