Fossil coral reefs and sea-level change: diving into the past to predict the future

Marc Humblet

Department of Earth and Planetary Sciences, Nagoya University

- What is a coral reef?
- What is sea-level change?
- Reconstructing sea-level history using fossil coral reefs

  Case studies:
  - *Great Barrier Reef, Australia*
  - *Seychelles Islands*

- What is a coral reef?

REEF

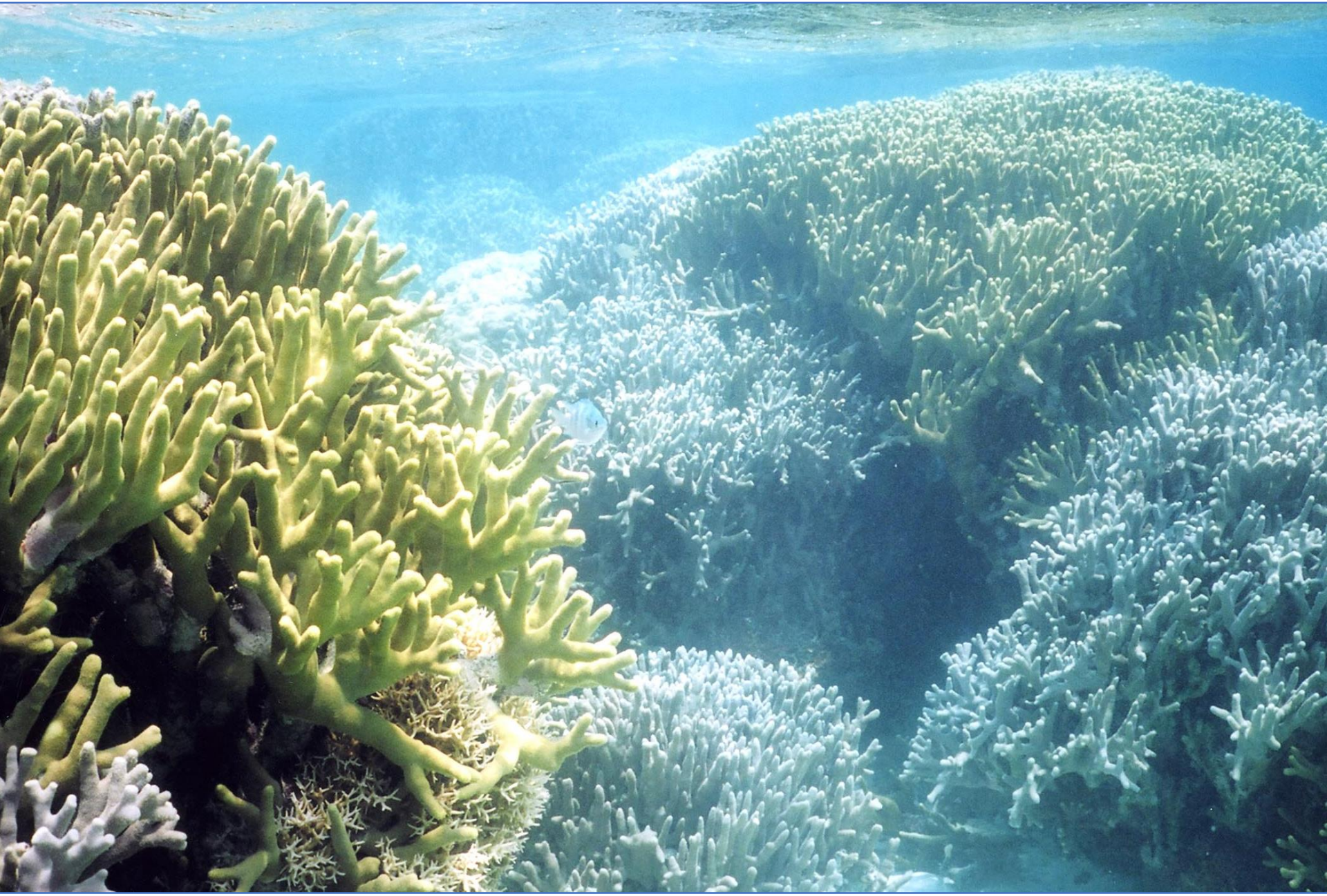
Old Norse word (Vikings, 8th-11th century) → "RIF" = shallow ridge in the sea

Online Etymology Dictionary (Douglas Harper, 2010)

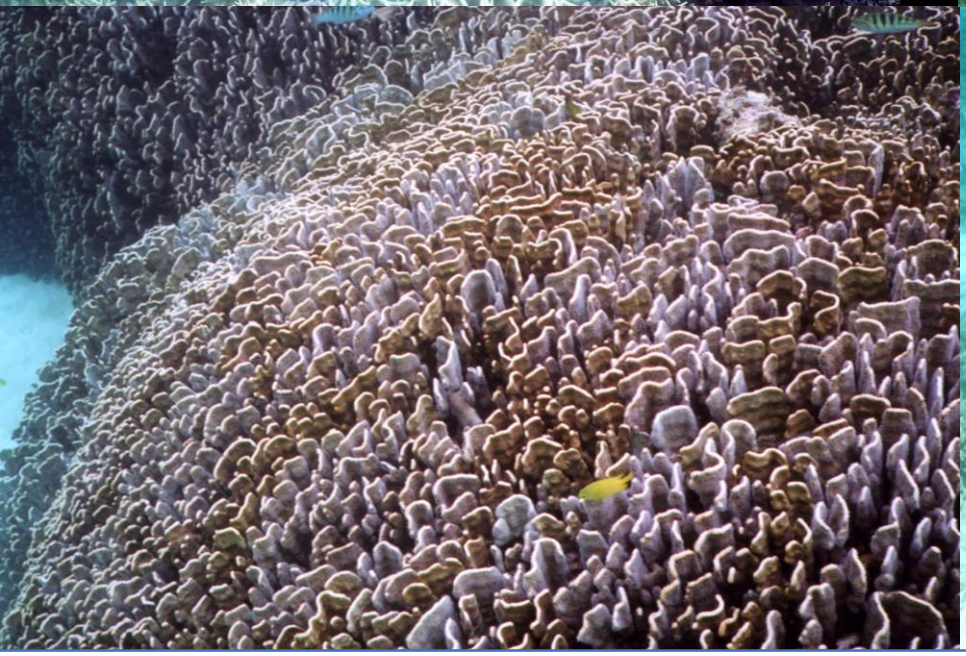
"A shallow elevation composed of consolidated material that may constitute a hazard to surface navigation."

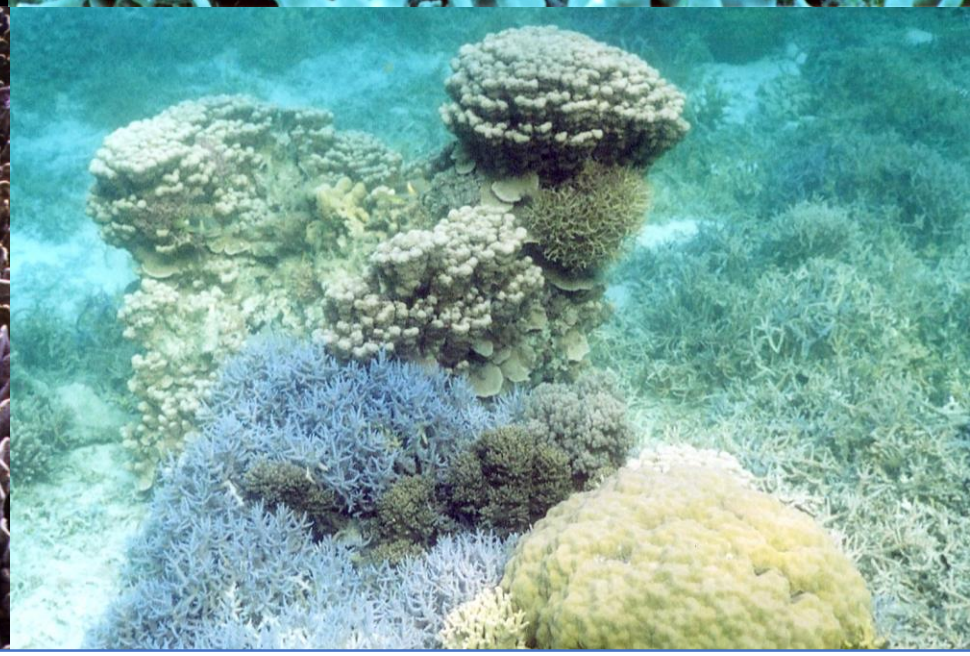
International Hydrographic Organization (2013)

Wikipedia



1. What is a coral reef?



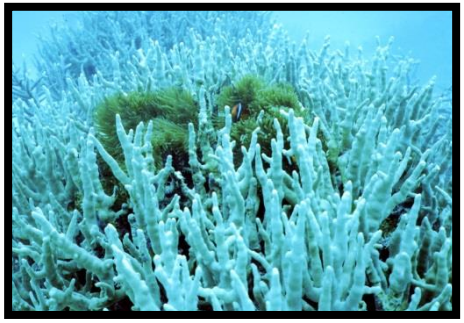


"Diversity of coral reef ecosystems represents 25% of known marine species"

from Ecological Society of America (ESA) website

Branching corals (Ishigaki-jima)

Branching corals (Ishigaki-jima)



Foliaceous coral (Ishigaki-jima)

Massive coral (Ishigaki-jima)

Flat worm on *Halimeda* sp. (Reunion)

Nudibranch feeding on tunicate

Soft coral (Micronesia)

Sea star (GBR, Australia)

Saddled butterfly fish

Blenny fish (Solomon Isl.)

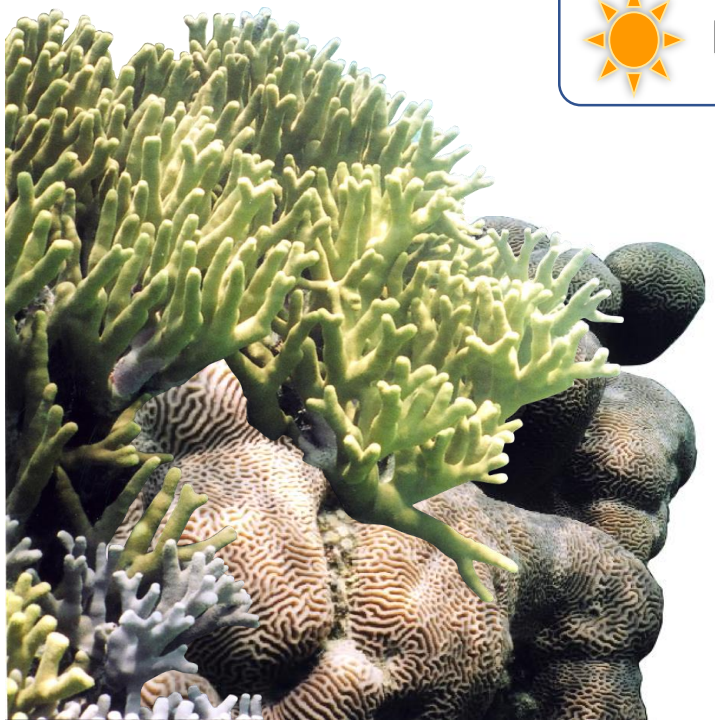
Clown fish and anemone

Sea turtle (Madagascar)

Image credits: reefbase.org, nationalgeographic.com, nature.org

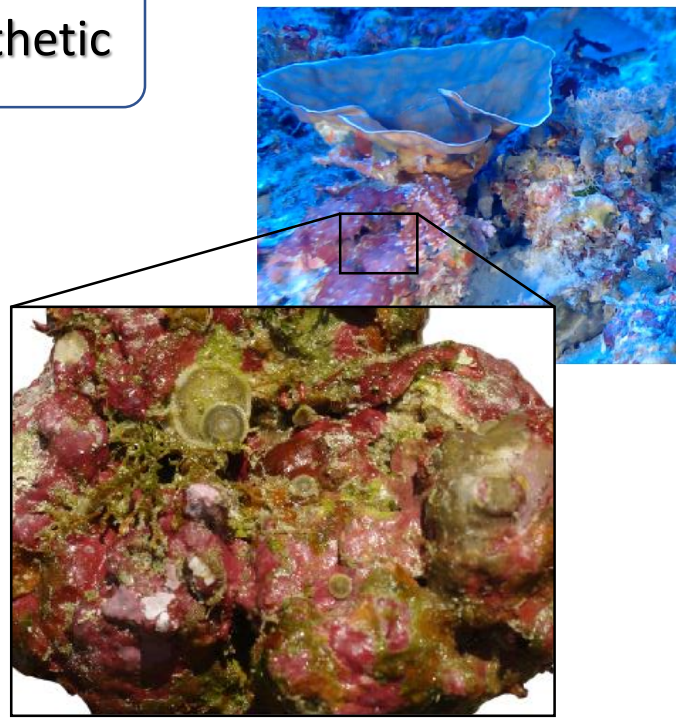
MAIN REEF-BUILDING ORGANISMS

CORALS



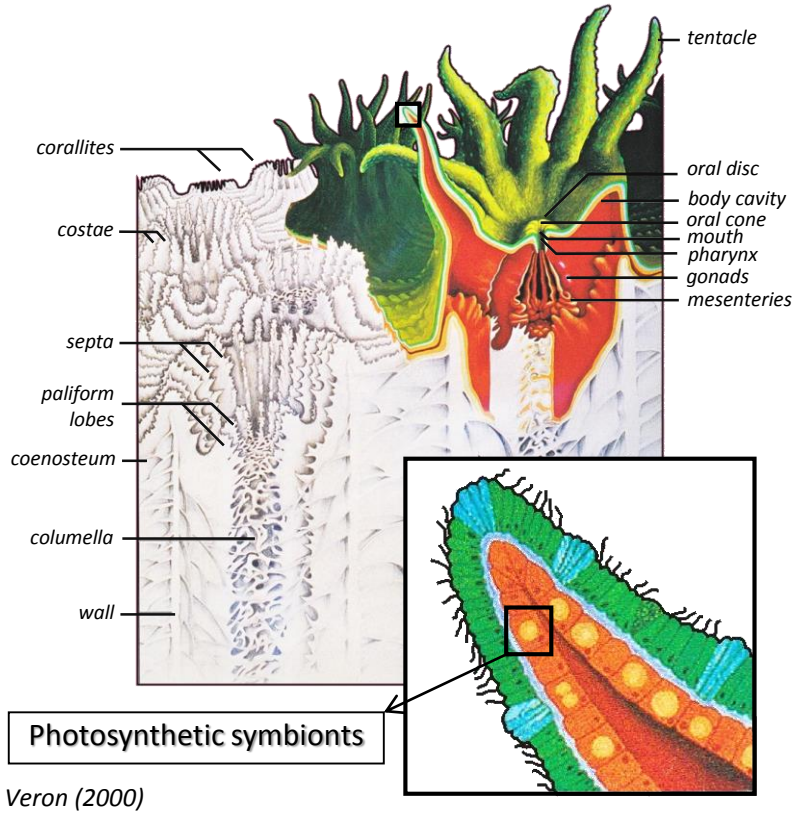
Photosynthetic

CORALLINE ALGAE



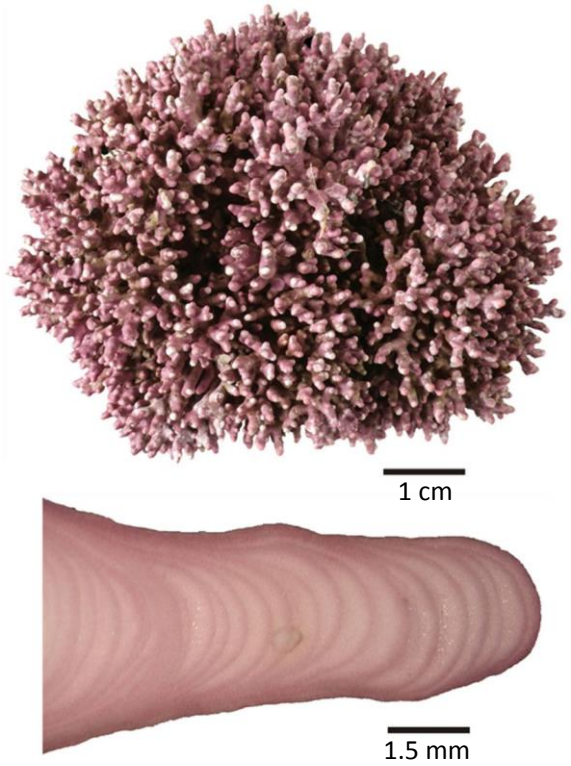
MAIN REEF-BUILDING ORGANISMS

CORALS

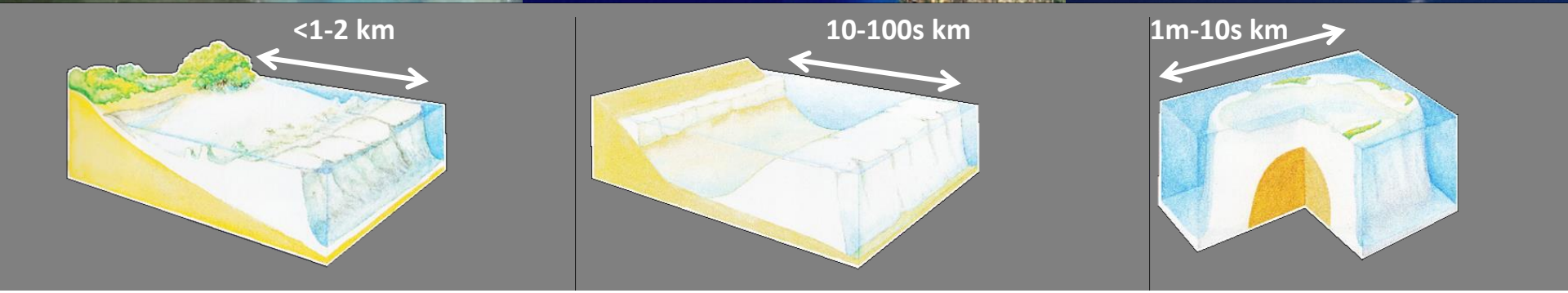


Veron (2000)

