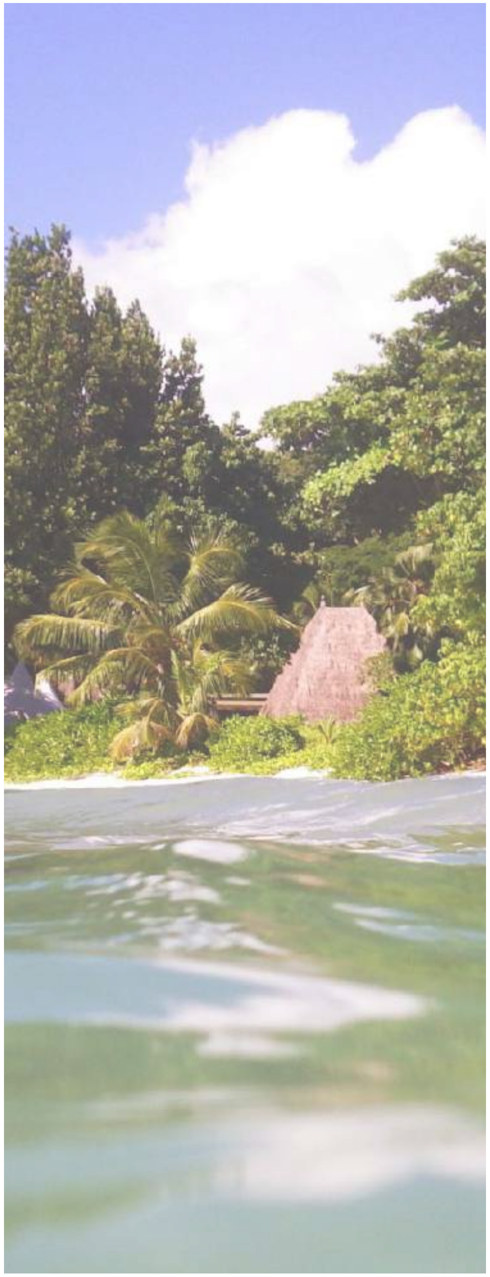


Fossil Coral Reefs as a Window into the History of Sea-level and Climate Change

Marc Humblet, Assoc. Prof.

Department of Earth and Planetary Sciences, Nagoya University

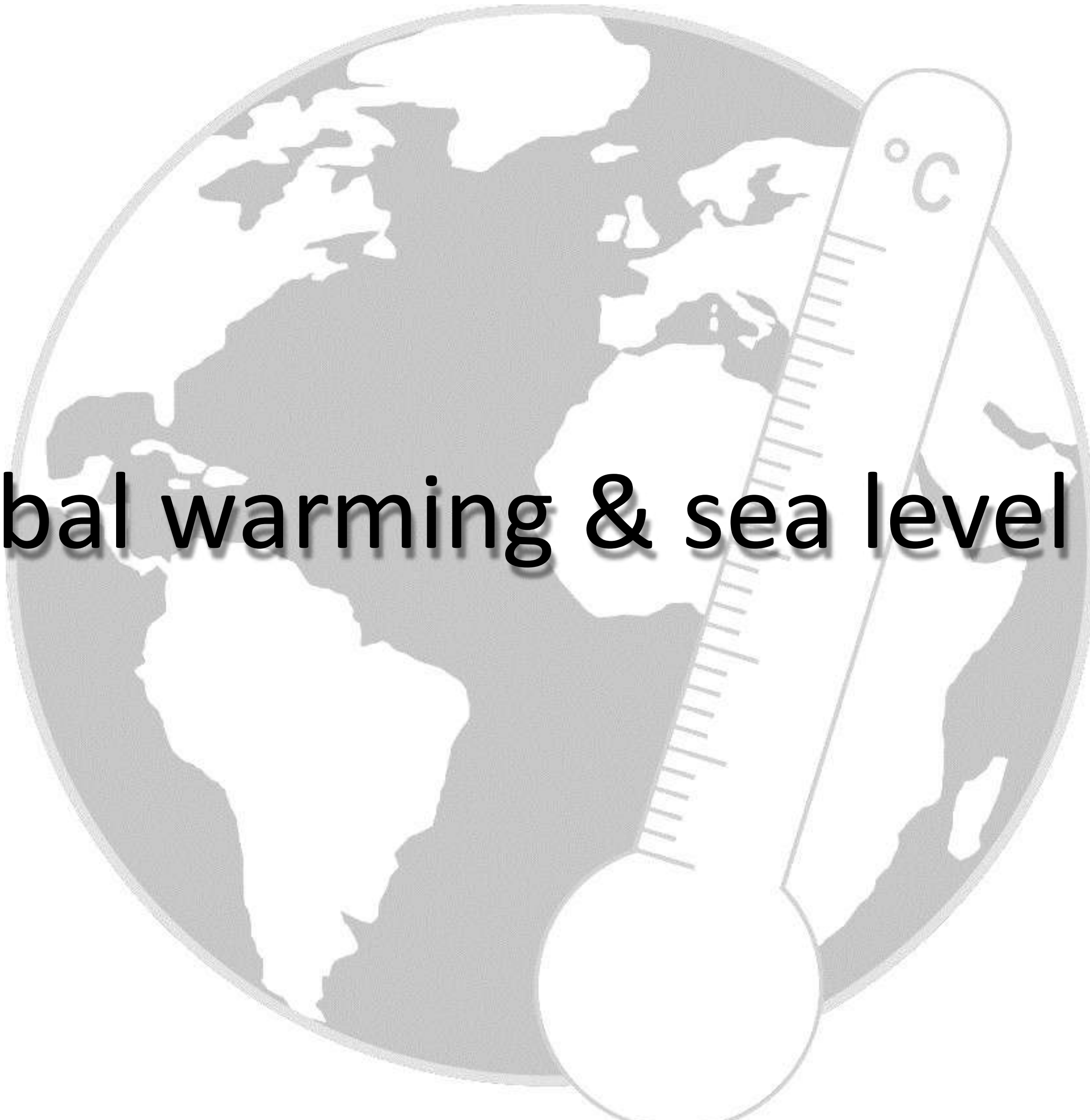
Outline

- Today’s global warming & sea level rise

- Case study: the Great Barrier Reef of Australia and the history of sea-level and climate change since 30,000 years ago

- The scientific method and the communication of scientific results

Global warming & sea level rise

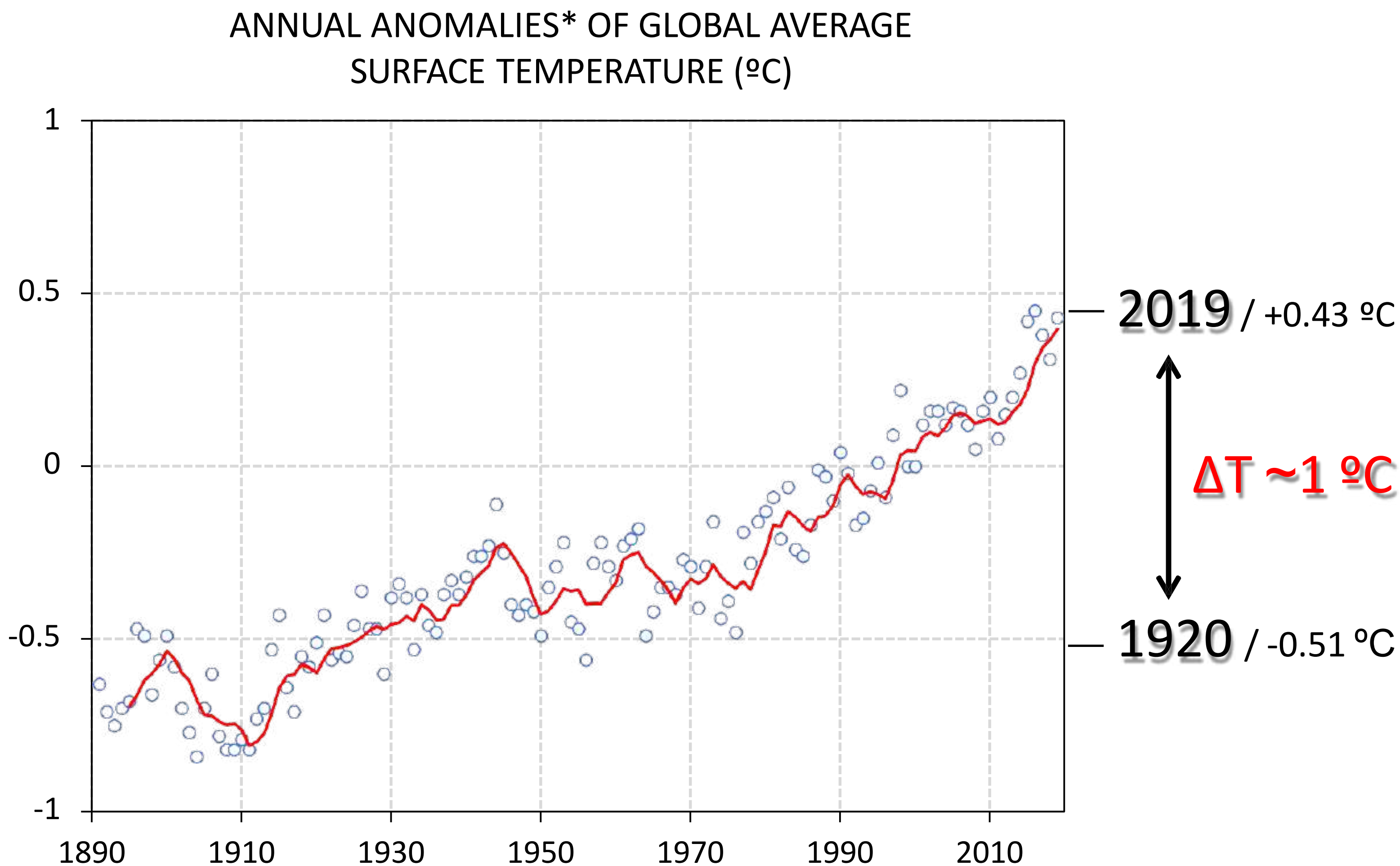


- The Earth is warming

  Evidence from direct measurements of

  - Surface air temperature
  - Sea surface temperature

Surface air temperature



* Relative to average temperature over the period 1981-2010

Data source: Japan Meteorological Agency

- Sea level is rising

Evidence from direct measurements using

- Tide gauges
- Satellite altimetry

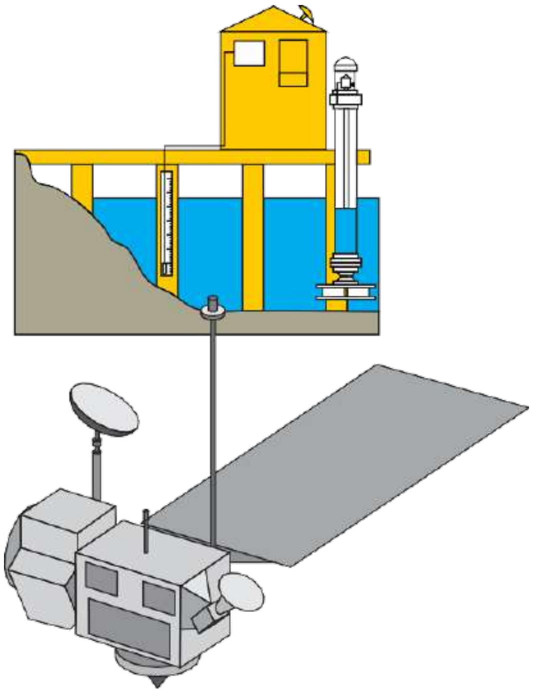
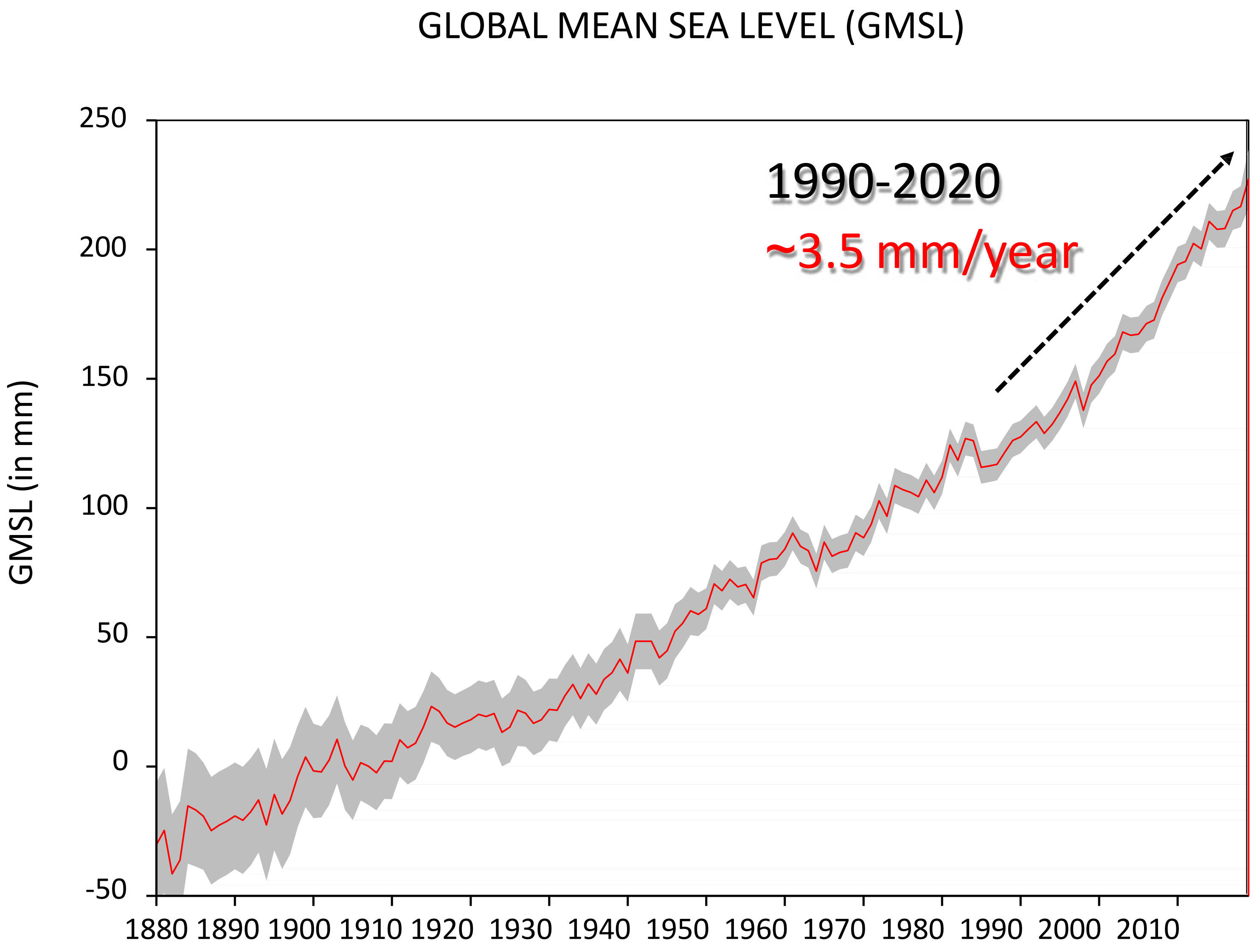