CORALLINE ALGAE



Cusack et al. (2015)



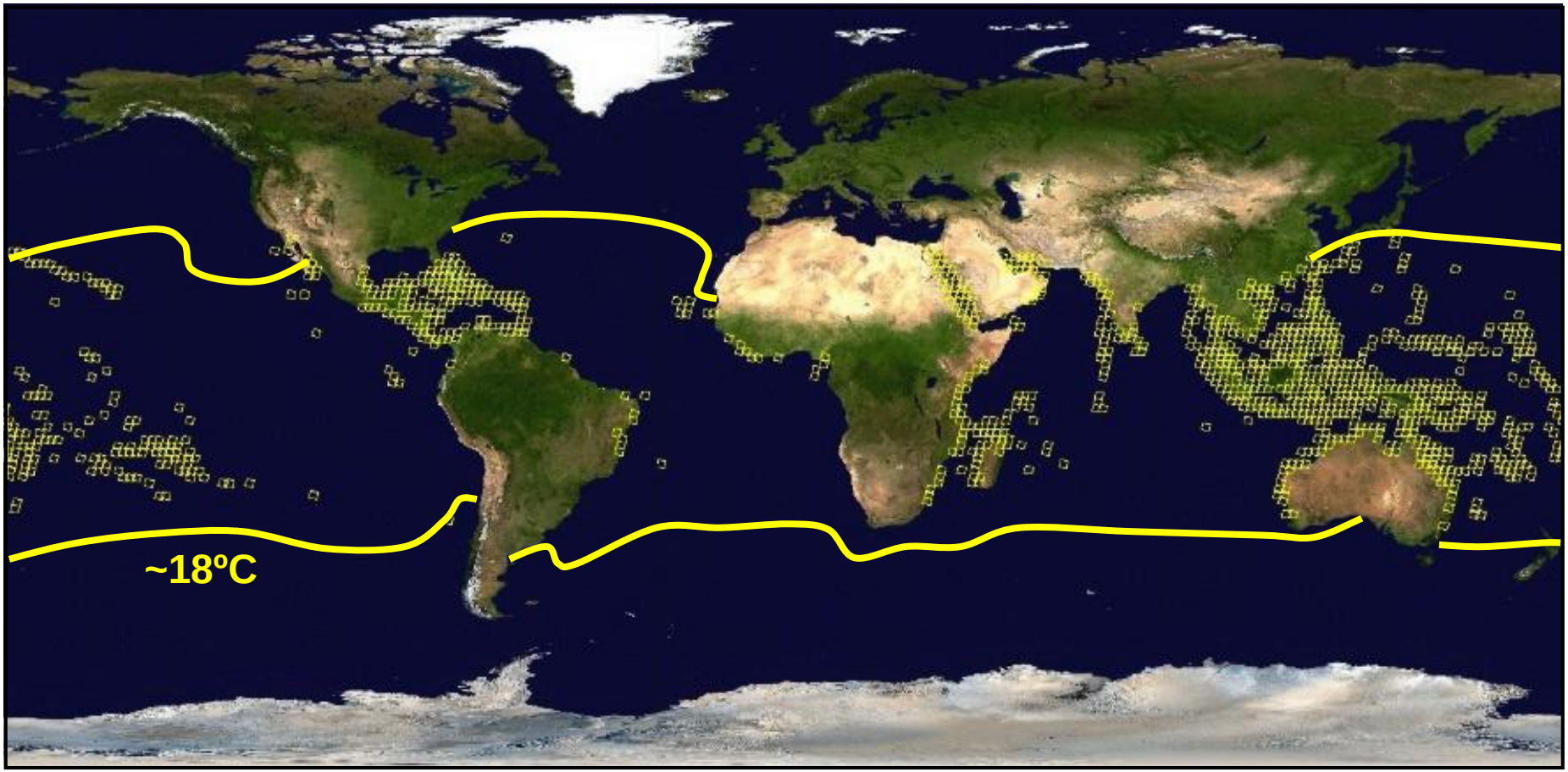
Ishigaki Isl., Japan | *New Caledonia* | *Atafu Atoll*

Image credits (from left to right): Google Earth, NASA, Wikipedia

FACTORS INFLUENCING CORAL REEFS

Environ. factor	Optimum
Temperature	23-29ºC (mean winter >18ºC) Prolonged heat wave leads to coral bleaching
Salinity	33-37‰ (normal marine)
Solar radiation	Within 30º Lat. N/S
Water motion	Some needed for metabolism, feeding
Oxygen	Near saturation
pH	8.1-8.4 (related to pCO_2)
Nutrients	Low concentration
Terrigenous sediments	Low input

Hallock, 2001. "Coral reefs, carbonate sedimentation, nutrients, and global change". In: Stanley, G.D. (Ed.), " The History and Sedimentology of Ancient Reef Ecosystems ".



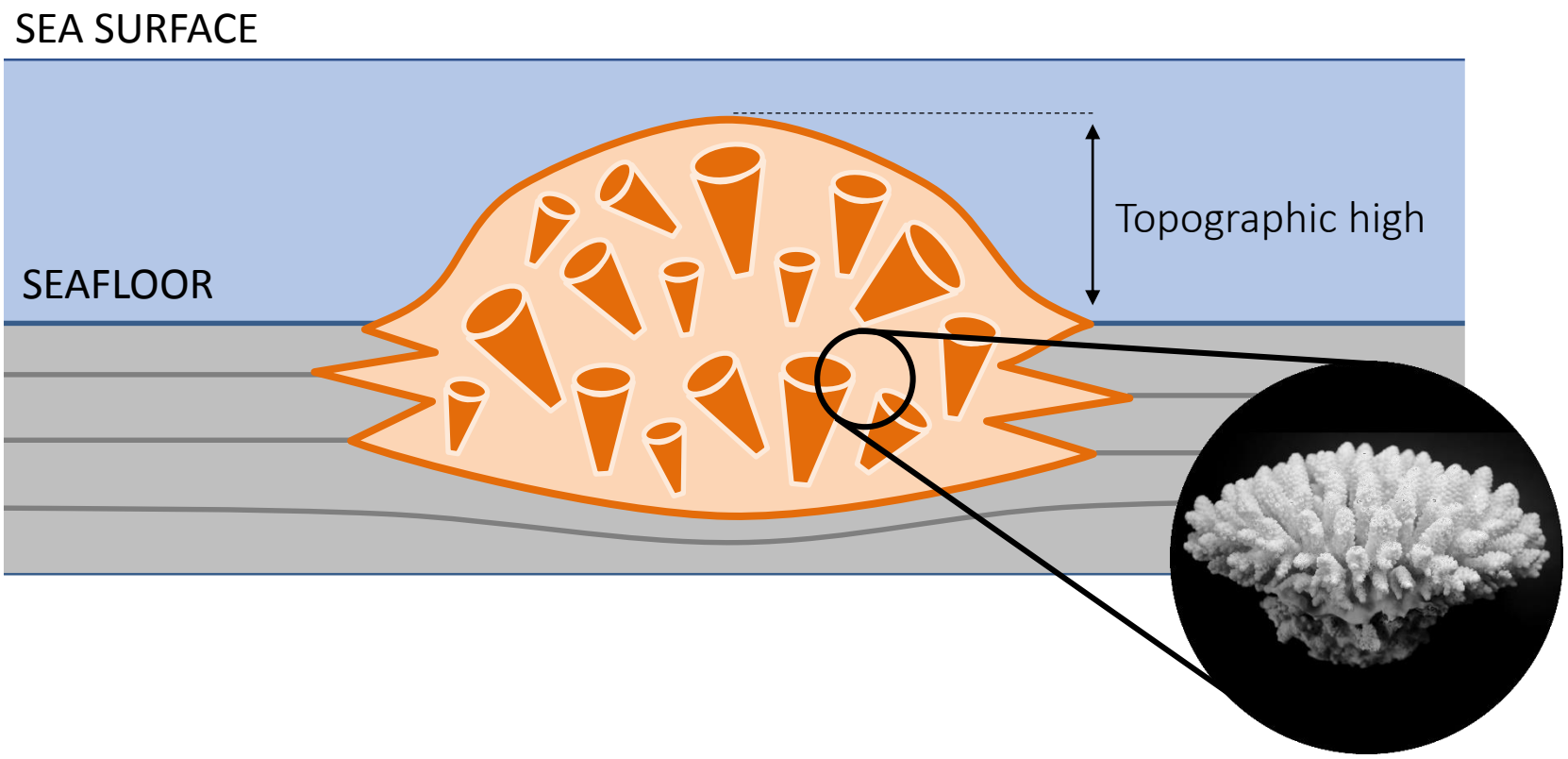
www.reefbase.org

1. What is a coral reef?

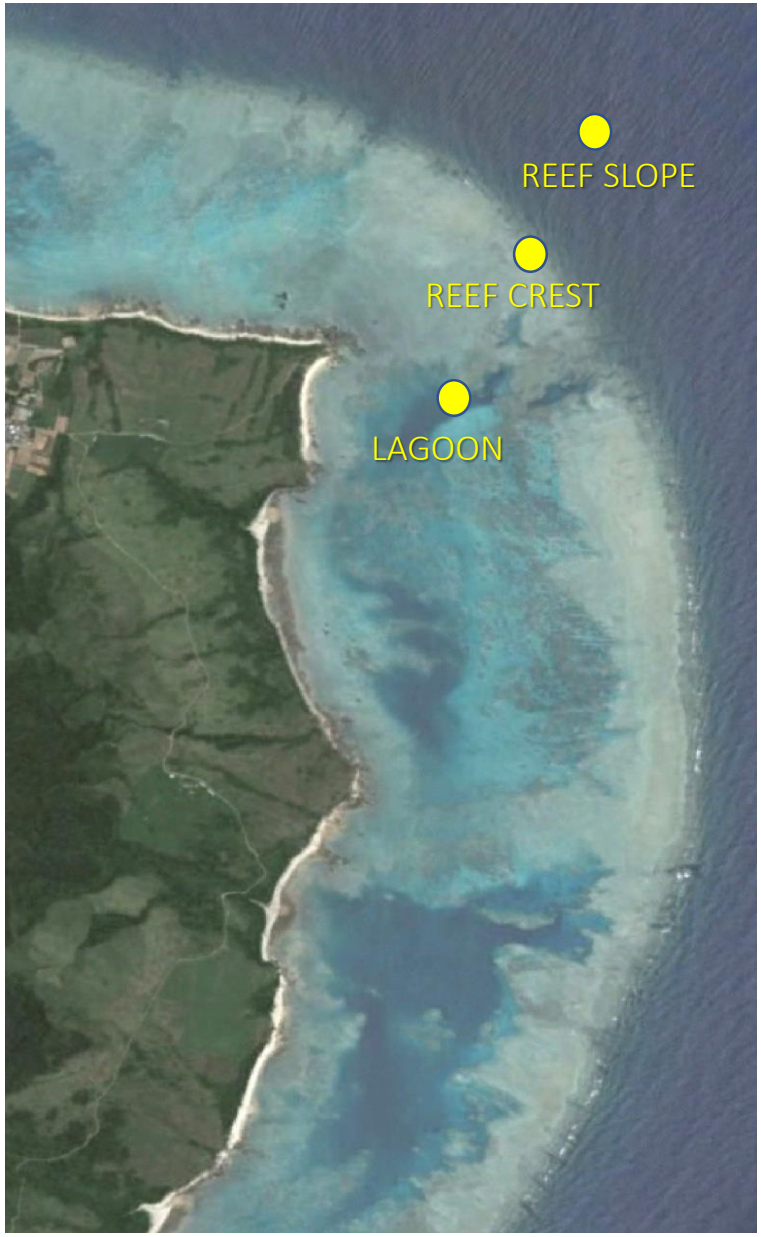
Image credits (clockwise from top left): Wikipedia, Google Earth, Kathryn Berry/James Cook University, NOAA

A reef is a local accumulation of hard parts of marine organisms living on the sea floor (sessile organisms) topographically higher than the surrounding sediments.

After Reef Evolution (Wood, 1999)



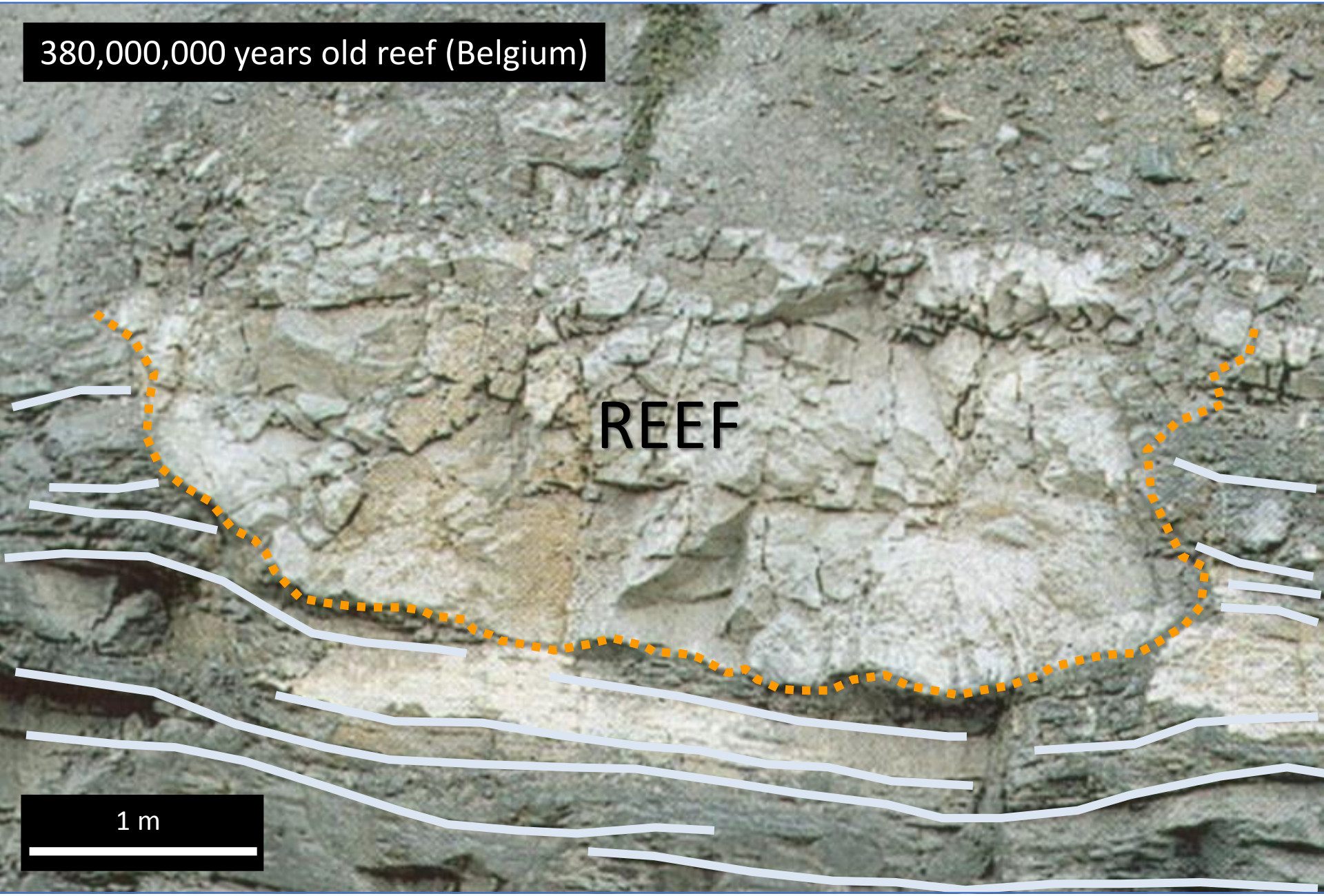
1. What is a coral reef?