Image credit: adapted from https://oceanservice.noaa.gov/facts/tide-gauge.html, https://www.cmar.csiro.au/sealevel/sl_meas_sat_alt.html

Sea level rise

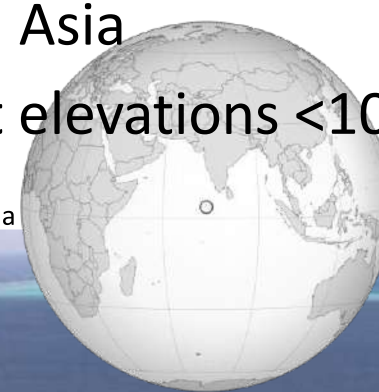


Data source: Commonwealth Scientific and Industrial Research Organization (CSIRO)

- Why is it important to study sea level change?

  - 190 million people in the World living in coastal areas are directly exposed to sea level rise

    - Most at risk are developing countries in Asia
    - 20% of Japan population live in cities at elevations <10 m



©Wikipedia

Malé, capital of the Maldives   Highest elevation = 2.4 m above mean sea level

Data from *Kulp & Strauss (2019), Nature Communications* *Image credit: Hironobu Kan*

- Impacts of sea level rise
  - Higher and more frequent coastal flooding
  - Increased erosion of the coast

©Wikipedia

Image credit: Terry Chea/Associated Press (https://www.eenews.net/special_reports/california_crumbling_coast/)

- What are the causes of sea level rise?

  - Melting of ice on land (polar ice sheets, glaciers)

  - Increasing volume of ocean water as it warms

Image credit: http://www.bbc.com/earth/story/20160408-this-is-how-far-seas-could-rise-thanks-to-climate-change, Pixabay

RATES OF SEA LEVEL (SL) RISE SEPARATED BY SOURCE FOR THE PERIOD 1993-2003

Source of SL rise	Rate of SL rise (mm/year)	Potential SL rise
Thermal expansion	1.6 ± 0.5	0.3 m (+ 3°C)
Glaciers and ice caps	0.77 ± 0.2	0.4 m
Greenland ice sheet	0.21 ± 0.07	7 m
Antarctic ice sheet	0.21 ± 0.35	57 m
Observed total SL rise	3.1 ± 0.7	

Ice cap: surface area < 50,000 km^2

Ice sheet: surface area > 50,000 km^2

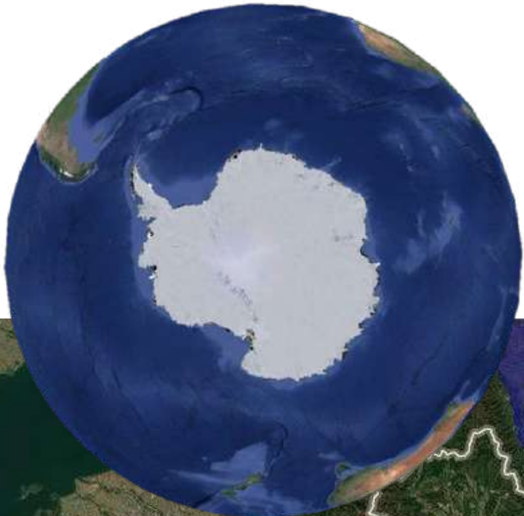
Data source: Bertler & Barrett (2014), Changing Climates, Earth Systems and Society

Melting of Greenland ice sheet

$1.7 \times 10^6 km^2$

Potential sea level rise = 7m

Image credit: http://flood.firetree.net/



Melting of Antarctic ice sheet

$14 \times 10^6 km^2$

Potential sea level rise = 57m

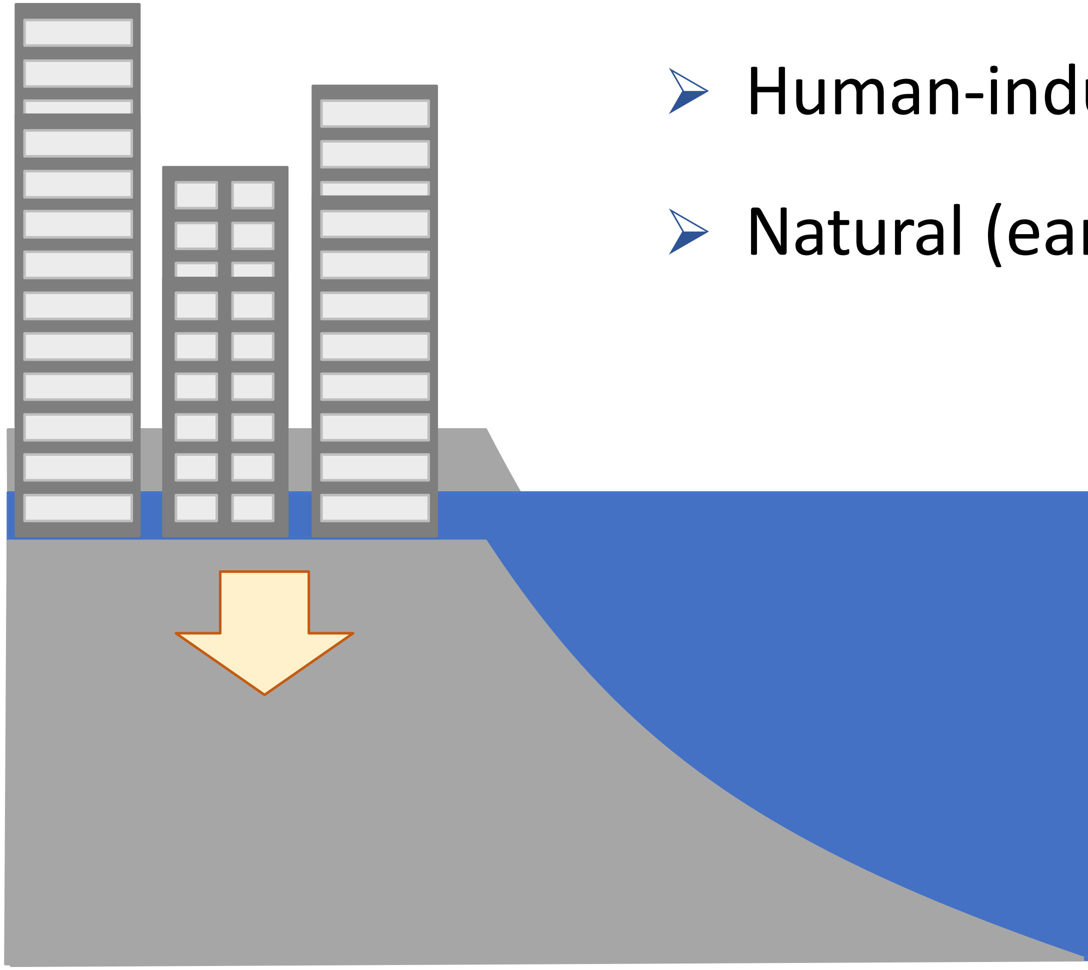
Image credit: http://flood.firetree.net/

Global change in sea level related to variation in the volume of ocean water

VS.

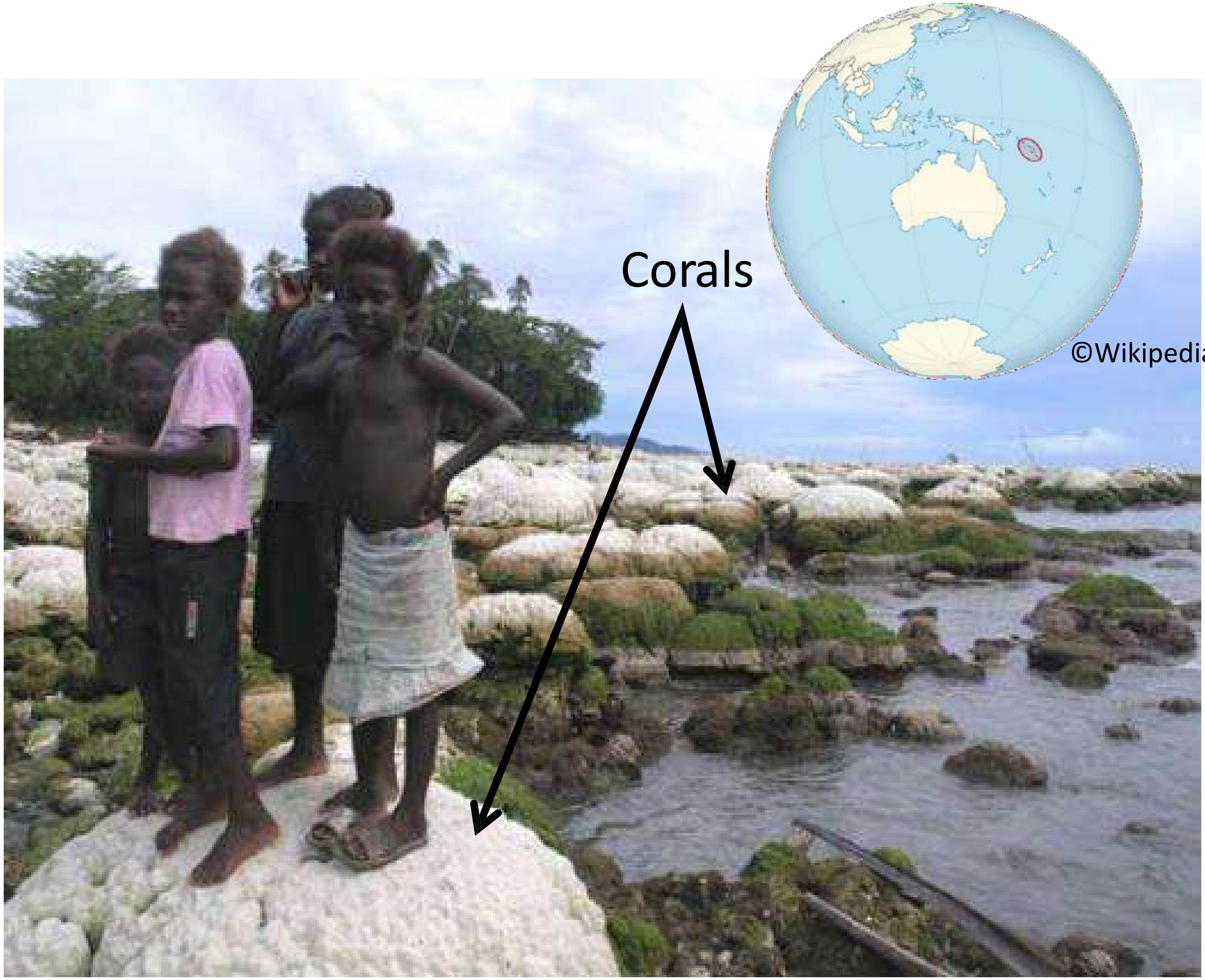
Local change in sea level related to up/down movements of the land

Influence of up & down land movements



- Human-induced
- Natural (earthquakes)