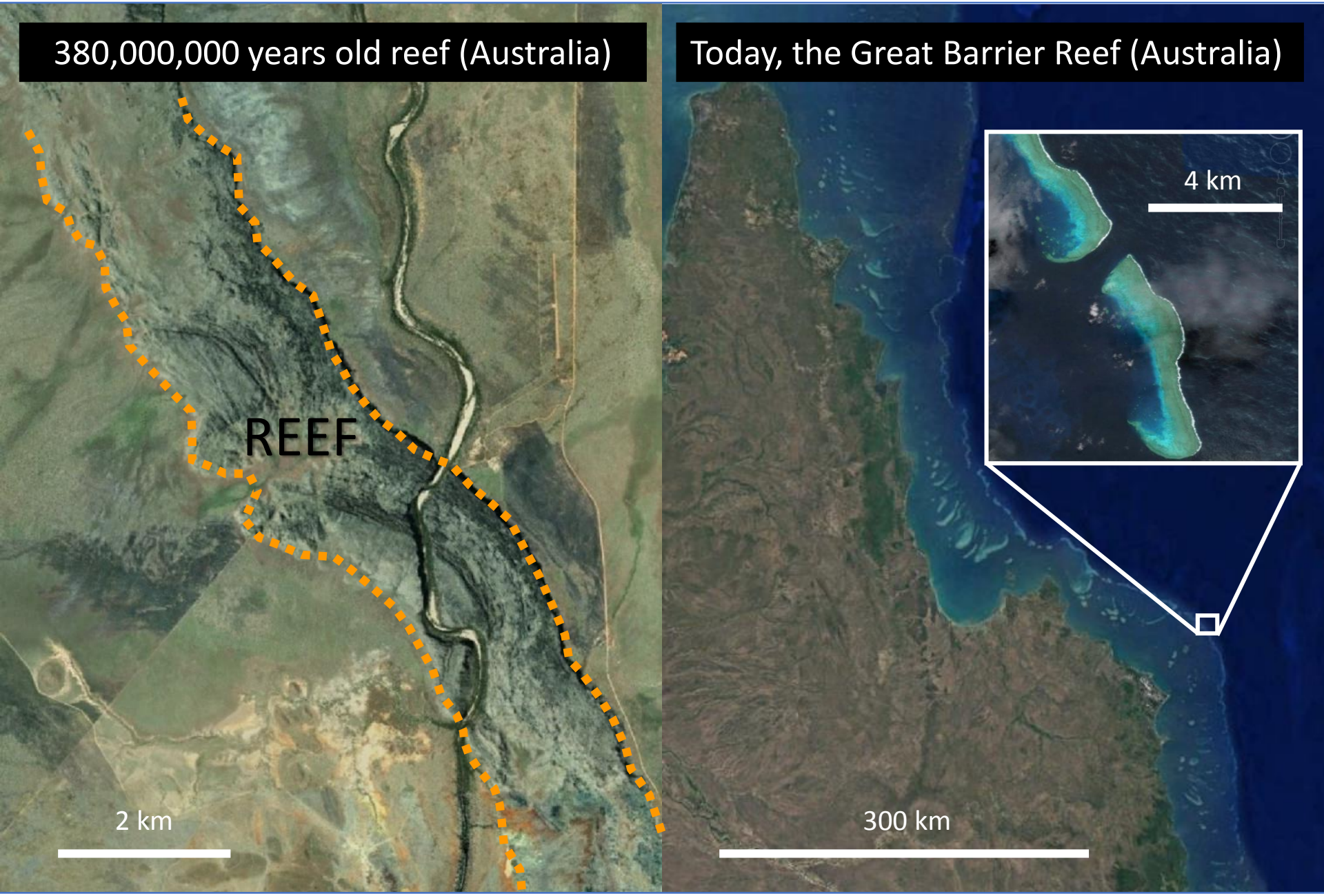


Corals

Coralline algae

Image credits: Left- Google Earth, Right- IODP Exp. 325

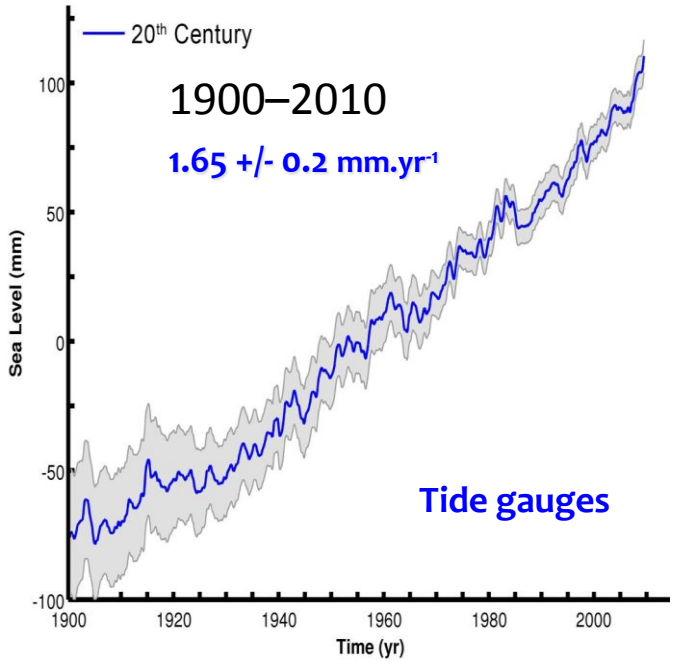

380,000,000 years old reef (Belgium)
REEF
1 m

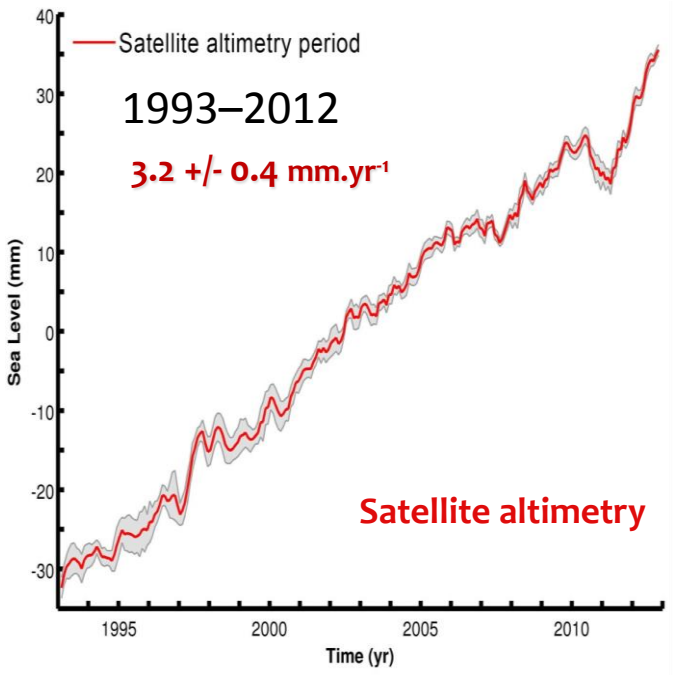


Google Earth

- What is sea-level change?

- Recent sea-level rise





Cazenave & Le Cozannet (2014)

Table 1 Rates of sea level rise separated by source for the last decades and the last decade of the twentieth century (from IPCC, 2007a, Table SPM-1). Potential sea level rise from ice from Lythe et al. (2001) and Lemke et al. (2007)

	Rate of sea level rise (mm/year)		Potential sea level rise
Source of sea level rise	1961–2003	1993–2003	
Thermal expansion	0.42 ± 0.12	1.6 ± 0.5	0.3 m for 3°C rise
Glaciers and ice caps	0.50 + 0.18	0.77 + .22	~0.4 m
Greenland ice sheet	0.05 + 0.12	0.21 + 0.07	7 m
Antarctic ice sheet	0.14 + 0.41	0.21 + 0.35	57 m
Sum of individual climate contributions to sea level rise	1.1 + 0.5	2.8 + 0.7	
Observed total sea level rise	1.8 + 0.5	3.1 + 0.7	

Bertler & Barrett (2014)

- Predictions

To predict the future, learn about the past.

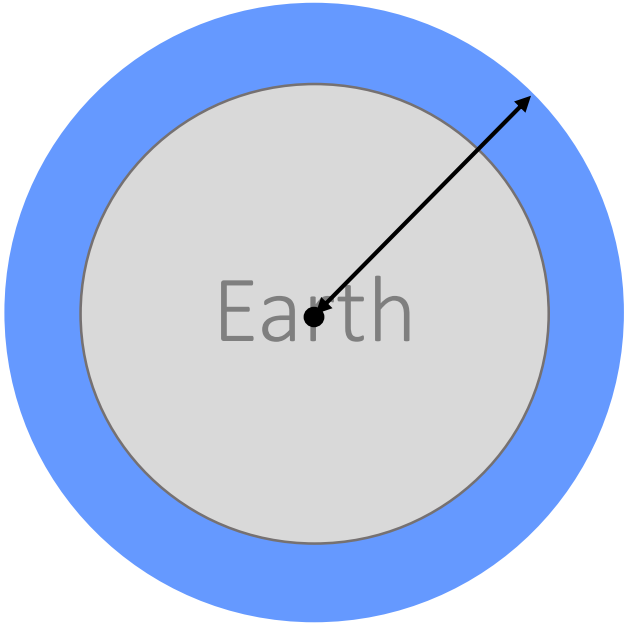
Models predicting the future trend of sea level or climate need to be validated against what wen know of the long-term sea-level and climate history.

Models need to be able to reproduce changes in sea level and climate that we identify when we study Earth history.

IPCC (2013)

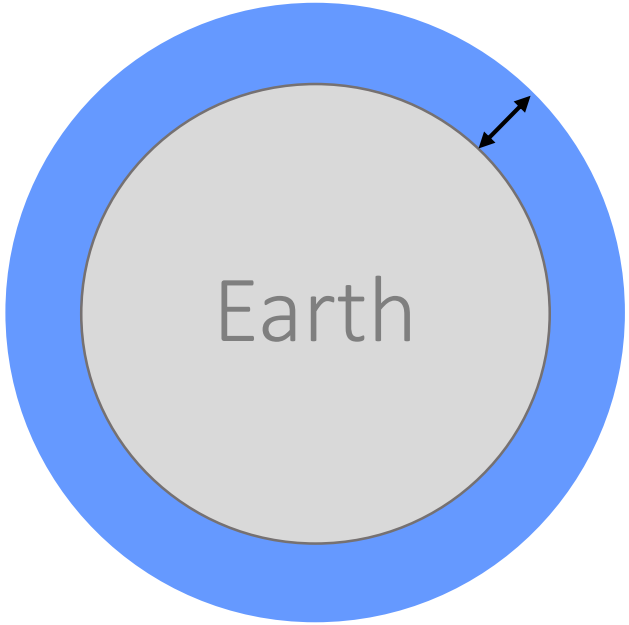
Image credit: Hironobu Kan

ABSOLUTE sea-level change



Relative to the center of Earth

RELATIVE sea-level change



Relative to the land at a particular location

Absolute sea-level change:

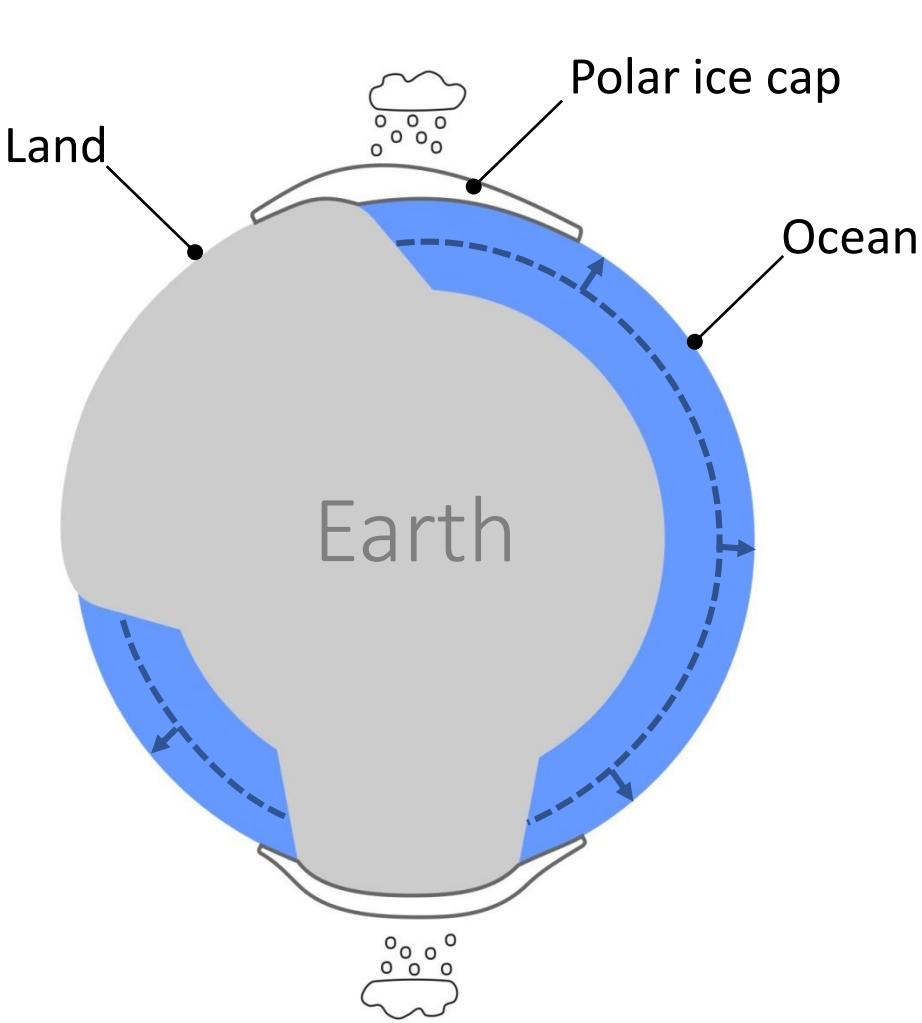
- Increase/decrease of ocean volume
  - Variations in polar ice volume
  - Temperature-related changes in ocean volume

Relative sea-level change:

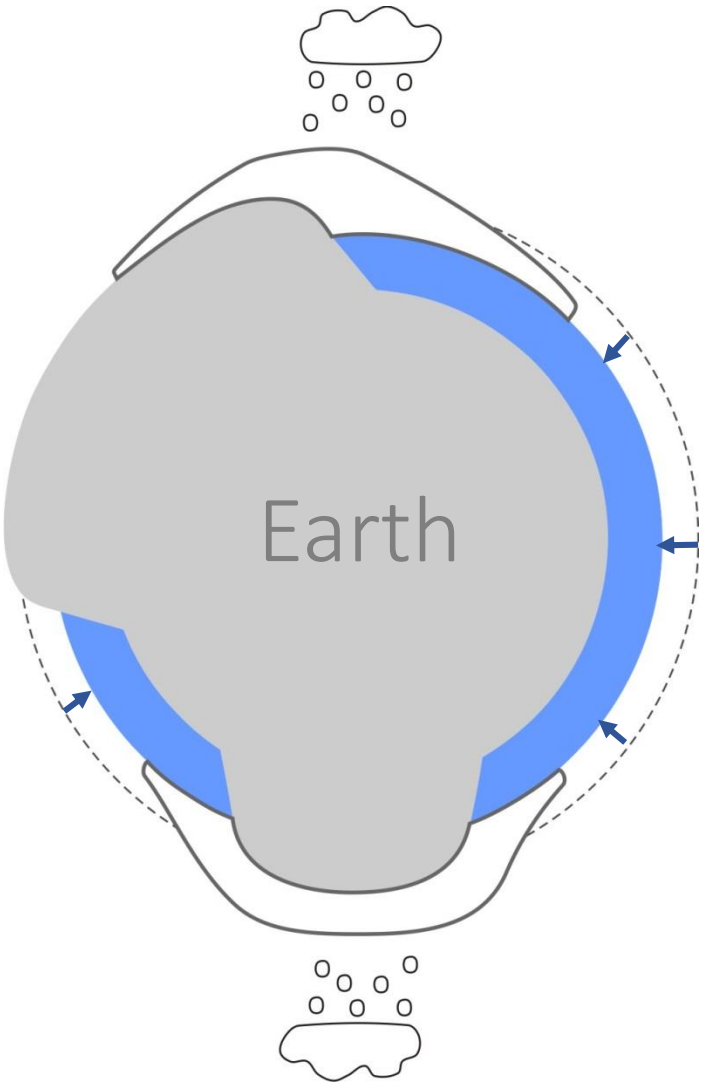
- Up/down movements of the land

Variations in polar ice volume

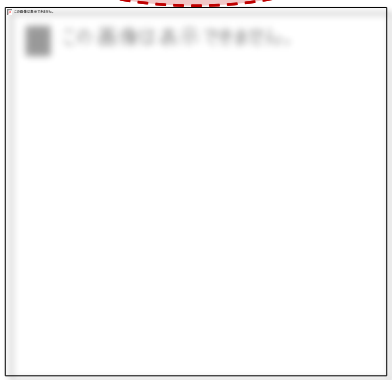
Interglacial (warm)