Illustration of a relative sea level fall caused by upward land movement



Sea level appears to have fallen

Actually, it is the land that has been raised

❼ 2007 M8.1 Solomon Islands earthquake raised land by 1-3 m

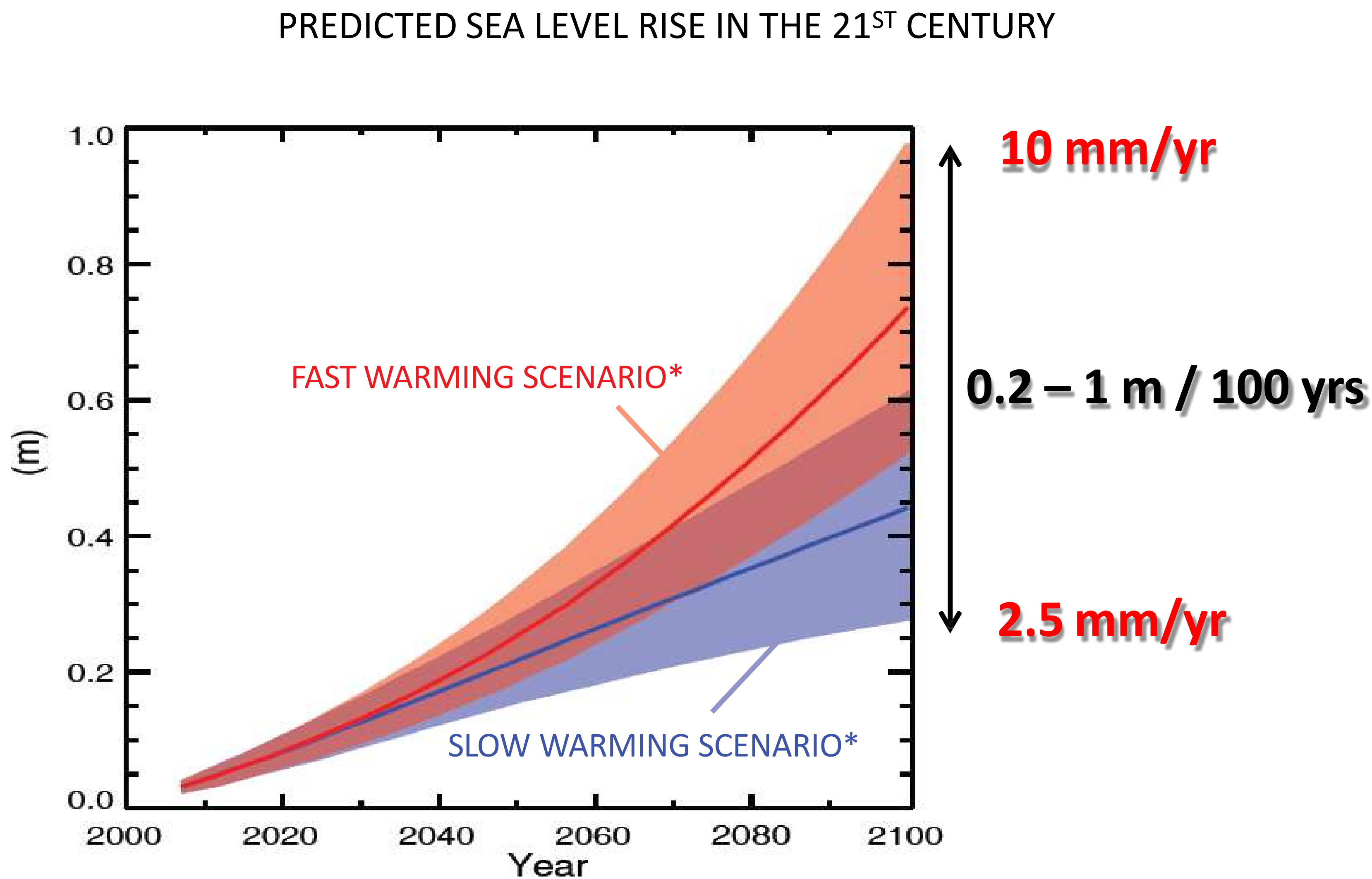
Image credit: Albert et al. (2007), Coral Reef

- How fast can sea level rise?

  - Today sea level is rising at a rate of 3.5 mm/year

    …but how fast will it rise in the future?

Predicted sea level rise



* Depend on how much greenhouse gases (mainly CO_2) humanity will emit

https://www.eea.europa.eu/data-and-maps/figures/projected-change-of-global-mean 2021/7/2 *Data source: IPCC (2013)*

Has sea level ever been changing that fast in the past?

How does the current sea level rise compare with sea level change in the past?

Is sea level capable of rising even faster?

To answer these questions, we need to study the history of sea level change

- Reconstructing past sea level change

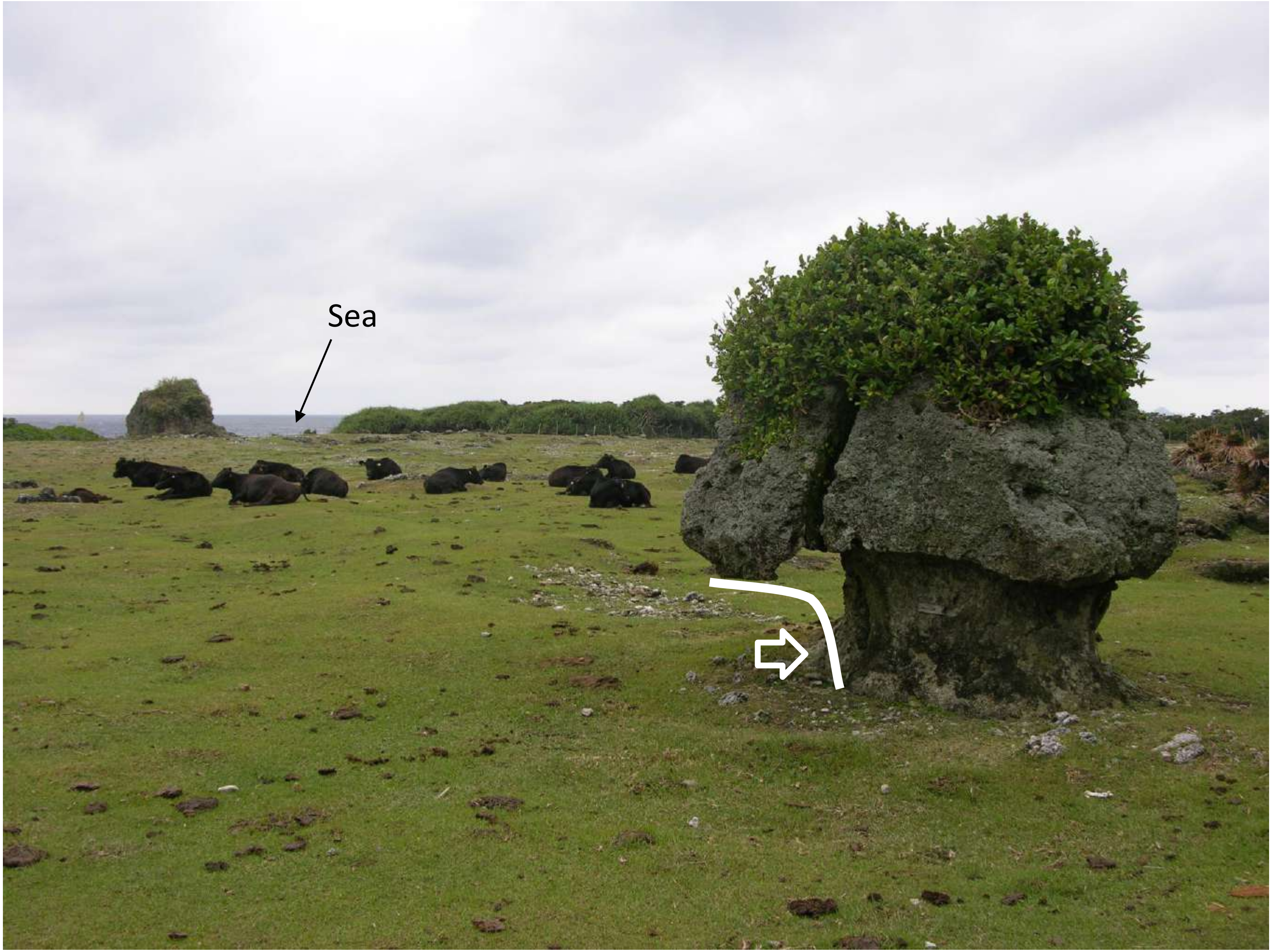
What do we need?

- Features of the landscape that can be linked to sea level (sea level indicators) and that can resist the passing of time to be studied by geologists

Examples: marine notches, coral reefs

marine notches as sea level indicator

Image credit: Pirazolli & Evelpidou (2013)


Sea

Coral reefs as sea level indicator

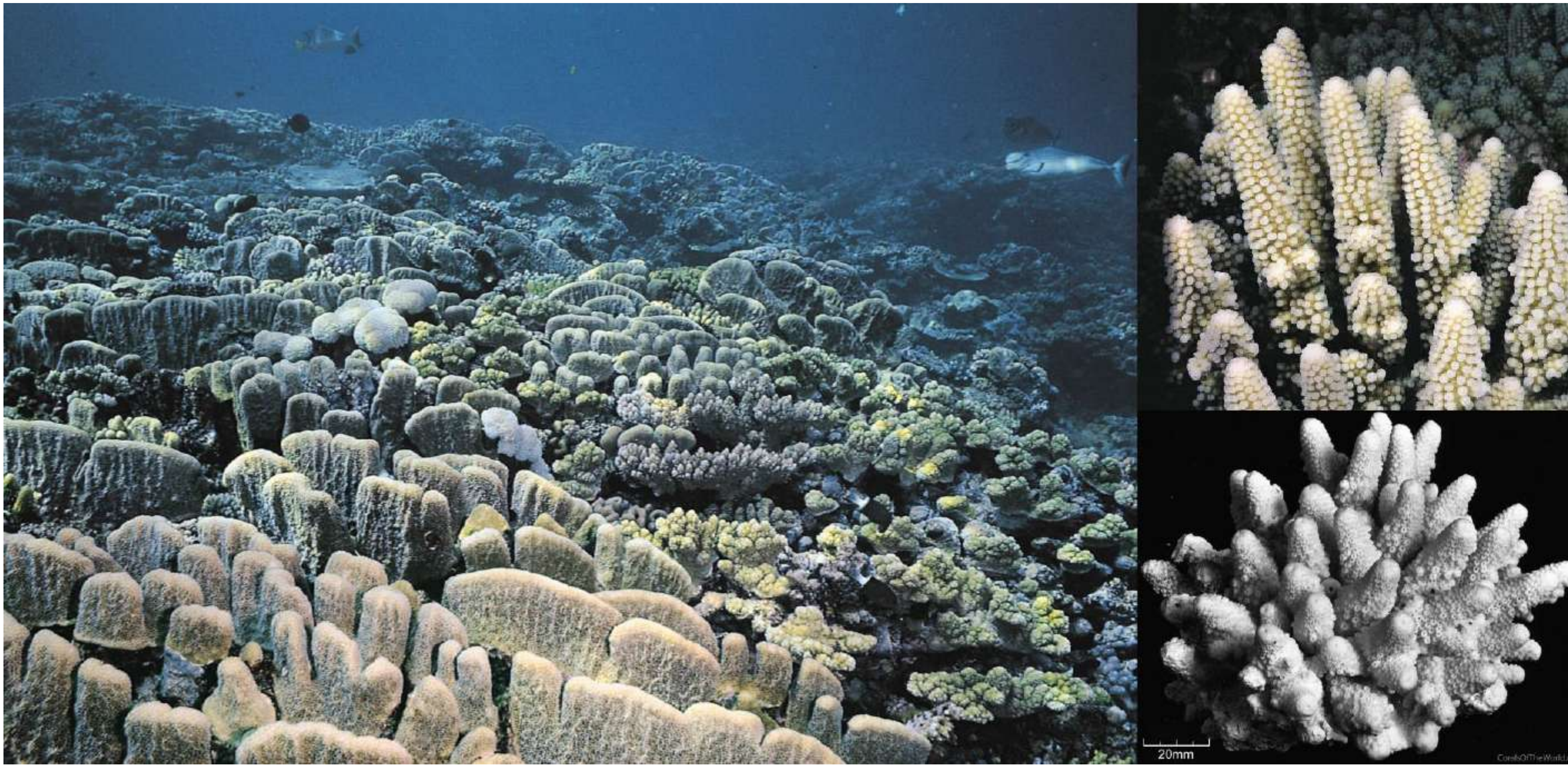
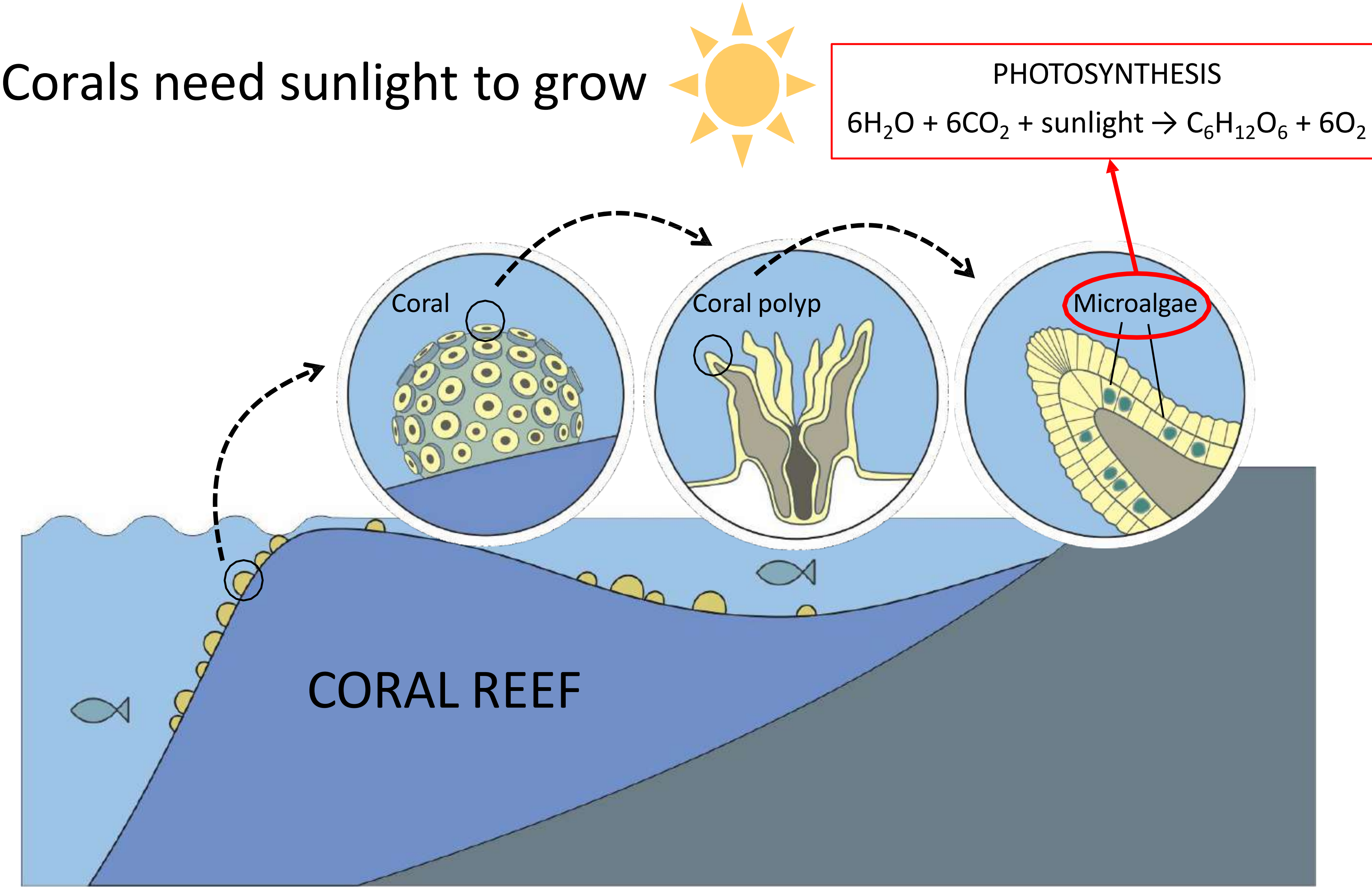
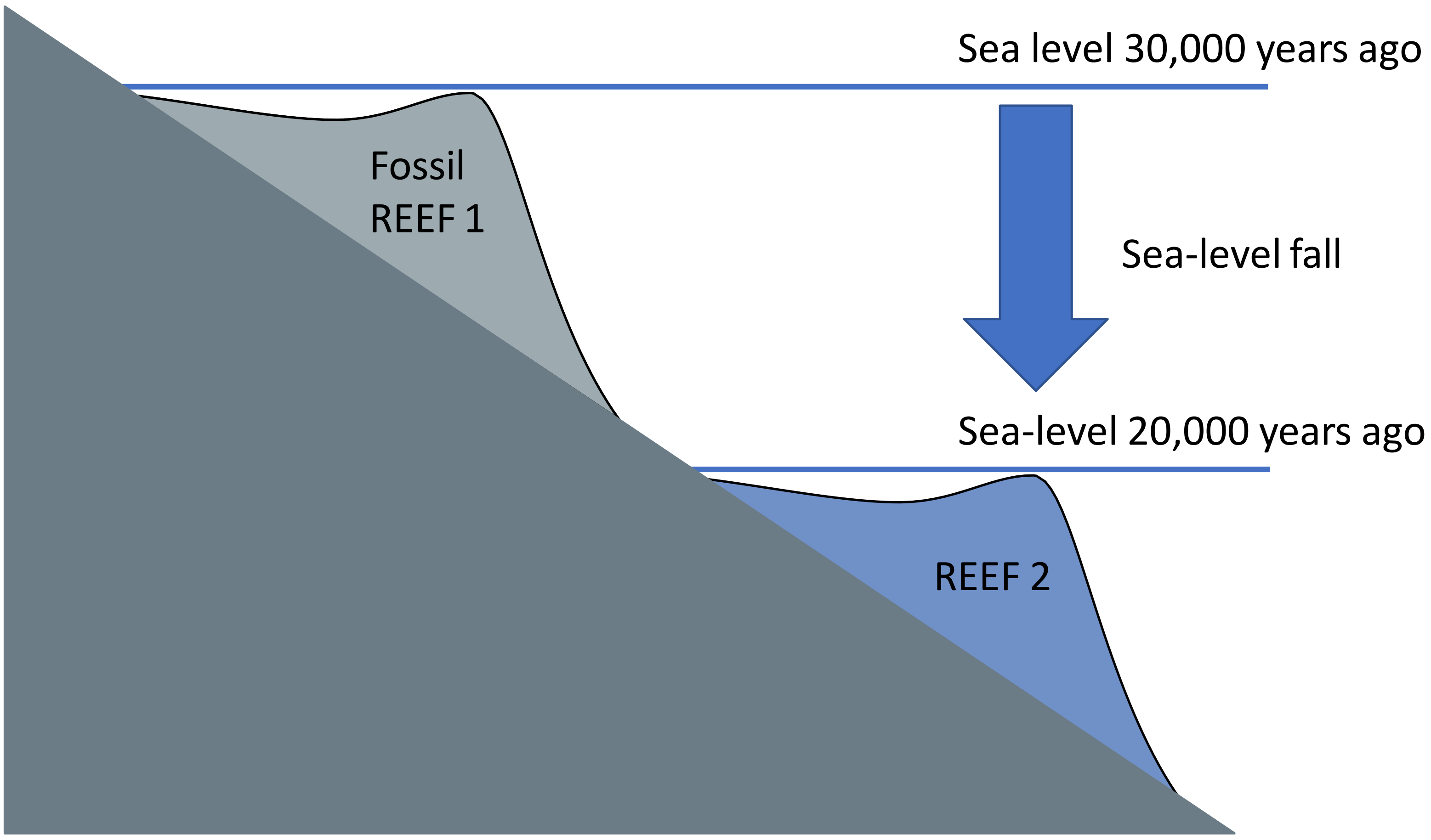


Image credit: http://www.coralsoftheworld.org/

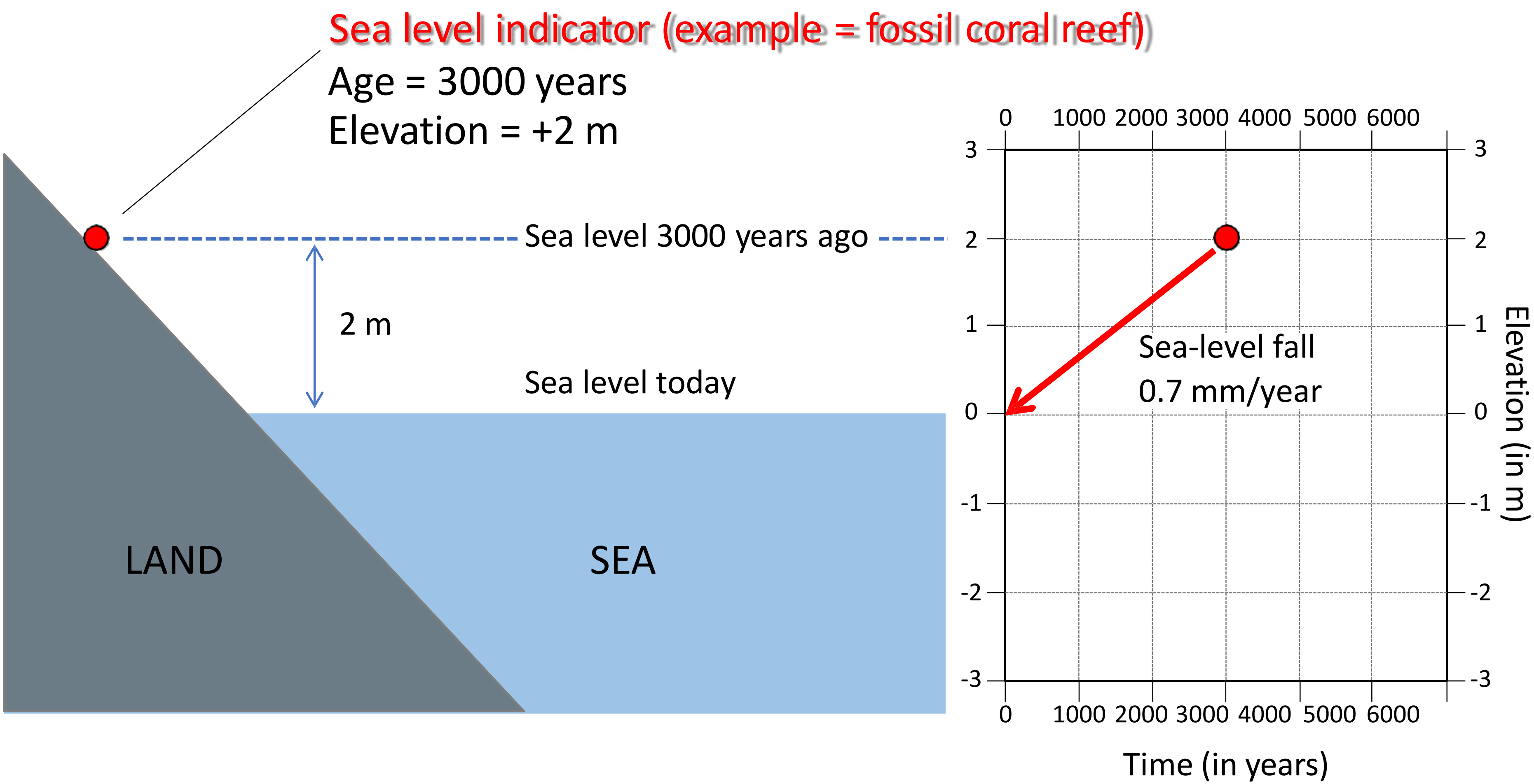
Corals need sunlight to grow



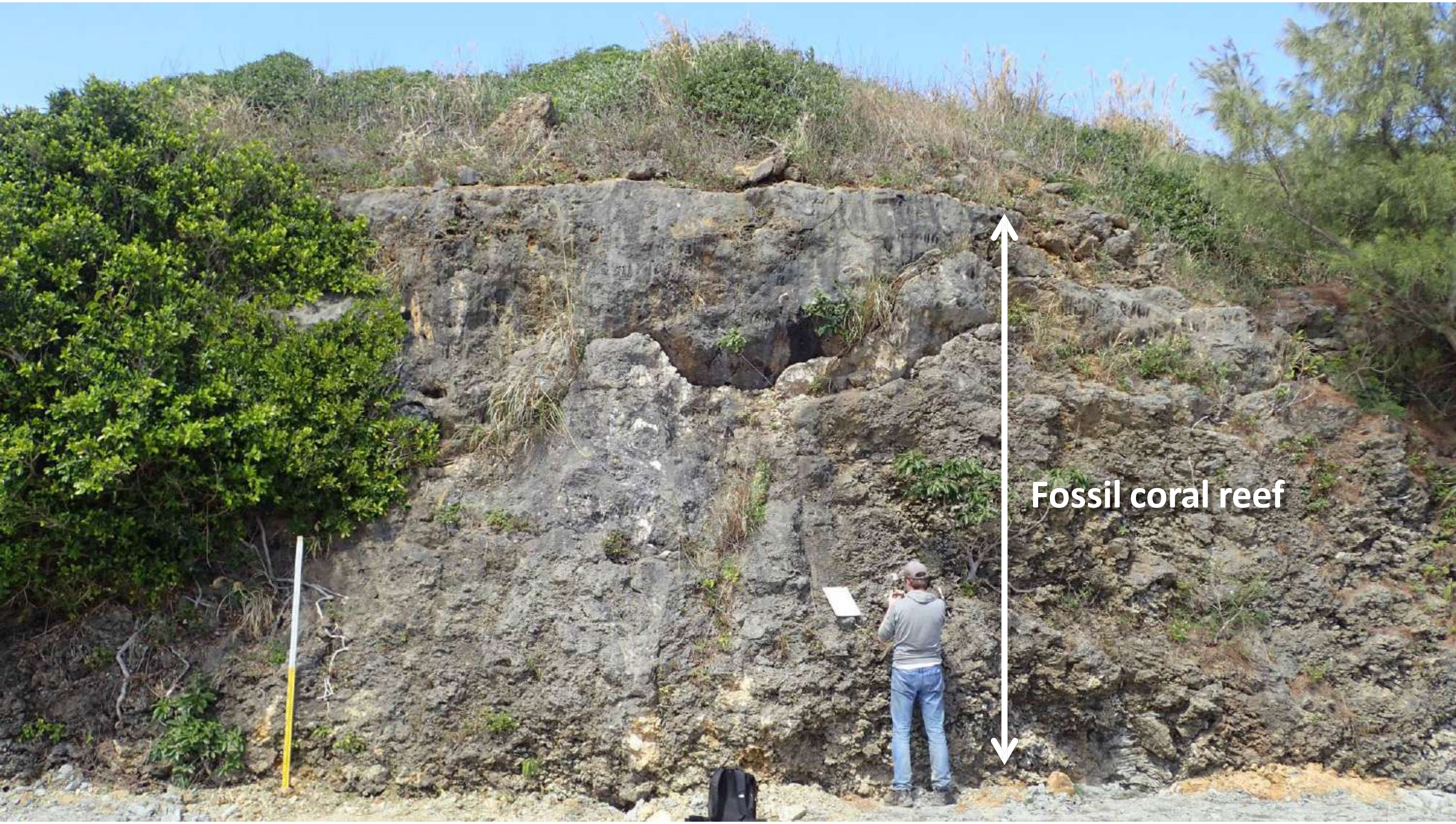
The position of coral reefs change with sea level