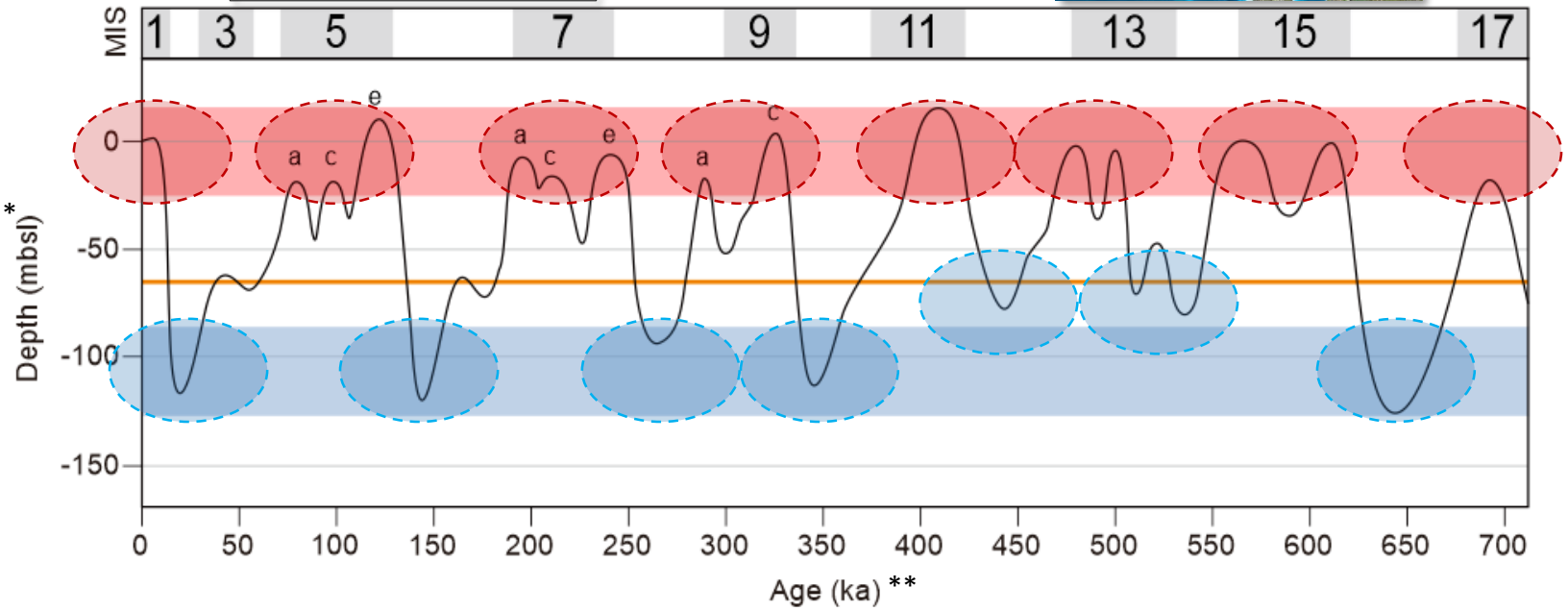
Glacial (cold, ice age)



Warm period



Ice age

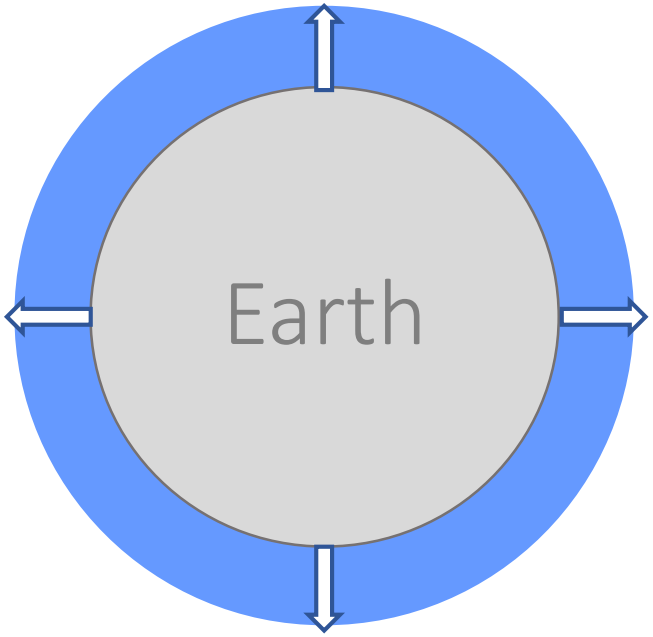


*mbsl = meter below sea level

**ka = kilo-annum = 1 thousand years

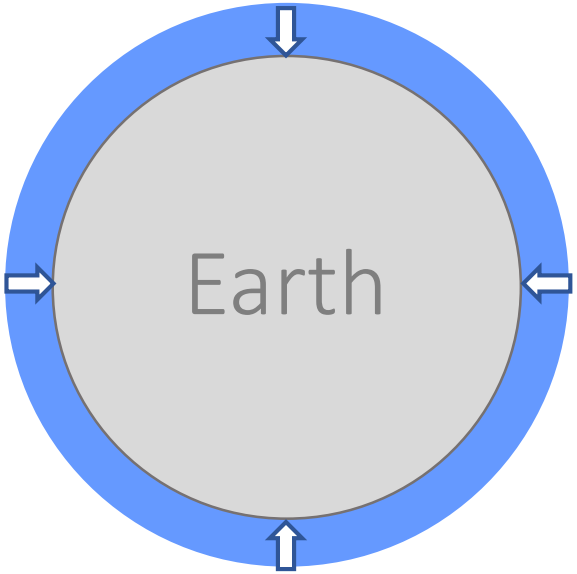
Temperature-related changes in ocean volume

Interglacial (warm)



DILATATION of ocean water

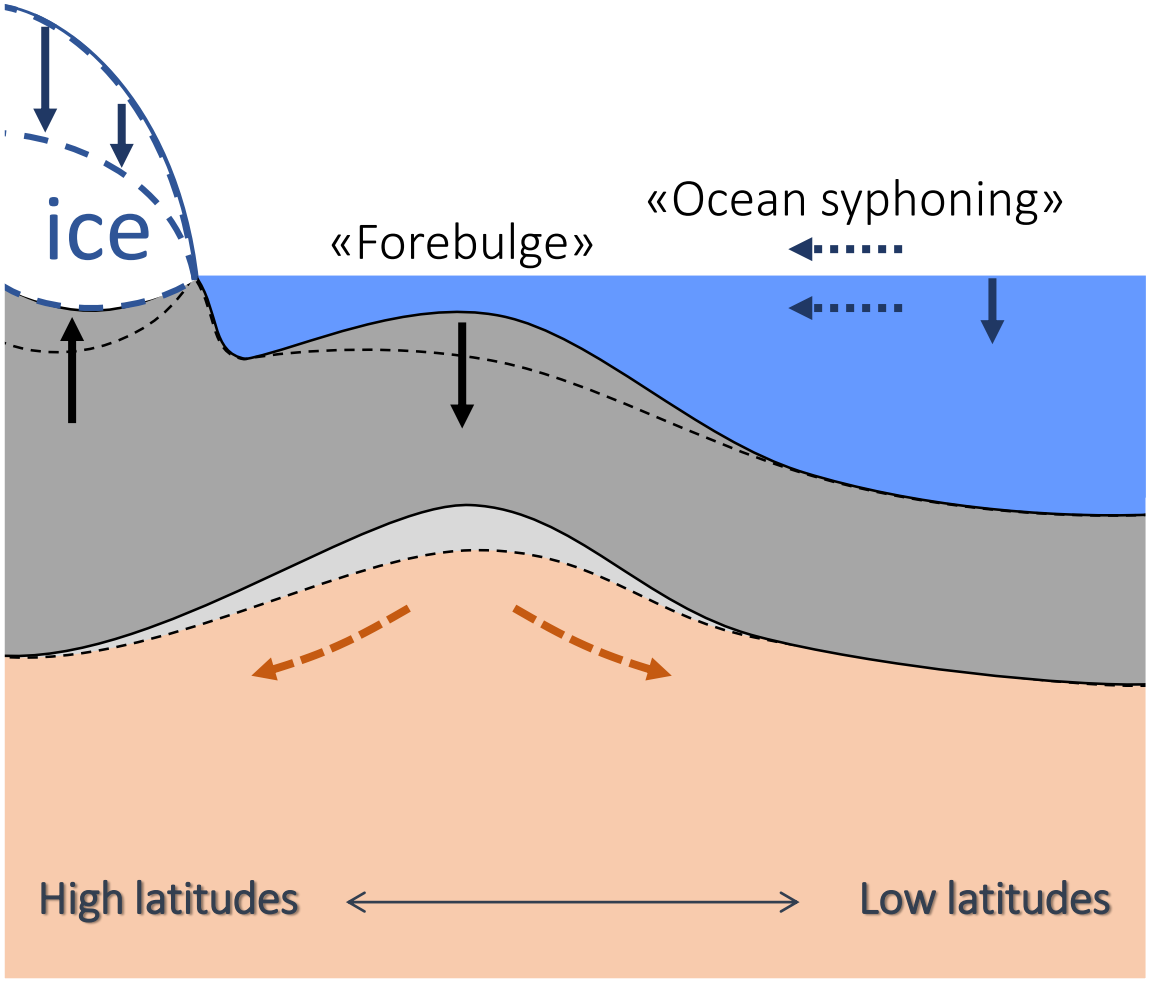
Glacial (cold, ice age)



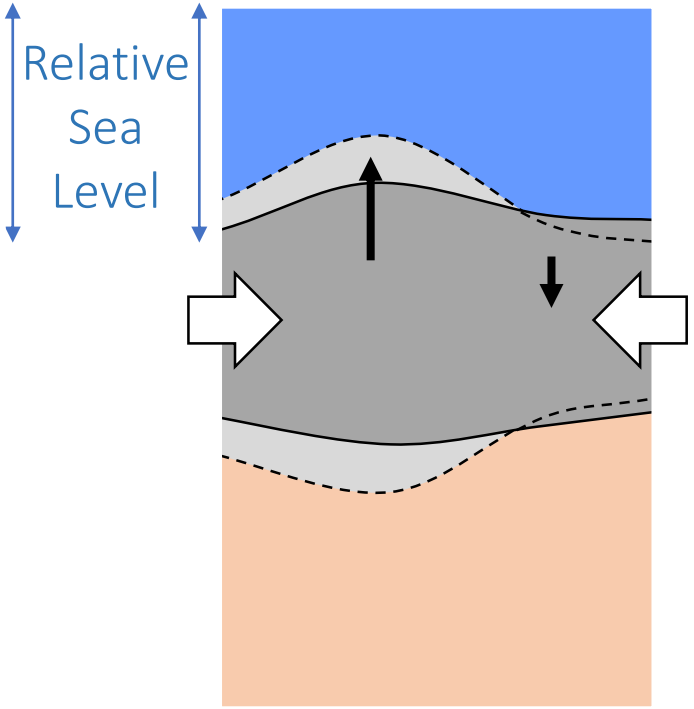
CONTRACTION of ocean water

Up/down movements of the land/seafloor

1. Isostatic deformation



2. Tectonic deformation



Albert et al. (2007)

Objective:

- Reconstruct changes in absolute sea level related to glacial-interglacial cycles

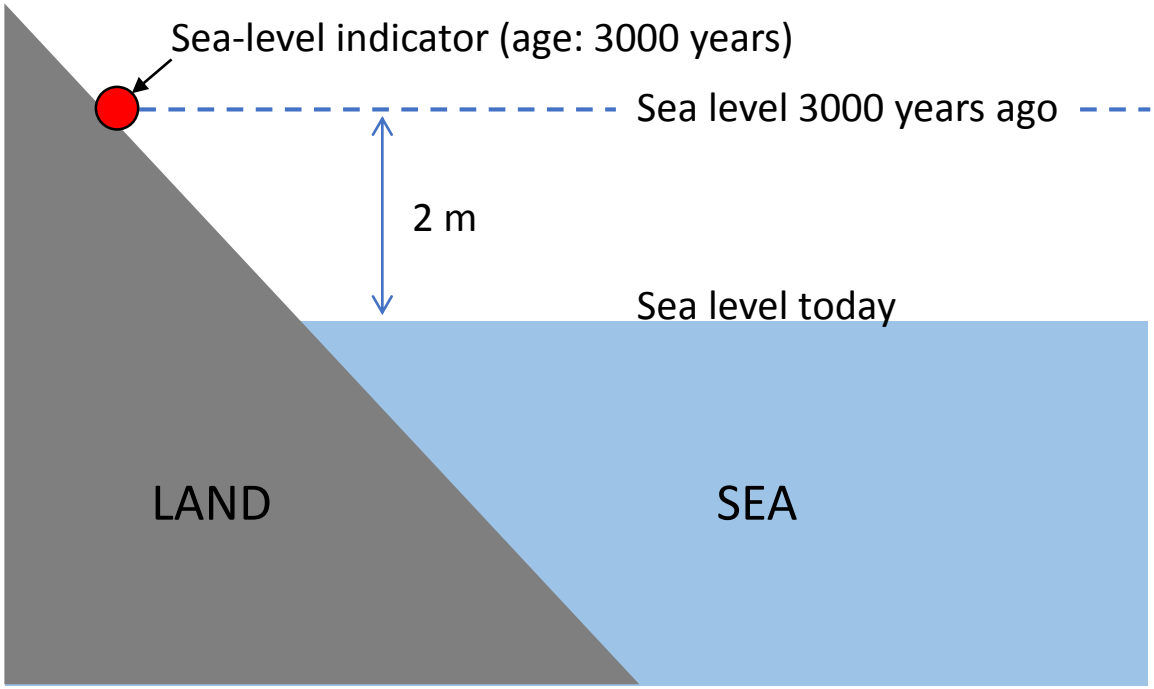
Why:

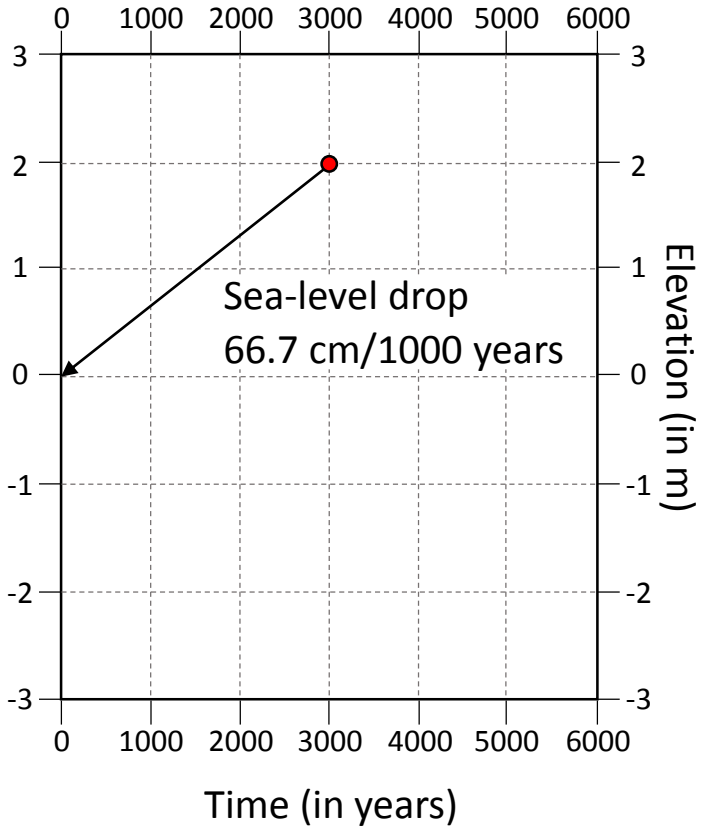
- Learn how much sea-level rise/fall (and how fast) can result from changes in polar ice volume
- Learn about the dynamics of polar ice sheets (expansion/retreat)

How:

- We need a good sea-level indicator
- We need regions far away from the poles and stable (limited up/down movements of land)

Measure of the elevation (relative to present sea level) and age of geological feature that can be linked to sea level.