Method to reconstruct past sea level change

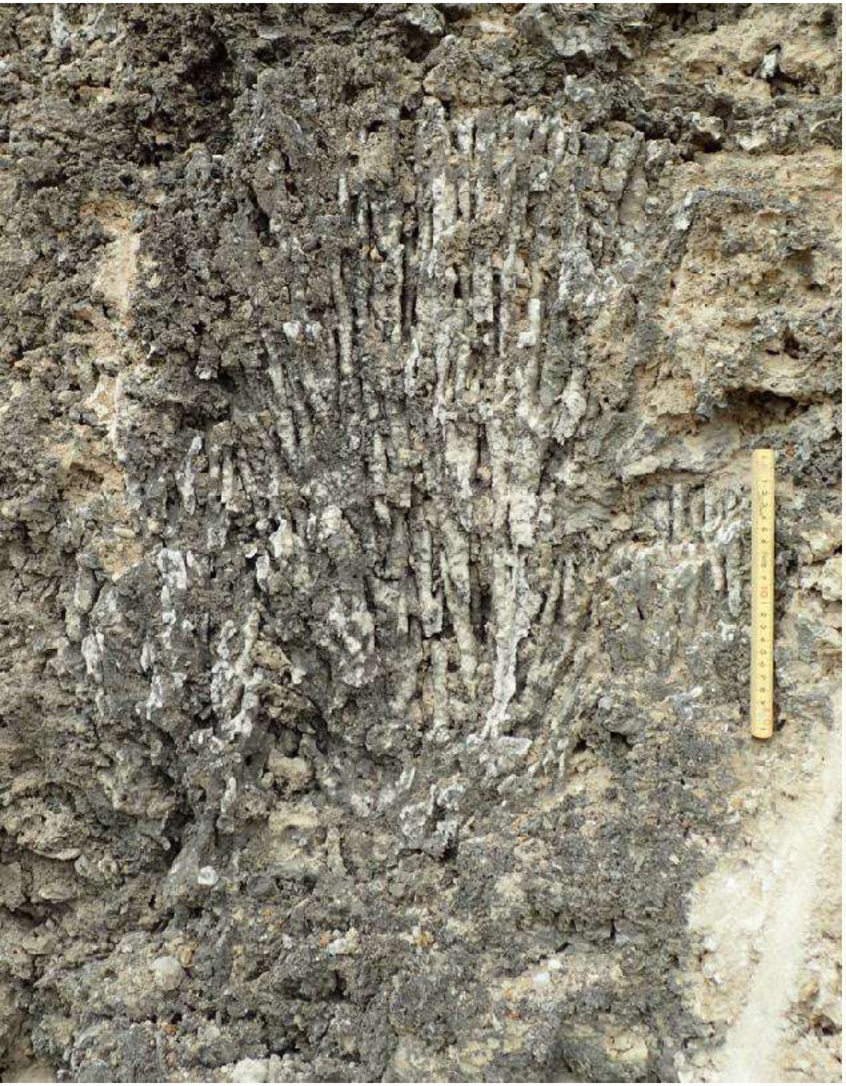


Fossil coral reefs - Okinawa



100,000-200,000 years old

Fossil coral reefs - Okinawa



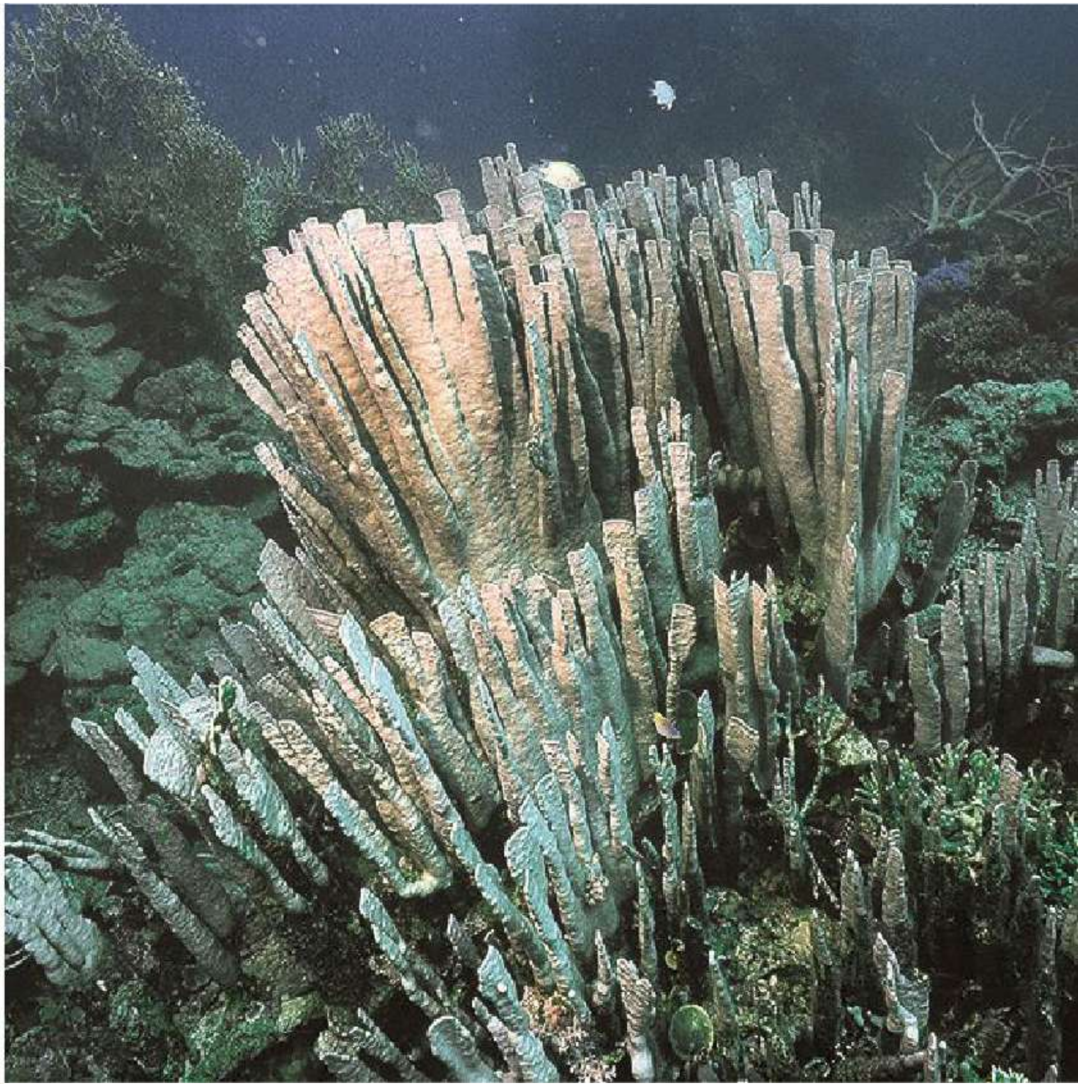
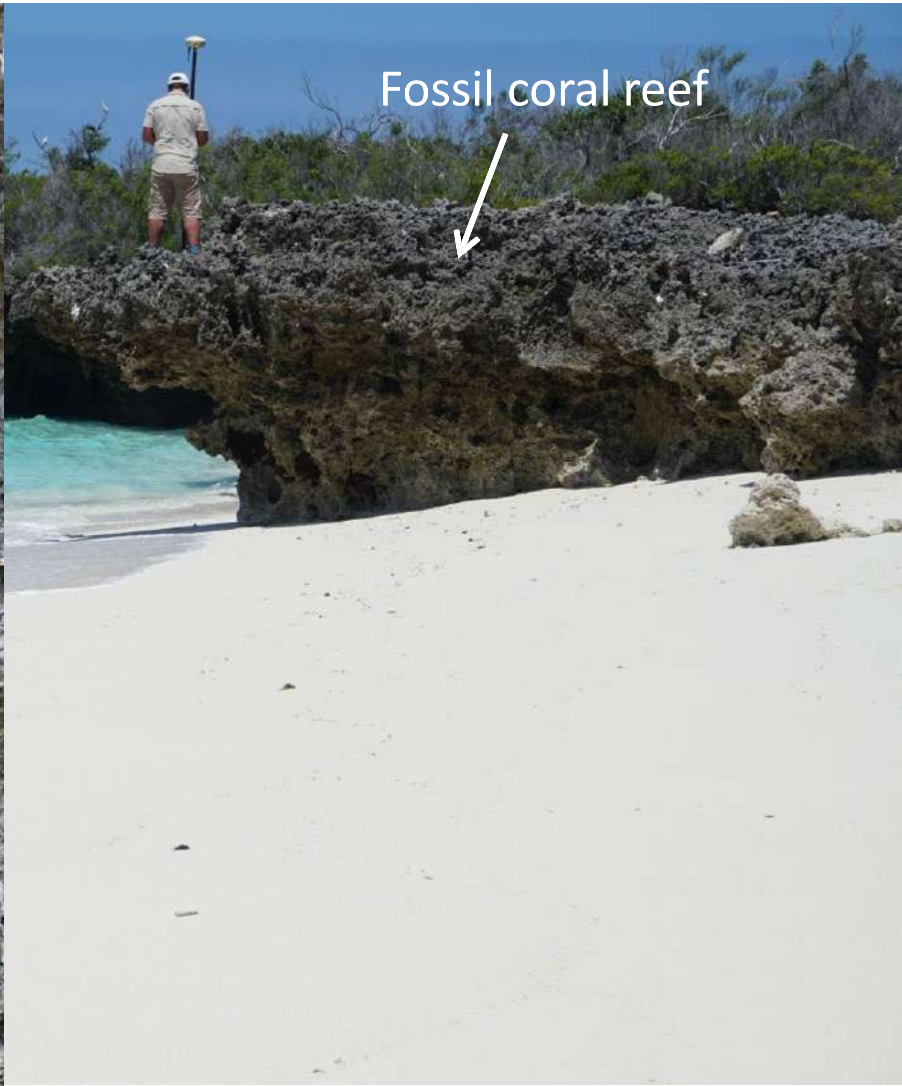


Image credit: Marc Humblet (left); http://www.coralsoftheworld.org/ (right)

Fossil coral reefs - The Seychelles Isl.