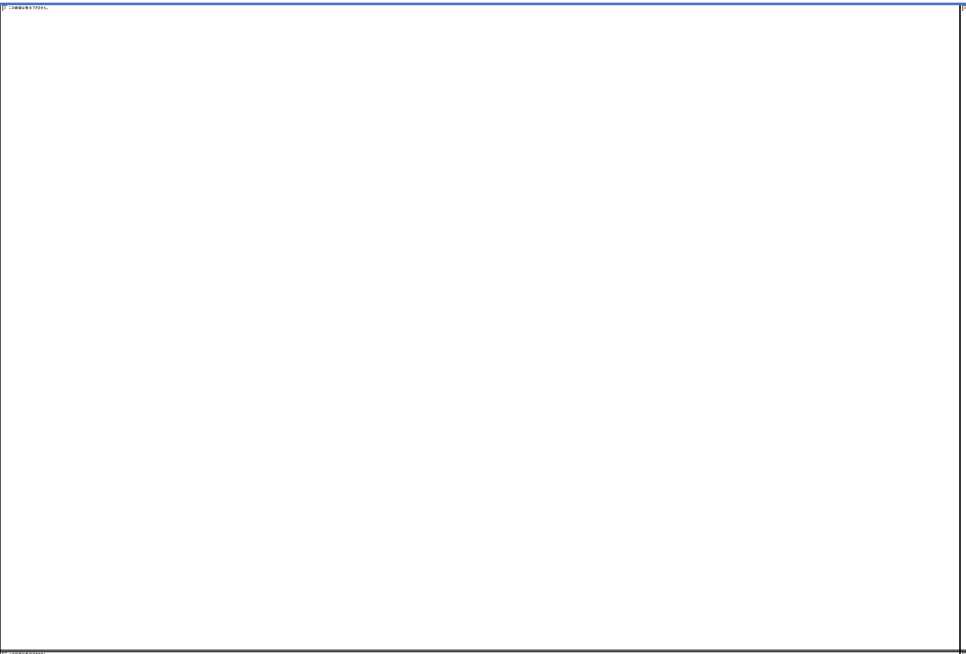




Examples of sea-level indicators:

- Marine notches
- Fossilized beach sediments
- Coastal marshes and wetlands
- Archeological indicators (harbor structures)
- Fossil coral reefs and reef organisms

2. What is sea-level change?



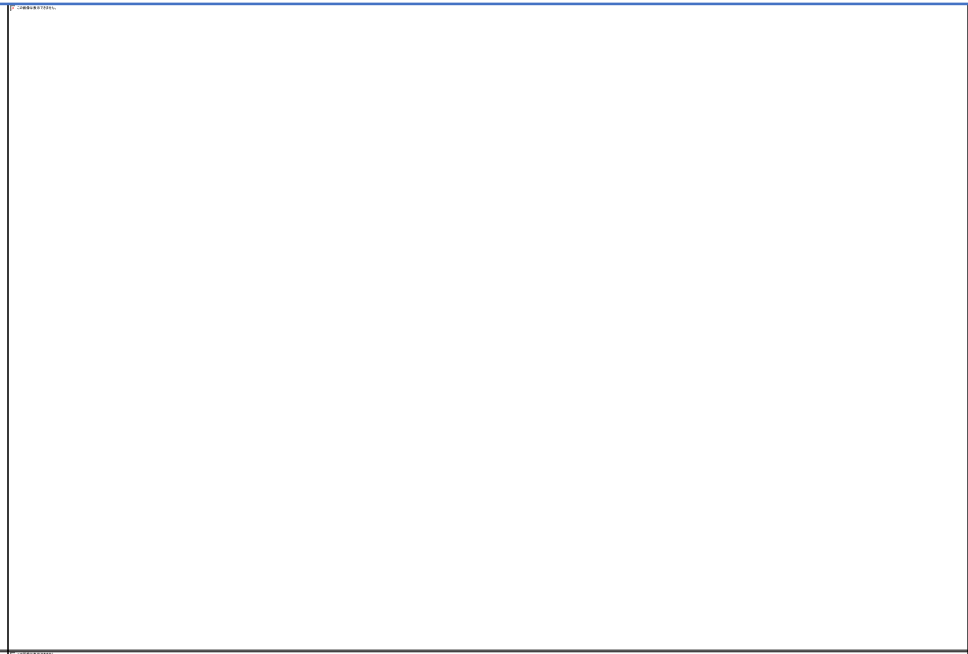
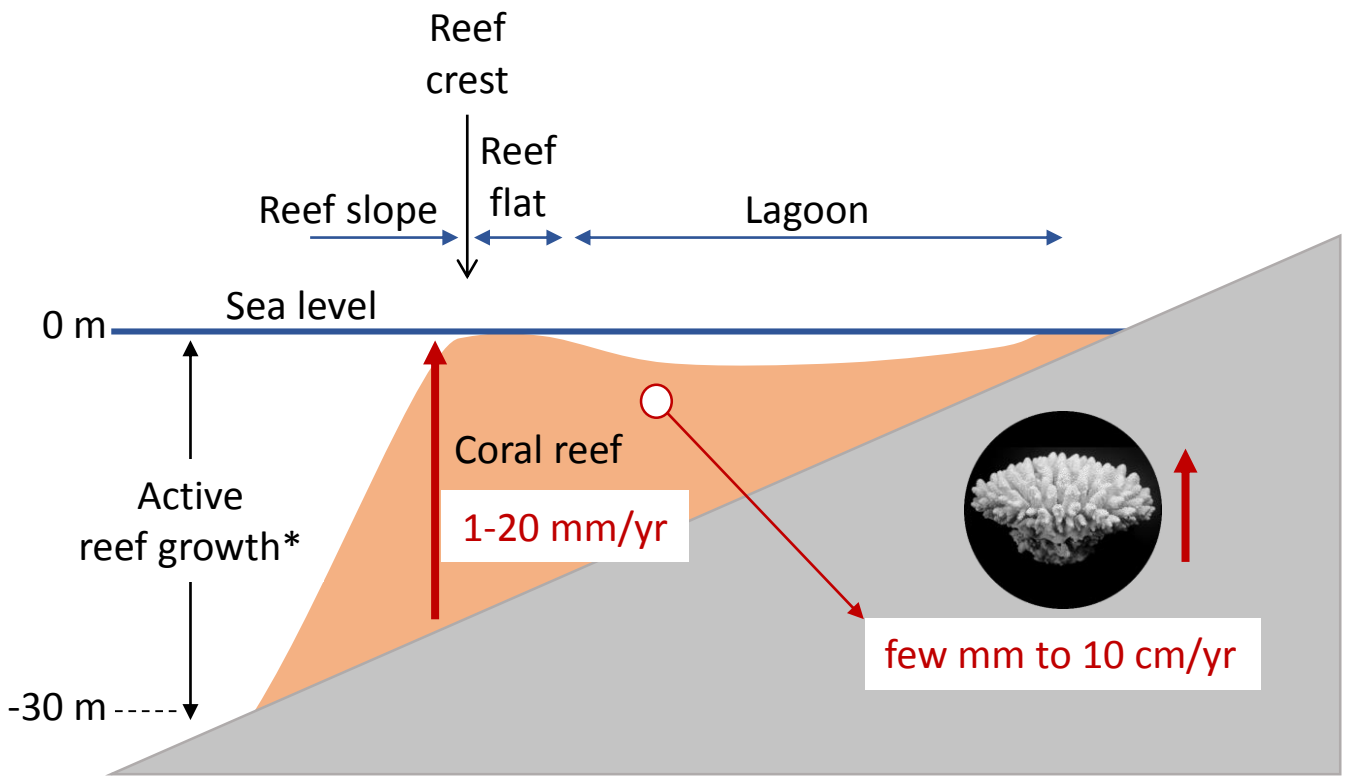
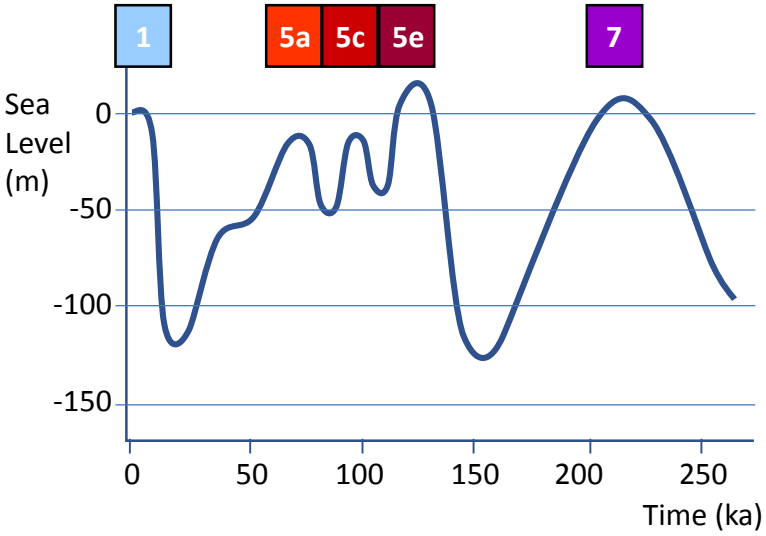


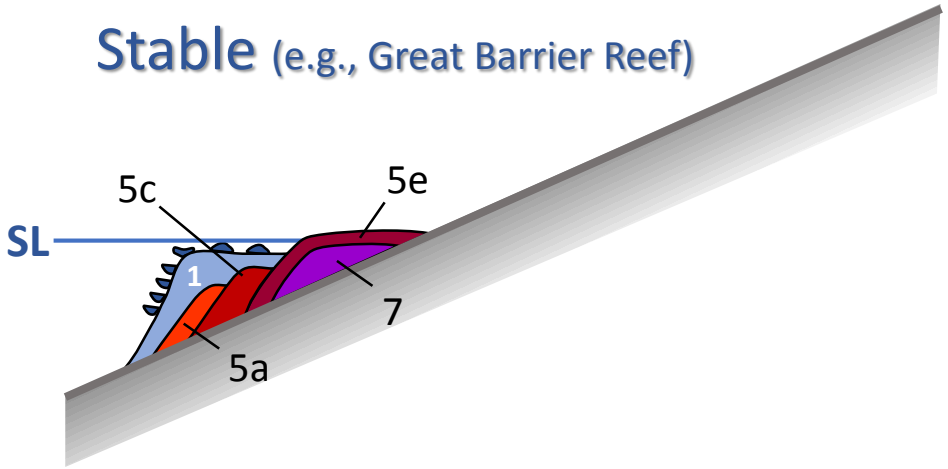
Image credits (clockwise from top left): Boulton and Stewart (2015), Wikipedia, Gehrels and Anderson (2015), Benjamin et al. (2017)

- Reconstructing sea-level history using fossil coral reefs

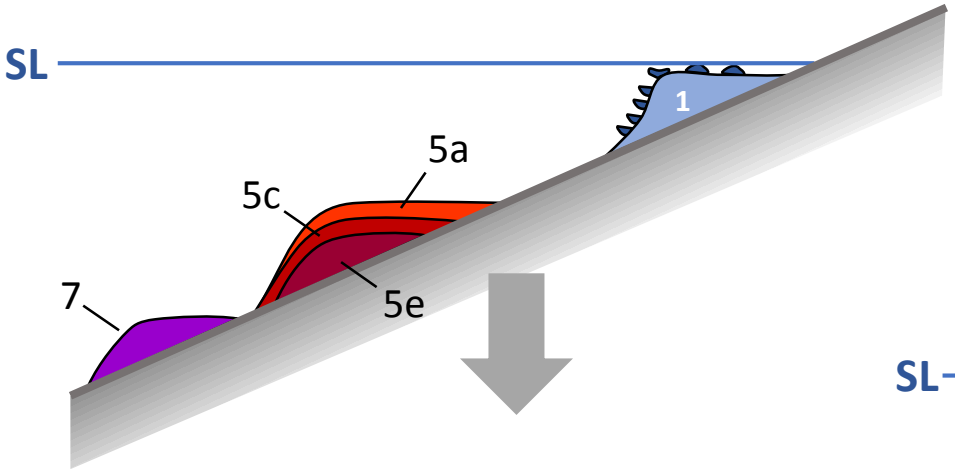

Reef
crest
Reef
flat
Reef slope
Lagoon
0 m
Sea level
Active
reef growth*
-30 m
Coral reef
1-20 mm/yr
few mm to 10 cm/yr



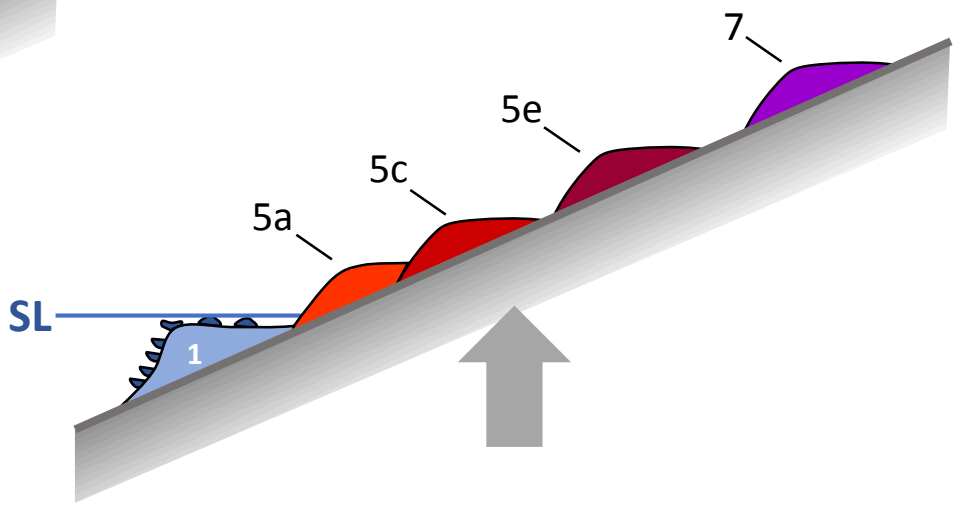
Stable (e.g., Great Barrier Reef)



Subsiding (e.g., Hawaii)



Uplifting (e.g., Ryukyus, Papua New Guinea)



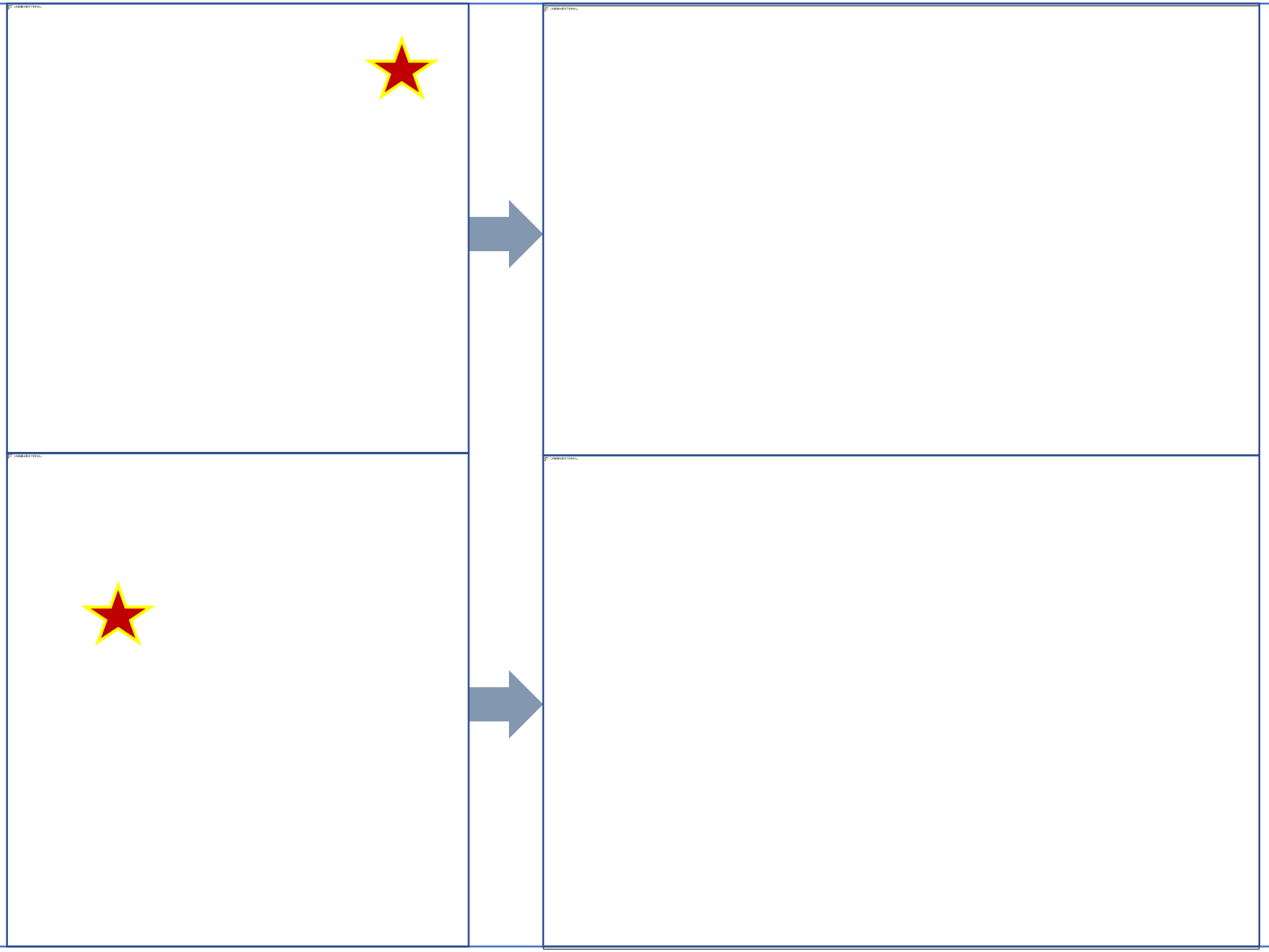


Image credits (clockwise from top left): Google map, Wikipedia, Webster et al. (2009)

- Coral communities as sea-level indicators

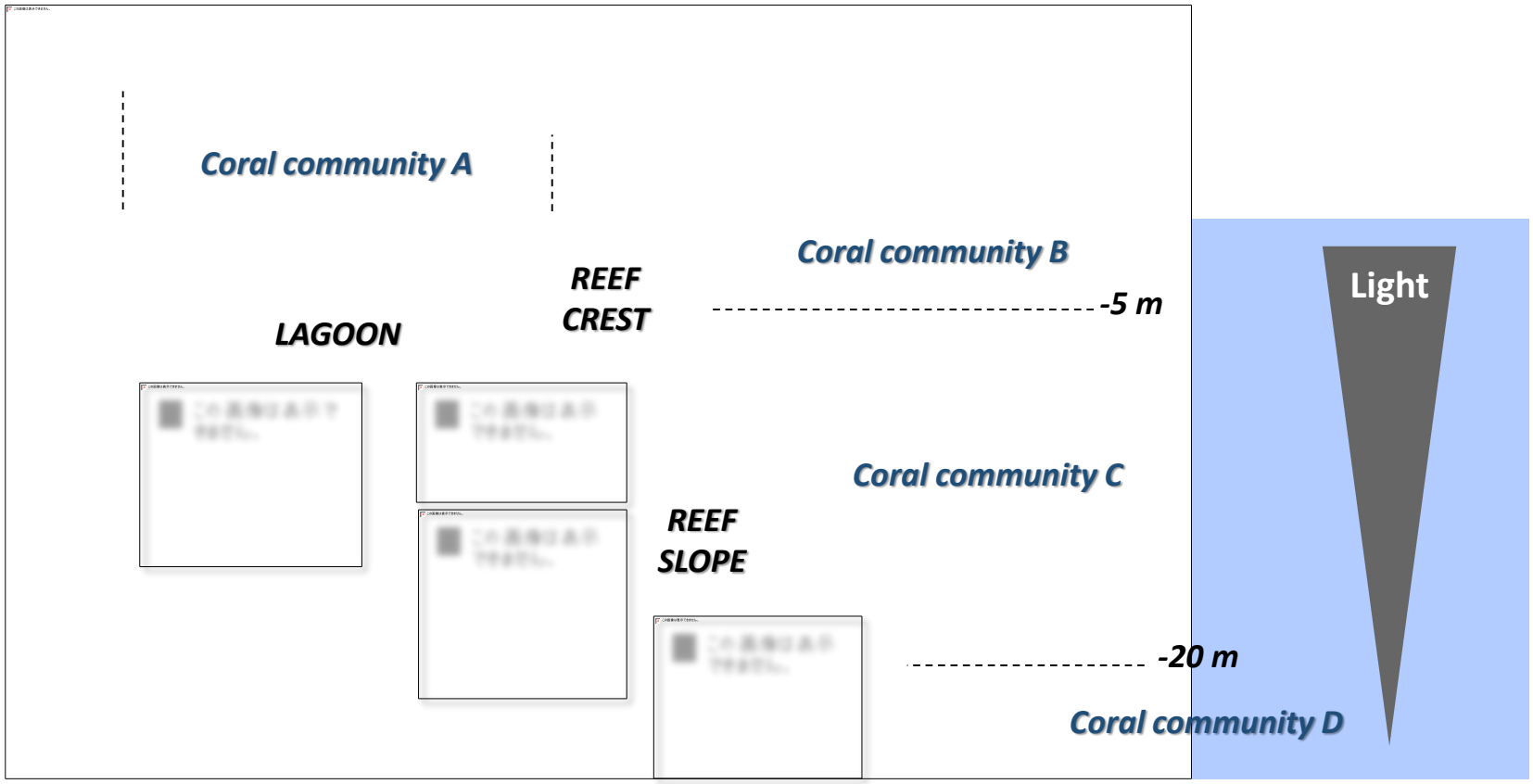


Image credit: Australian Institute of Marine Sciences

- Algal communities as sea-level indicators

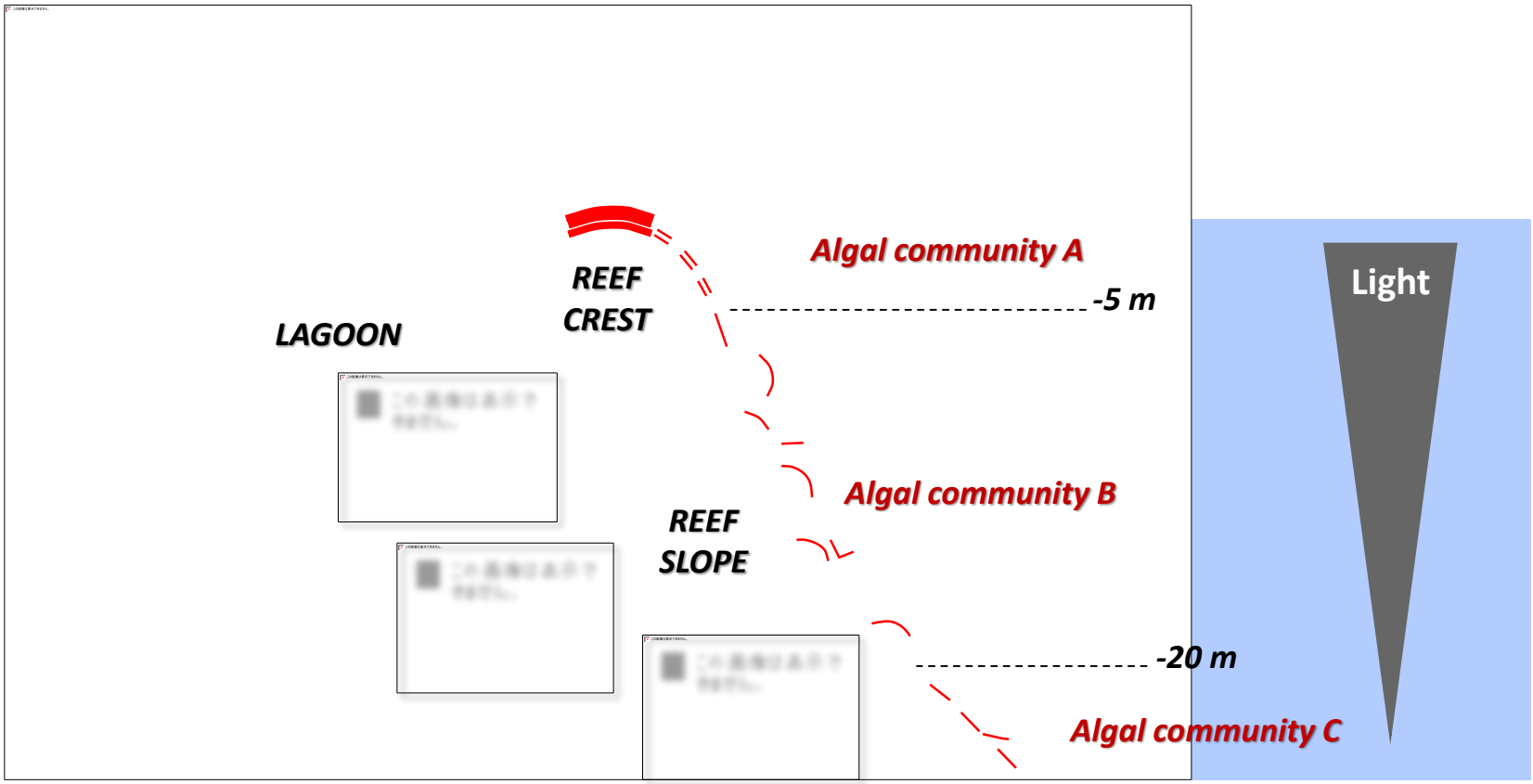
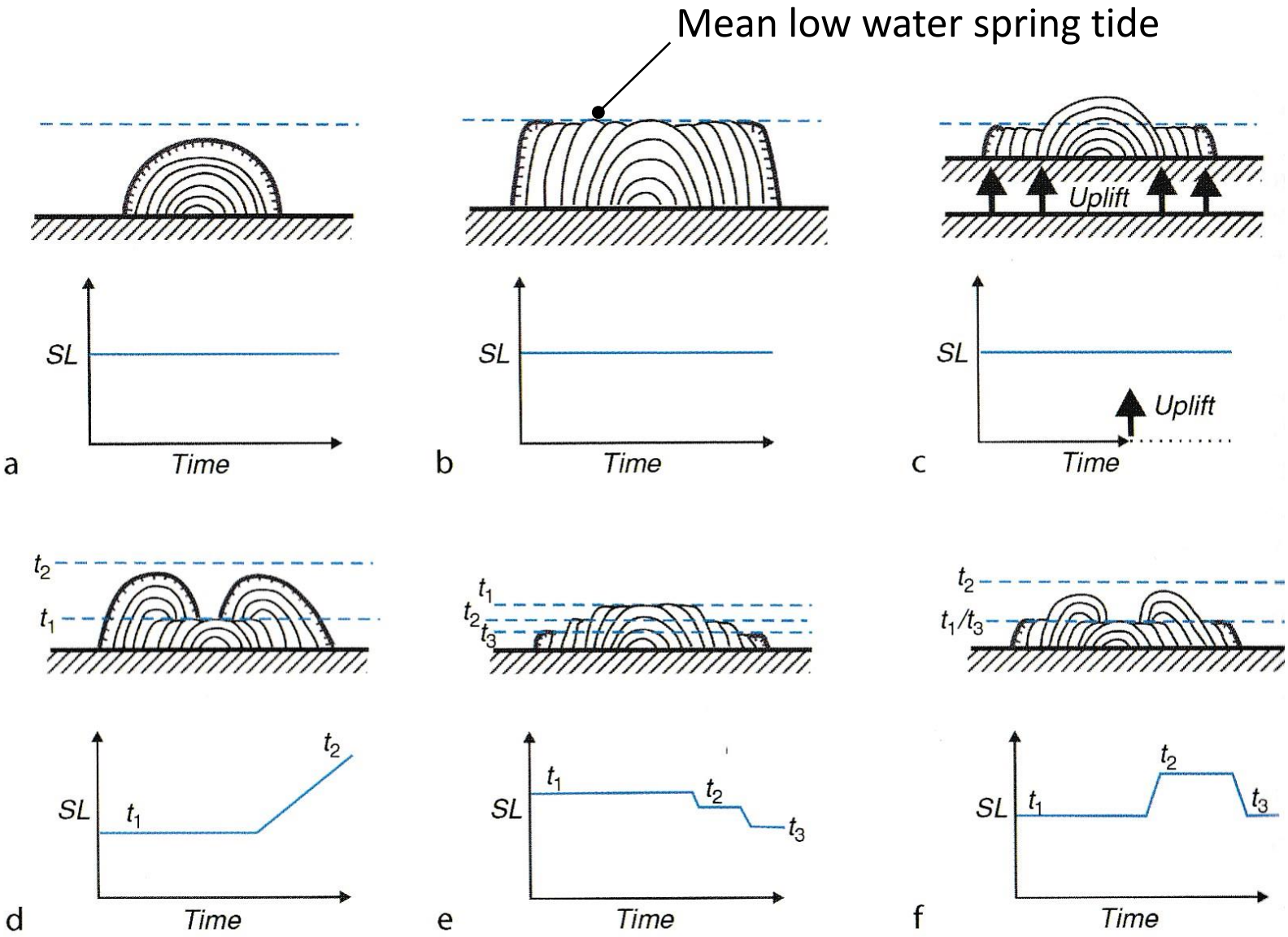


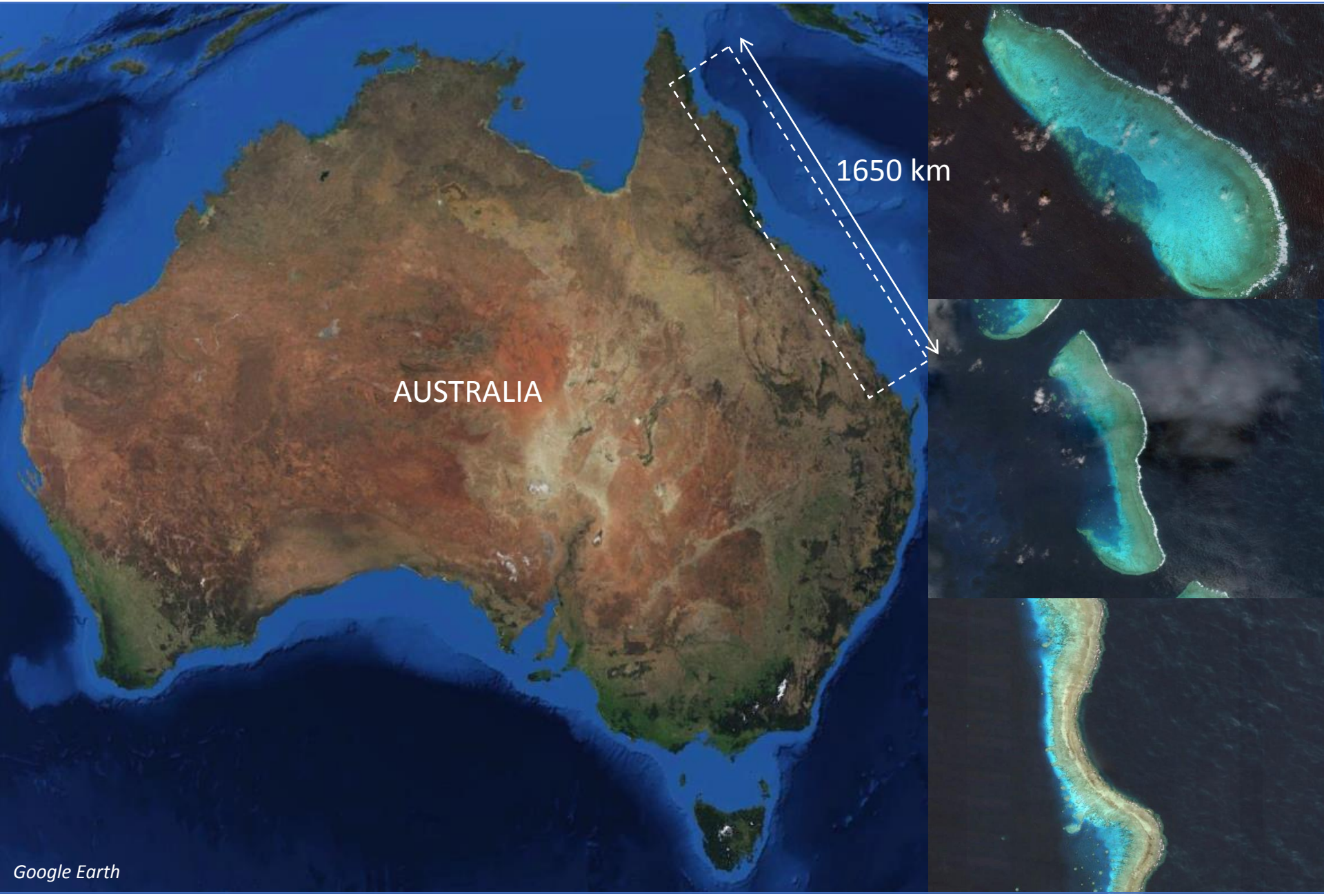
Image credits: IRD, UC Santa Barbara, Kansas University (Derek Keats)

Microatolls

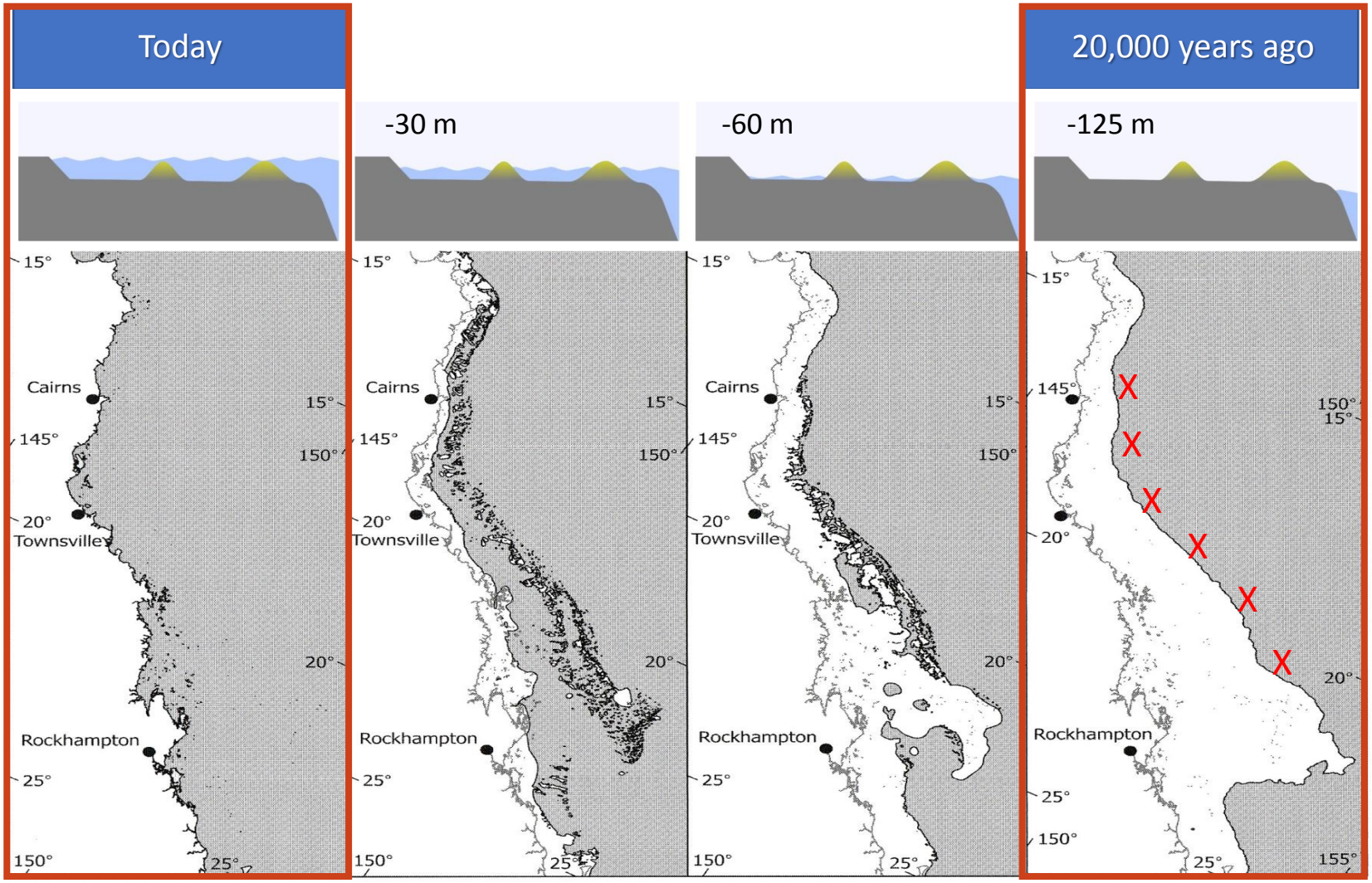
Image credit: Dr. Alton Meltzner (Earth Observatory of Singapore)