100,000-200,000 years old

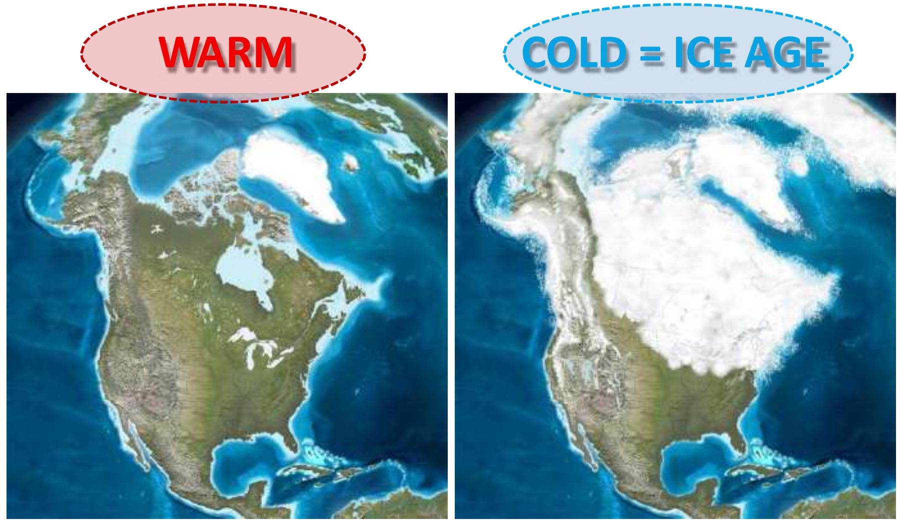


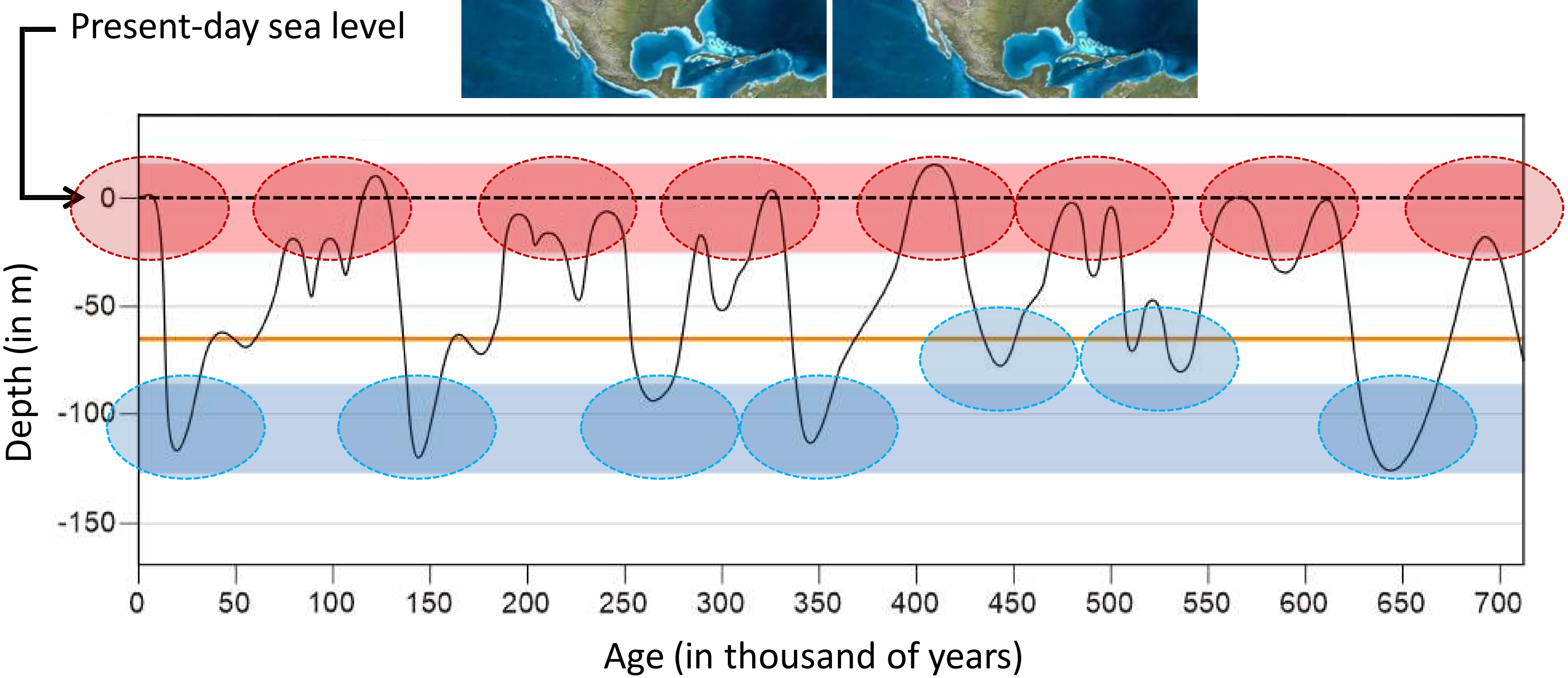
Fossil coral reefs - The Seychelles Isl.

image credit: Nadine Hallmann

Past sea level change

Photo: Dr. Ron Blakey, Paleogeography and Geologic History of North America





Data source: https://www.dur.ac.uk/, Lisiecky & Raimo (2005)

Case study:

The Great Barrier Reef of Australia and the history of sea-level and climate over the past 30,000 years

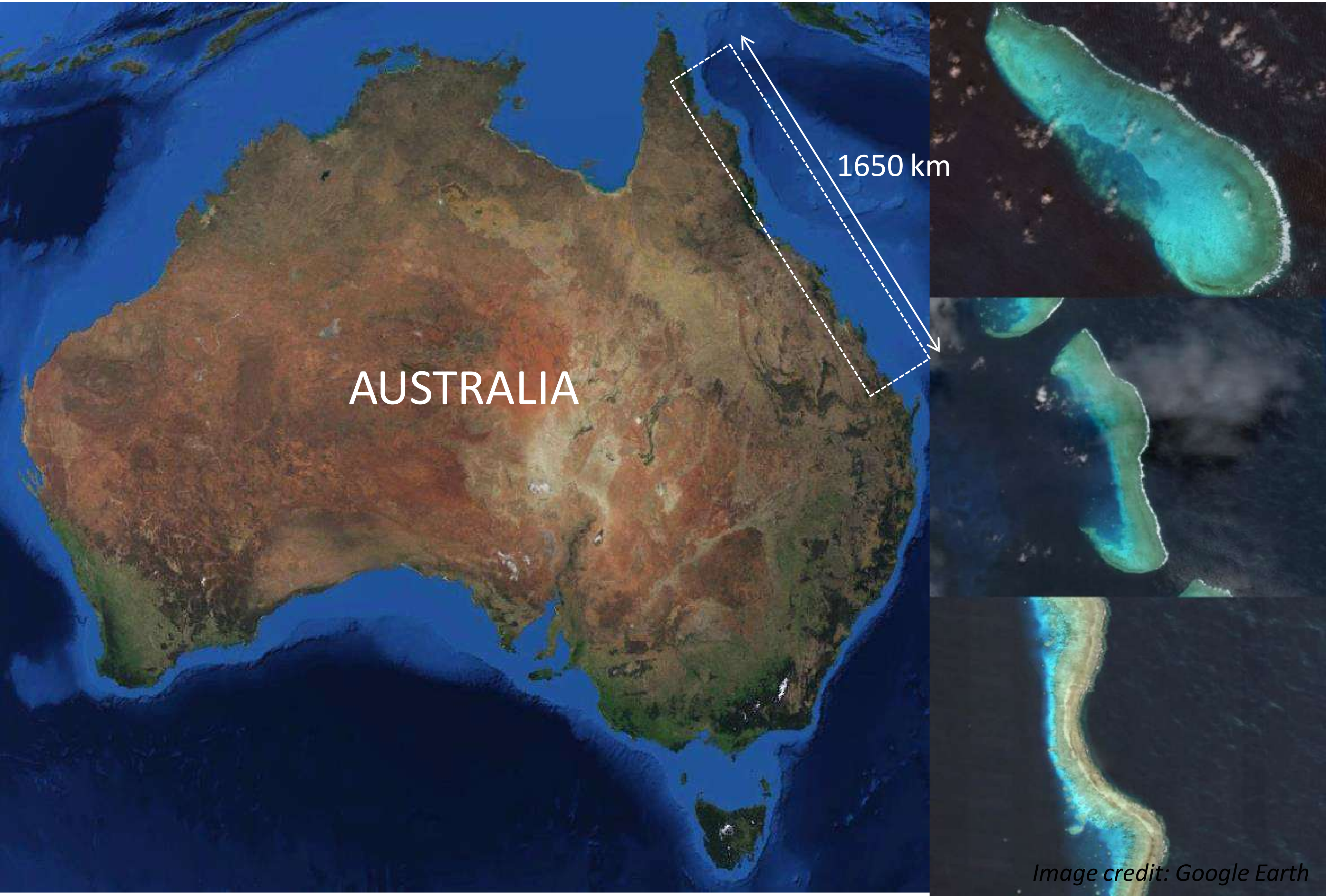
- Study case: Great Barrier Reef of Australia

OBJECTIVES:

- Reconstruct sea level change since last Ice Age

- Reconstruct the history of the Great Barrier Reef

The Great Barrier Reef of Australia



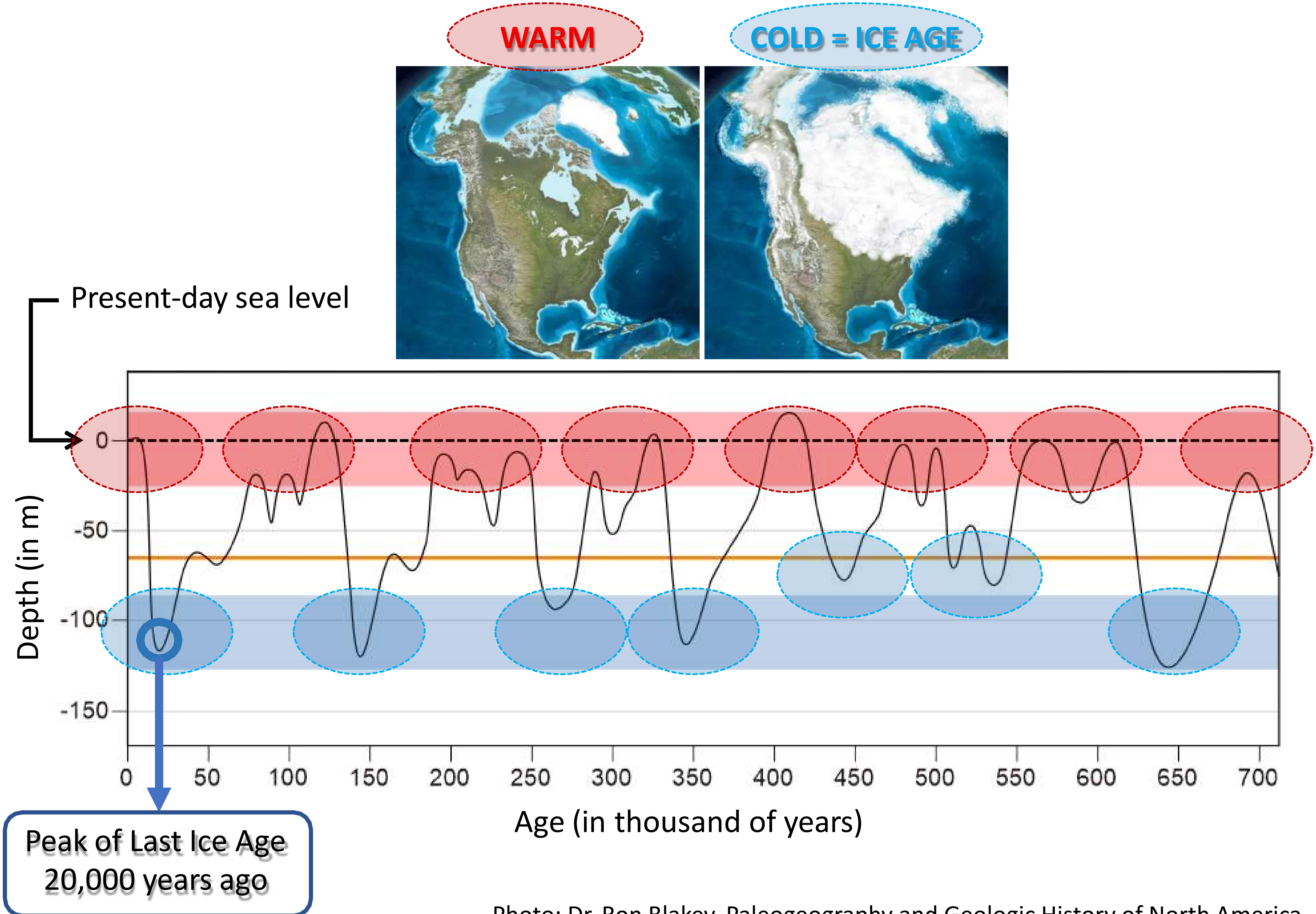
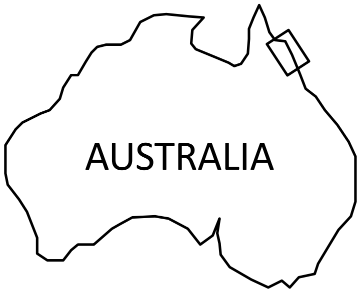


Photo: Dr. Ron Blakey, Paleogeography and Geologic History of North America
Data source: https://www.dur.ac.uk/, Lisiecky & Raimo (2005)

Were there coral reefs during the Last Ice Age?

If they were present, where should we look for their fossil remains today?