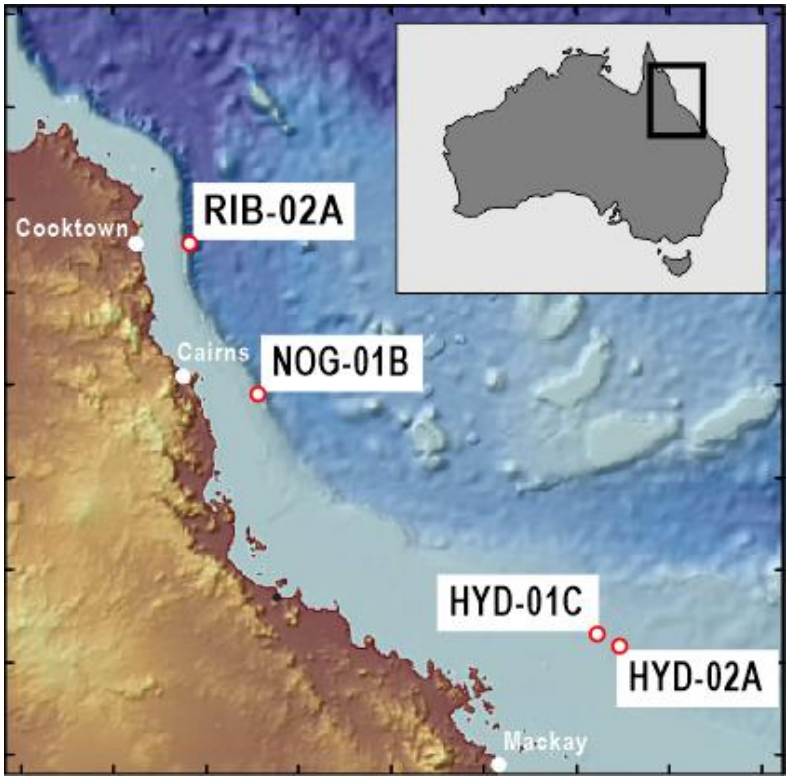


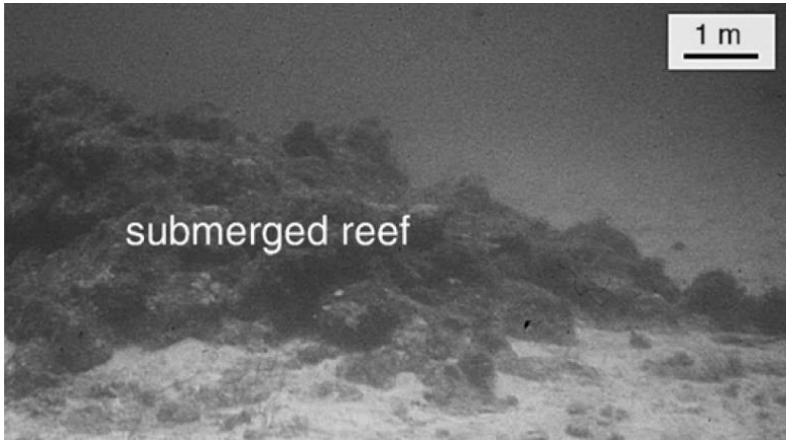
Smithers (2011)

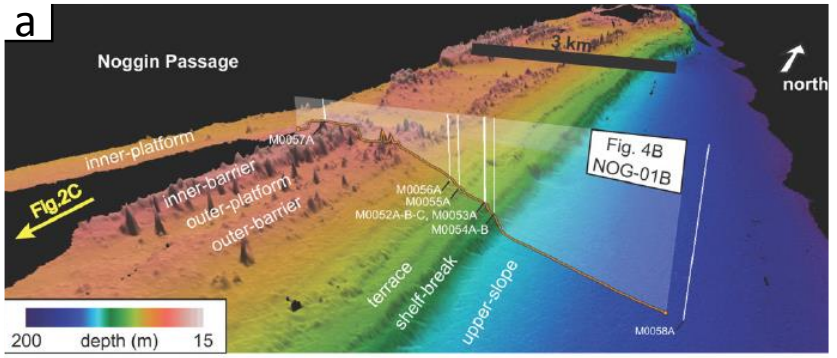

1650 km
AUSTRALIA
Google Earth

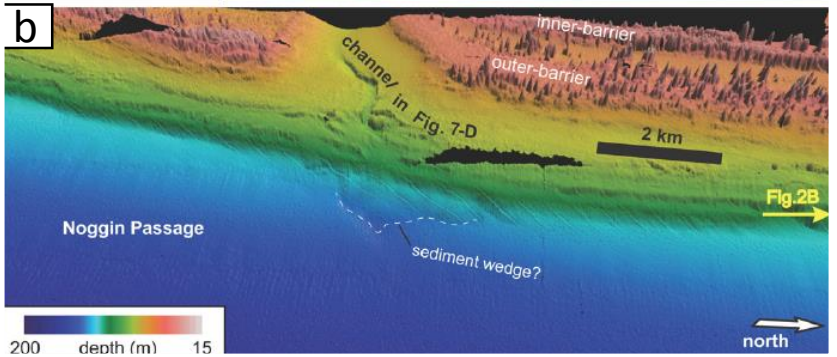
Objective: Reconstruct history of Great Barrier Reef and sea level since the last Glacial period

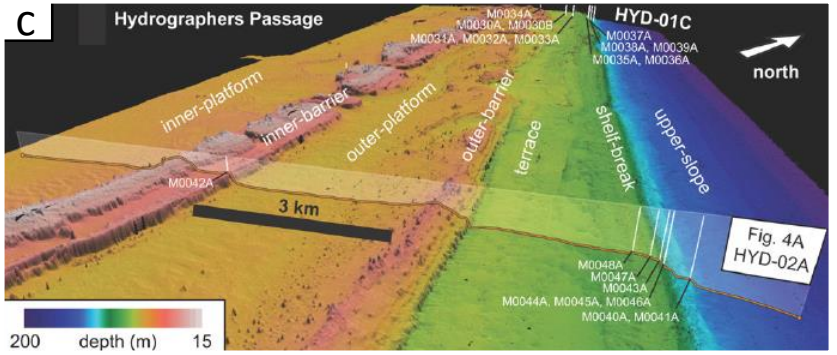




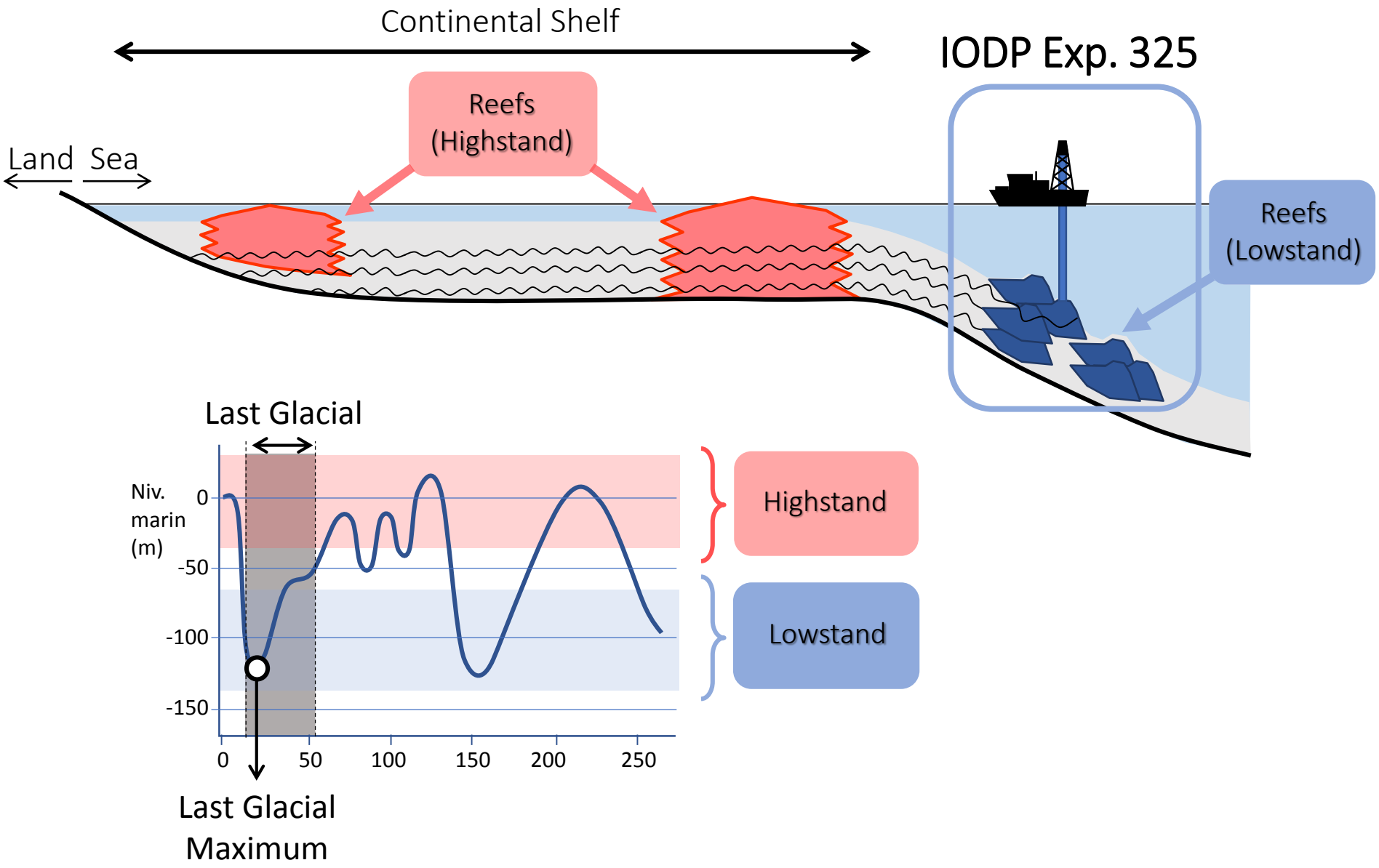








Hinestrosa et al. (2016)


Continental Shelf
IODP Exp. 325
Reefs
(Highstand)
Land
Sea
Reefs
(Lowstand)
Last Glacial
Niv.
marin
(m)
0
-50
-100
-150
0
50
100
150
200
250
Highstand
Lowstand
Last Glacial
Maximum


EEE


RESEARCH VESSEL

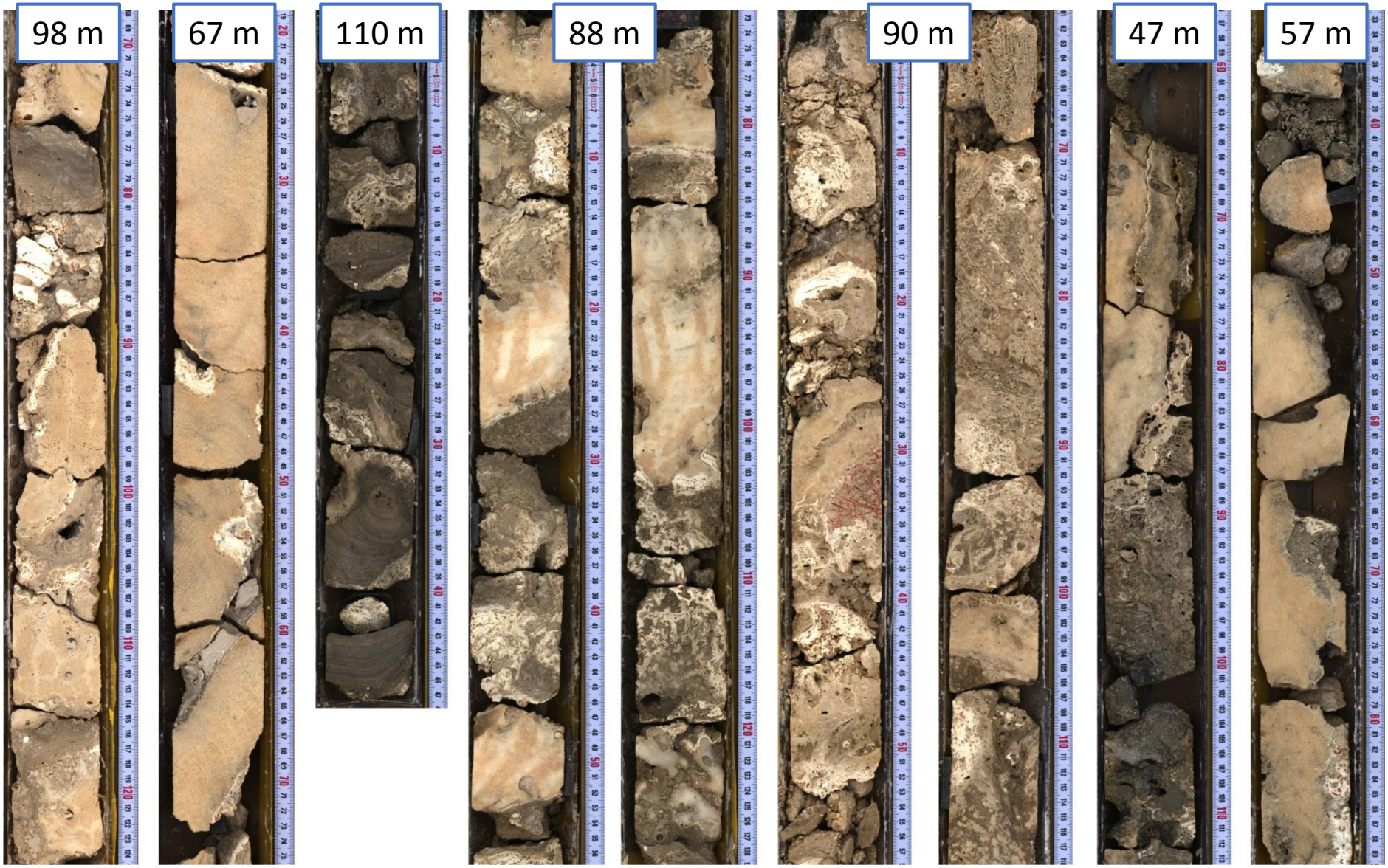
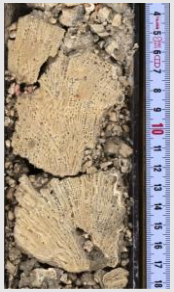
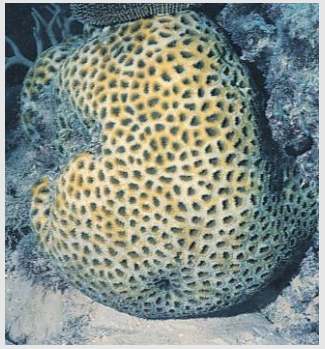


Image credit: IODP

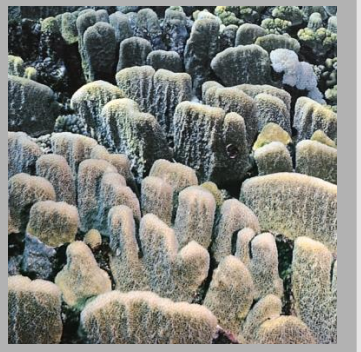
Acropora gr. *humilis*


Seriatopora hystrix

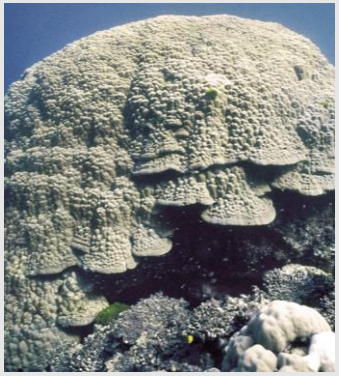

Favia sp.

Massive *Isopora* sp.

Massive *Porites* sp.

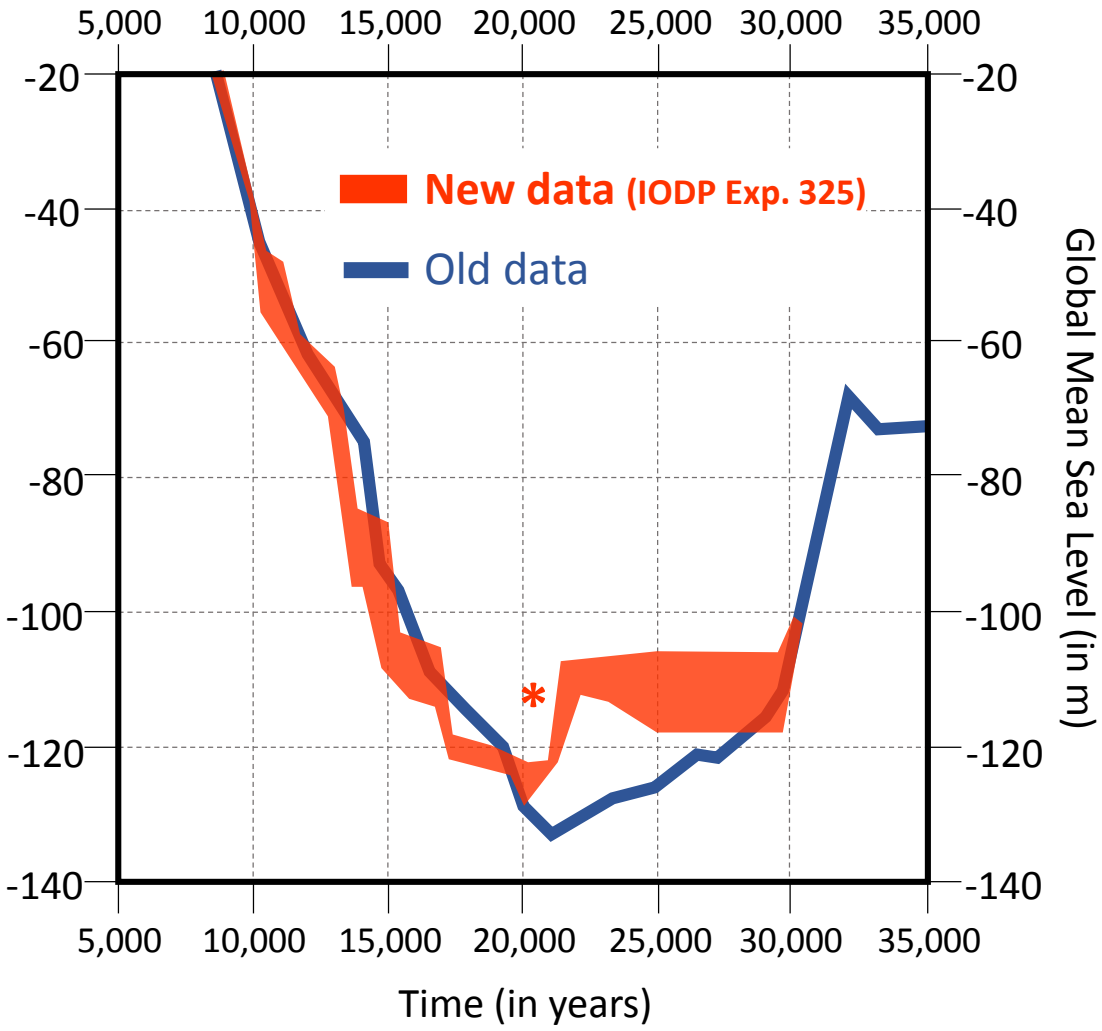
Montipora sp.


Stylophora pistillata

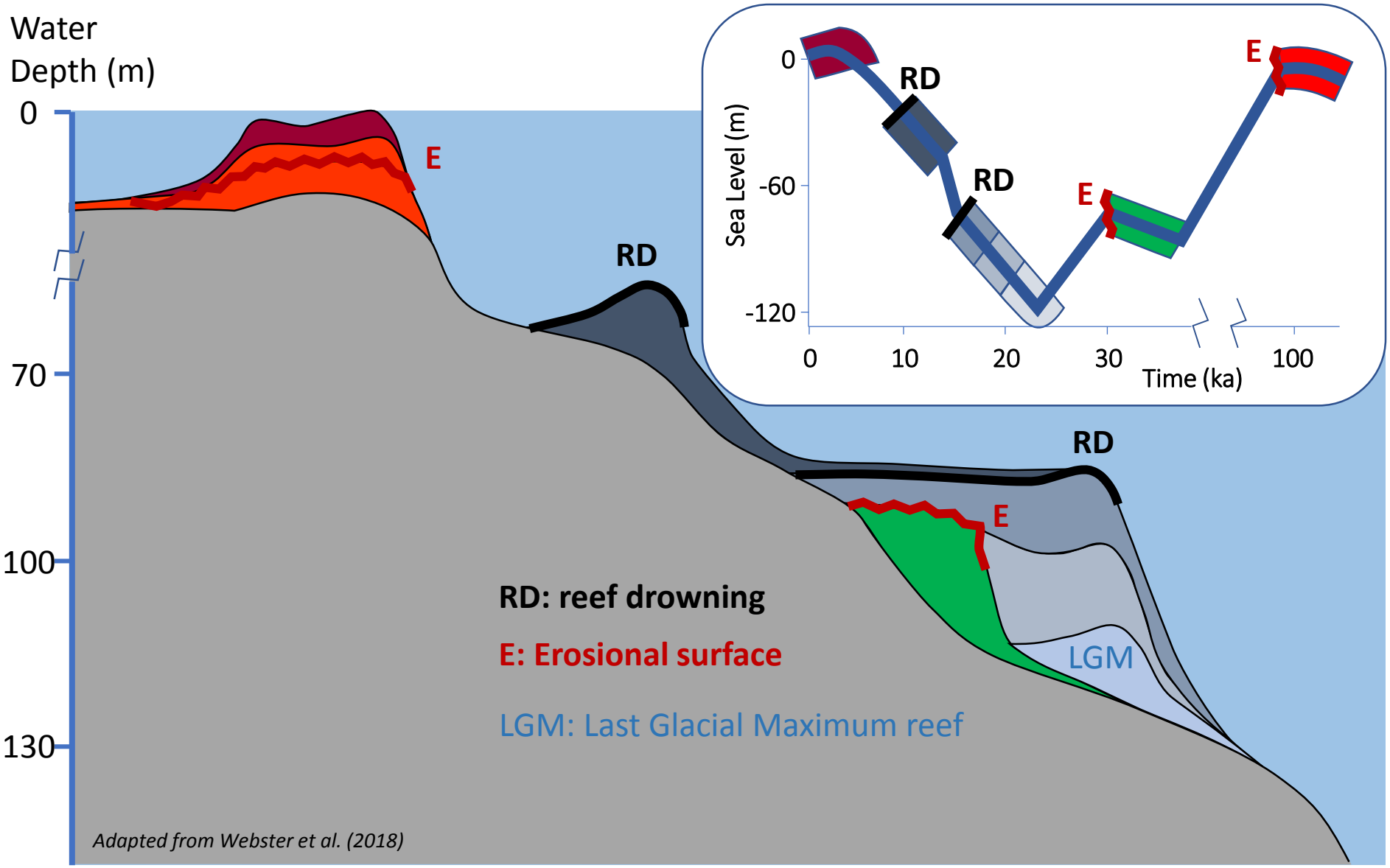

Tubipora musica

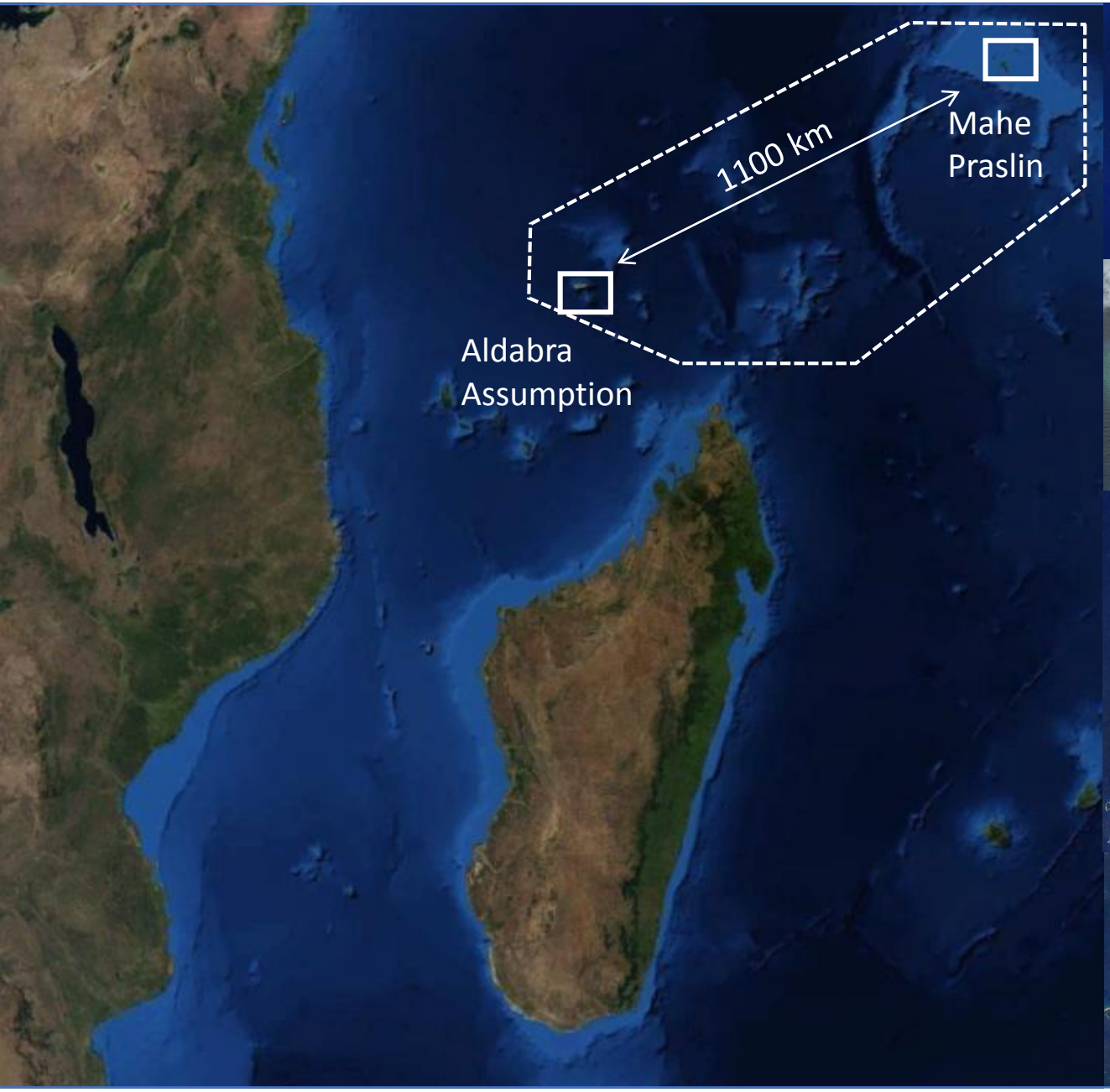

Pachyseris speciosa

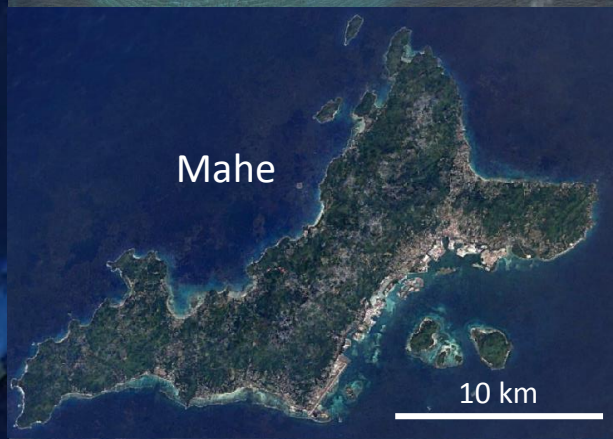

Image credit: Australian Institute of Marine Sciences



* Rapid glaciation → 20 m sea-level drop in 1400 years (1.4 cm/year)

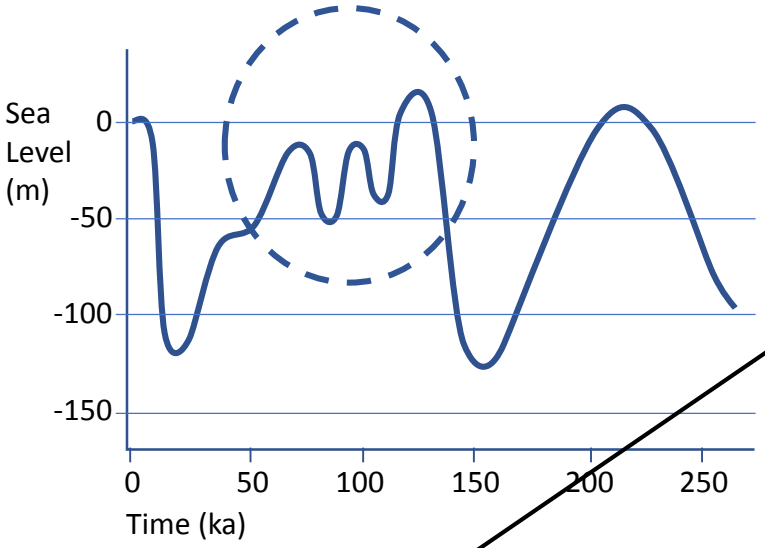

Water
Depth (m)
0
70
100
130
E
RD
RD
RD
E
RD: reef drowning
E: Erosional surface
LGM
LGM: Last Glacial Maximum reef
Adapted from Webster et al. (2018)
Sea Level (m)
0
-60
-120
0
10
20
30
100
Time (ka)
RD
RD
E
E





Google Earth

Objective: Reconstruct history of coral reef and sea level at Aldabra and Assumption during the Last Interglacial



Wikipedia

- ✓ Geochemistry

  (datings & climate proxies)
- ✓ Sedimentology
- ✓ Paleobiology,
- ✓ Diagenesis
- ✓ Geophysical modeling
- ✓ Climate modeling

CEREGE, Aix-en-Provence (France; www.cerege.fr)

Gilbert Camoin: Carbonate sedimentology, Reef geology, Sea-level change

Nadine Hallmann: Carbonate sedimentology, Paleoclimate tracers in corals

Edouard Bard: Palaeoceanographic tracers in corals

Claude Vella: Coastal sedimentology and morphology, GPS positioning, Mapping, 3D photogrammetry

Philippe Dussouillez: GPS positioning, Mapping

Jules Fleury: GPS positioning, Mapping

Ifremer, Brest (France; wwz.ifremer.fr)

Stéphan Jorry: Carbonate sedimentology, Reef geology

Gwenael Jouet: Carbonate sedimentology, Reef geology

MARUM Bremen (Germany; www.marum.de/index.html)

Alessio Rovere: Coastal sedimentology and morphology, Sea-level change, GPS positioning

Thomas Felis: paleoclimate tracers in corals

GEOMAR Kiel (Germany; www.geomar.de)

Anton Eisenhauer: U-series dating of corals

University of Geneva (Switzerland; www.unige.ch)

Elias Samankassou: Carbonate Sedimentology, Paleoclimate tracers in corals

Nicholas Farley: Paleoclimate tracers in corals

University of Granada (Spain; www.ugr.es)

Juan Carlos Braga: Taxonomy of red algae

University of Nagoya (Japan; http://en.nagoya-u.ac.jp)

Marc Humblet: Taxonomy of corals

University of Ottawa (Canada; www.uottawa.ca)

Glenn Milne: Geophysical modelling

University of Glasgow (UK; www.gla.ac.uk)

Colin Braithwaite: Carbonate sedimentology, Reef geology

PetroSeychelles (Seychelles; www.petroseychelles.com)

Patrick Samson: Geology of the Seychelles, Sedimentology

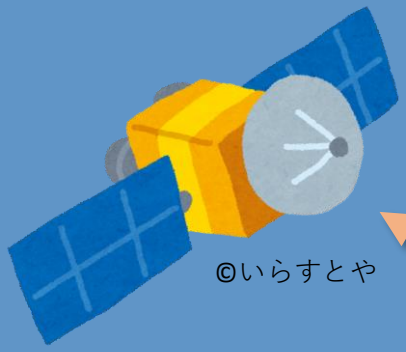
Image credits: Nicolas Tisne

METHODS

著作権等の都合により、
ここに挿入されていた画像を削除しました

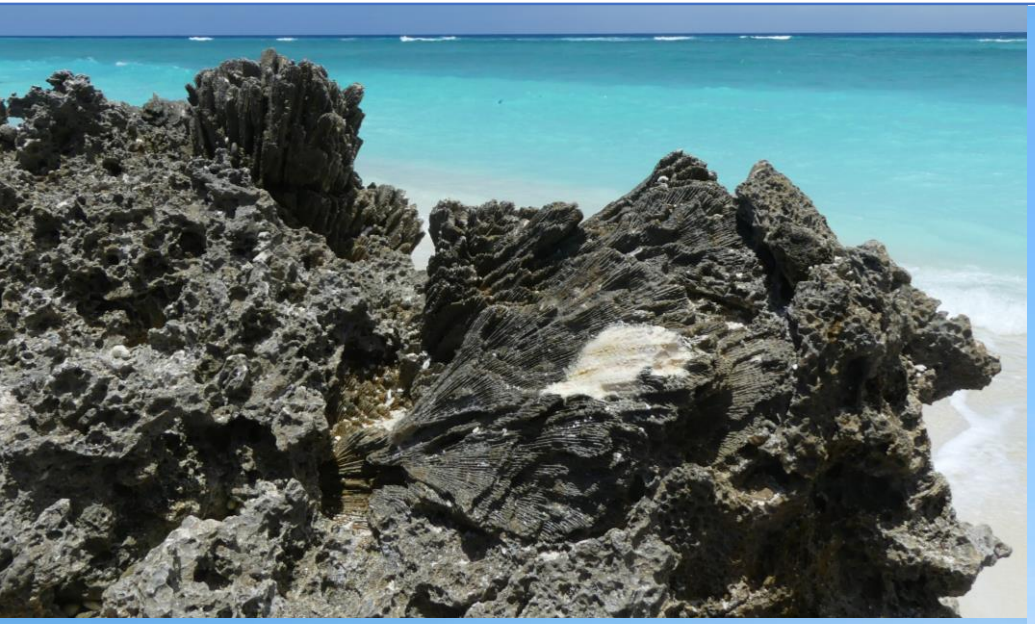
*Mavic Pro mini-drone*の画像

- **3D mapping and photo coverage**
  - Mapping of the LIG reef unit
  - Aerial photography of the studied outcrops
- **High-precision GPS measurements**
  - Hundreds of GPS measurements on the 4 study sites
  - 40 topographic transects
- **Field descriptions**
  - Description/interpretation of depositional environments
  - Description/interpretation of reef communities
- **Sampling**
  - Coring/sampling in situ fossil coral colonies for radiometric dating



Base

Mobile unit



One of 150,000 giant turtles of Aldabra


THANK YOU!
ANY
QUESTIONS?