Today

0 m

10,000 years ago

-40 m

20,000 years ago

-120 m

image credit : Google Earth

©Google Earth

image credit : https://www.jamstec.go.jp/e/about/equipment/ships/kaiko7000.html 2021/7/2

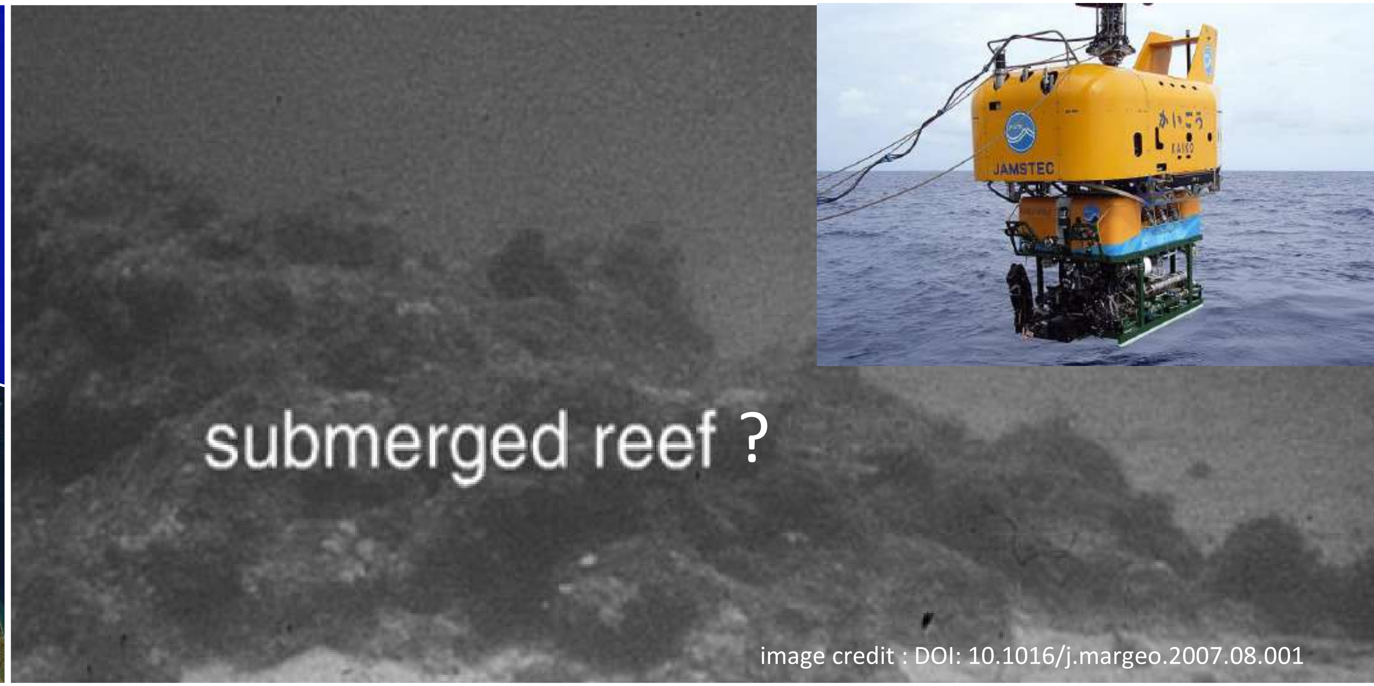
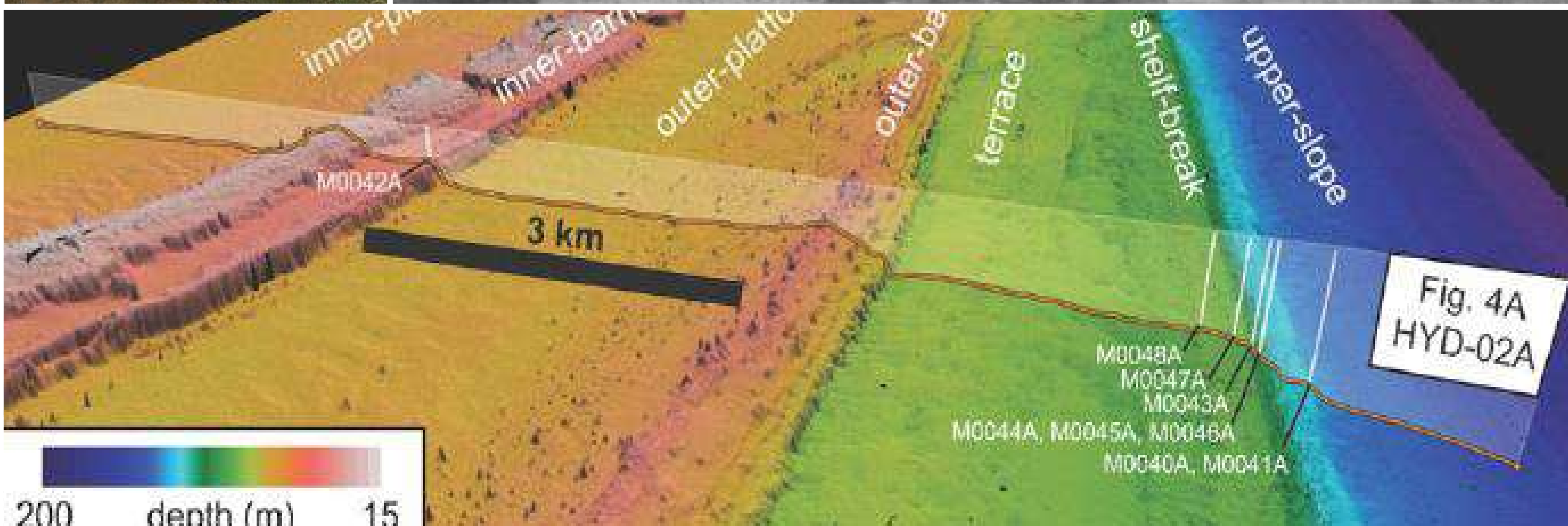
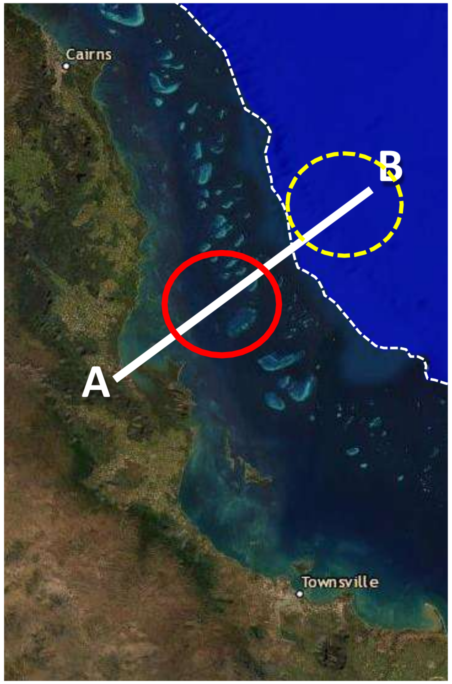


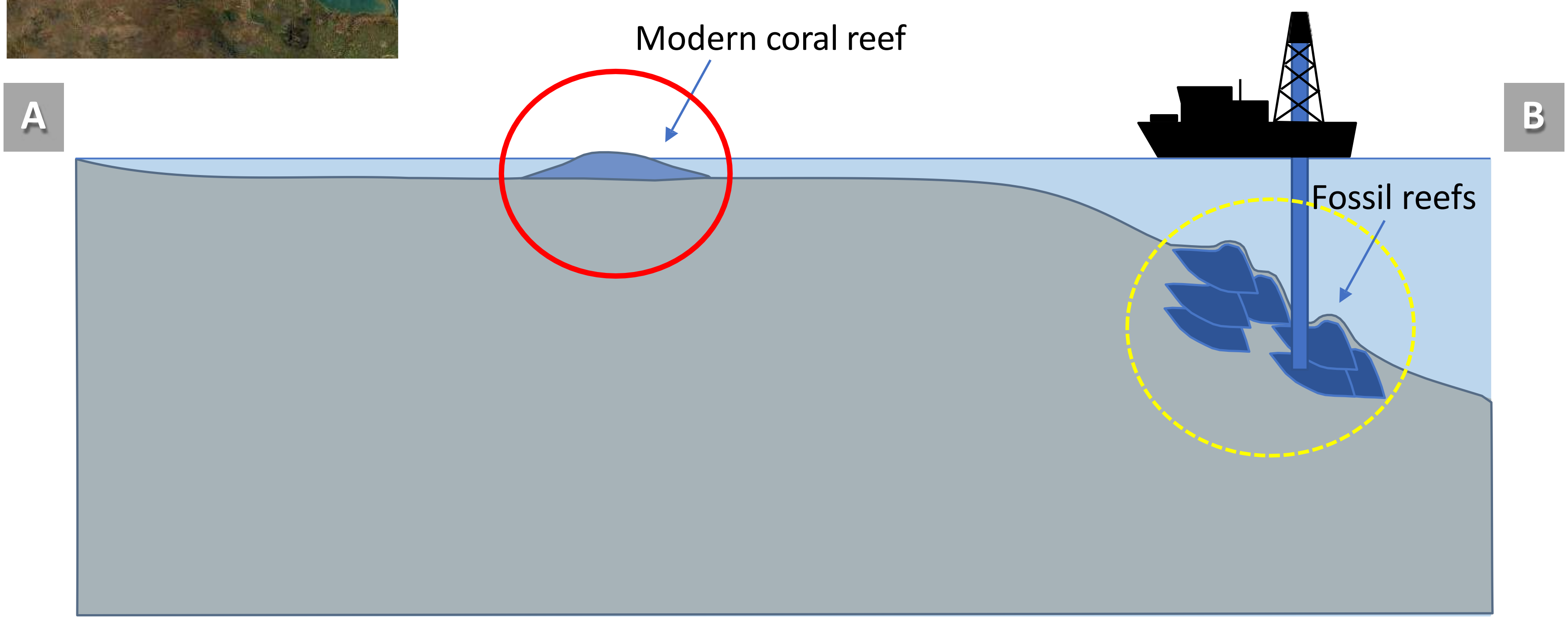
image credit : DOI: 10.1016/j.margeo.2007.08.001



Data source: Hinestrosa et al. (2016); JAMSTEC

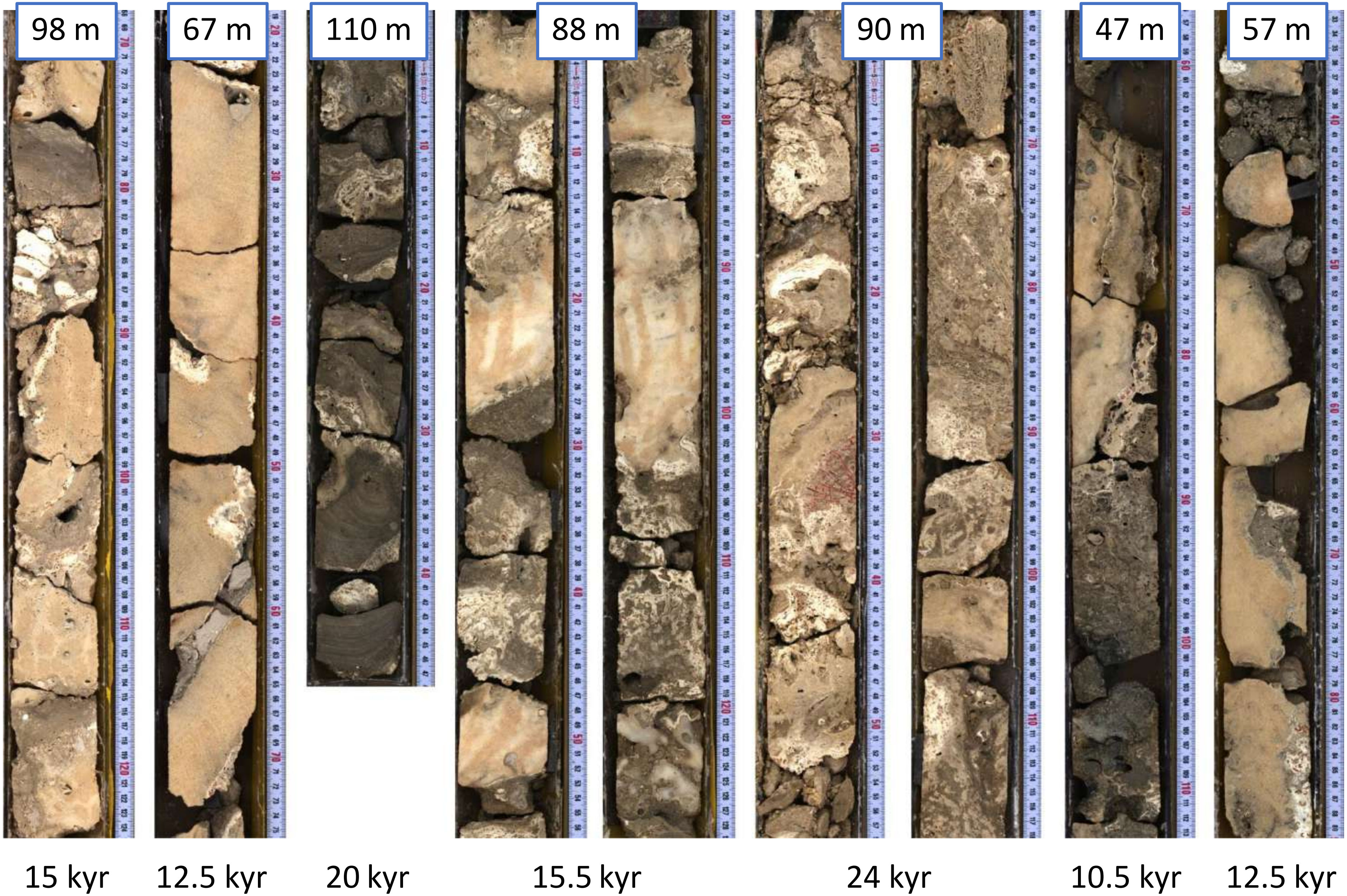
How do we take samples?





IODP (Integrated Ocean Drilling Program) Expedition 325

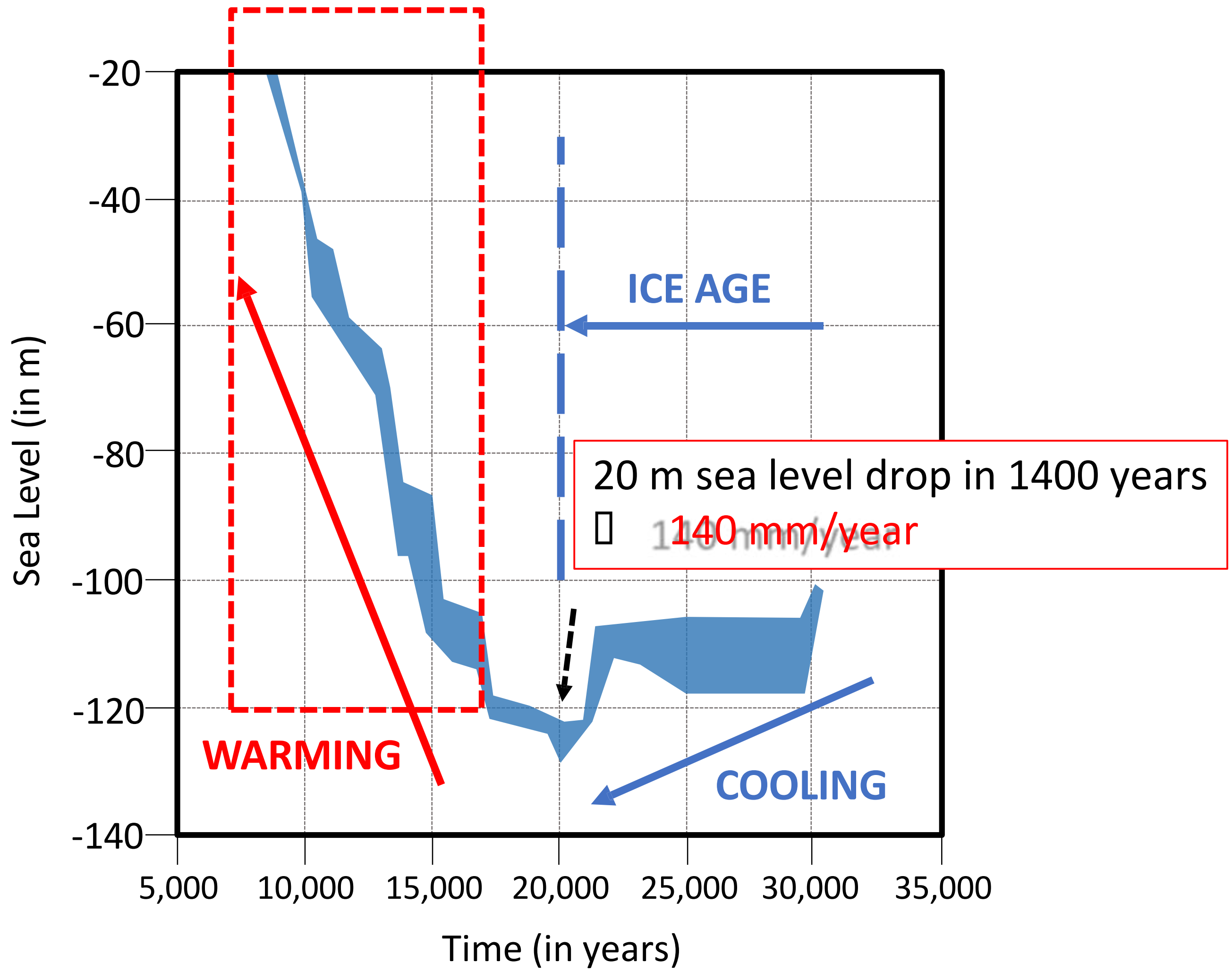
Image credit: IODP



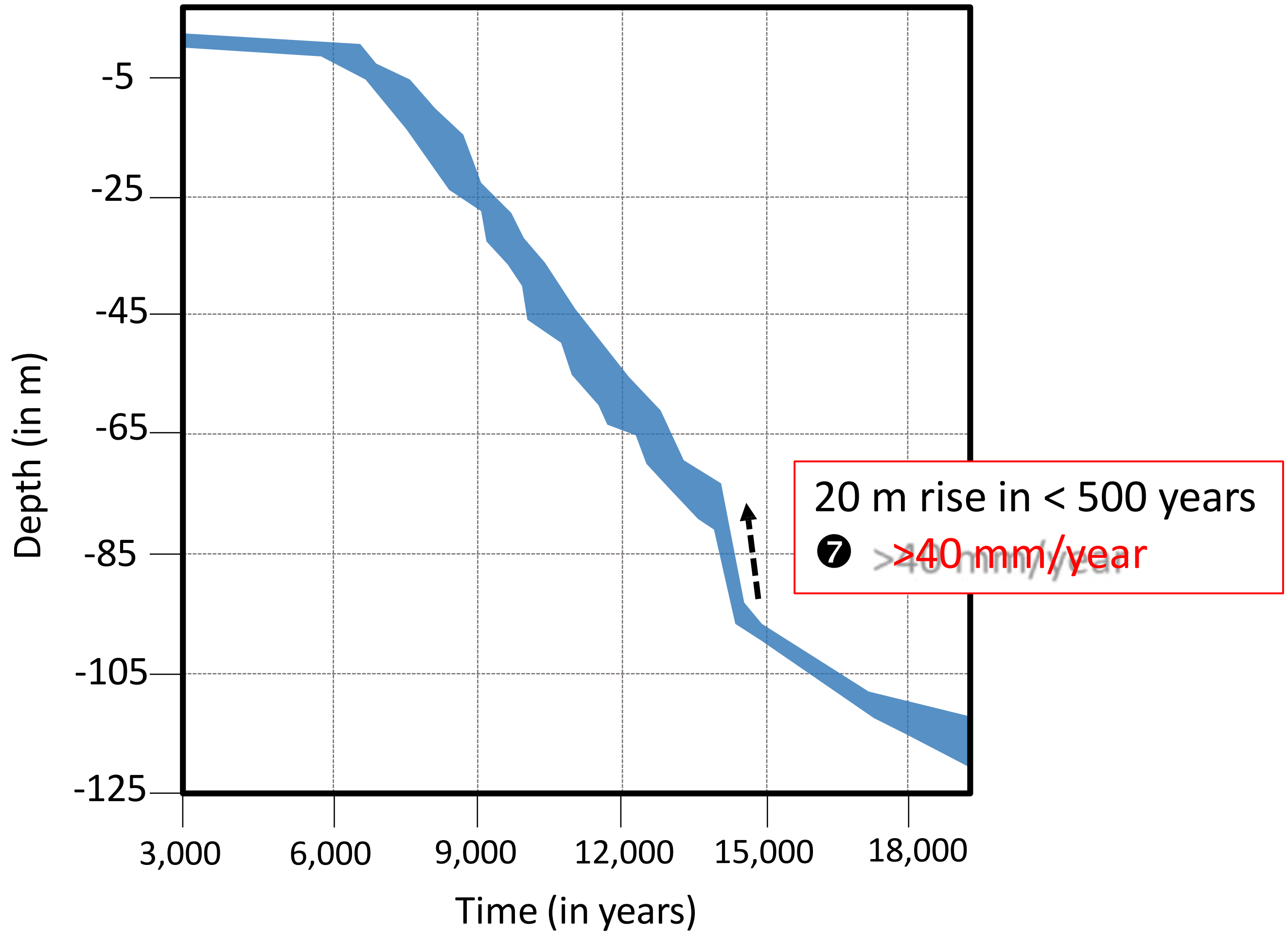
1 kyr = 1000 years

Image credit: IODP

Results



Data source: Yokoyama et al. (2018)

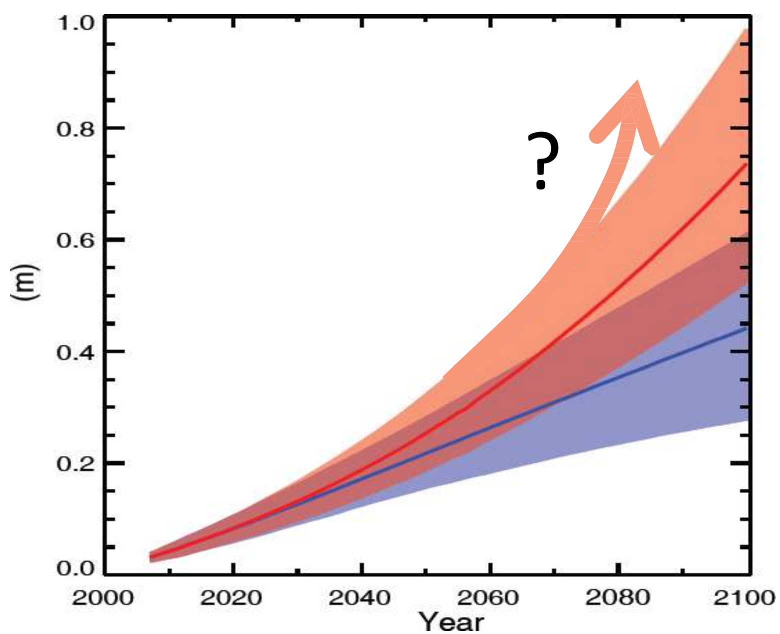


Data source: Deschamps et al. (2012)

What do we learn from these results?

- Models predicting future sea-level rise produce rates of 2.5 to 10 mm/year by the end of the century.

- Study of fossil reefs show that sea level can change at rates several times higher than those predicted (up to 40 mm/year for sea level rise).



Is sea level capable of rising that fast in the future?

❼ We need to investigate mechanisms that generate such fast sea level rise

Data source: IPCC (2013)

The scientific method and the communication of scientific results

Outline of the scientific method

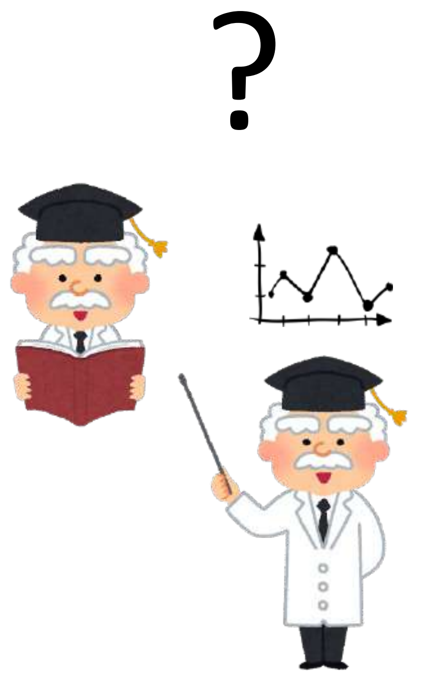
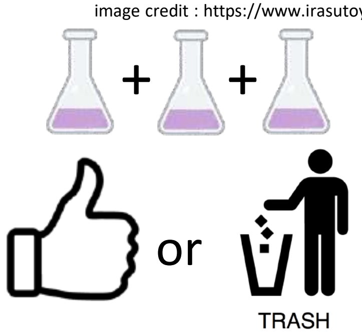


image credit : https://www.irasutoya.com/

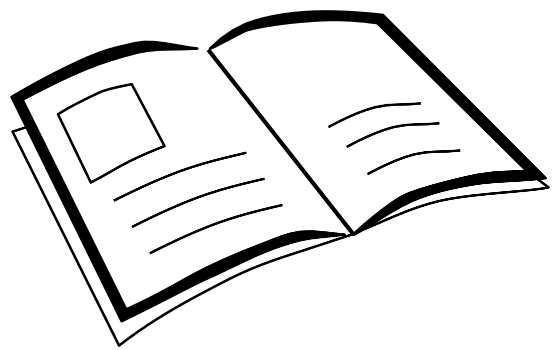


- Define a problem to solve
- Collect data to solve the problem
  (observations, experiments)
- Analyze data (to extract useful information)
- Formulate a hypothesis (tentative explanation)
- Test your hypothesis against new data
- Reject / modify / keep as it is
  (depending on the new results obtained)

When scientists work on something, they want to share the results of their work with others.

↓

Publication in a scientific journal



Scientific journals

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Generalist

nature

Sience

PNAS

Proceedings of the **N**ational **A**cademy of **S**ciences of the United States of America

PLOS ONE

Open access

Free online

Specialized

Economics

ECONOMETaRICA

Medicine

THE LANCET

Experimental biology

Cell

American Journal of Potato Research

Paleontology

Lethaia

Biology

Current Biology

Popular science magazines

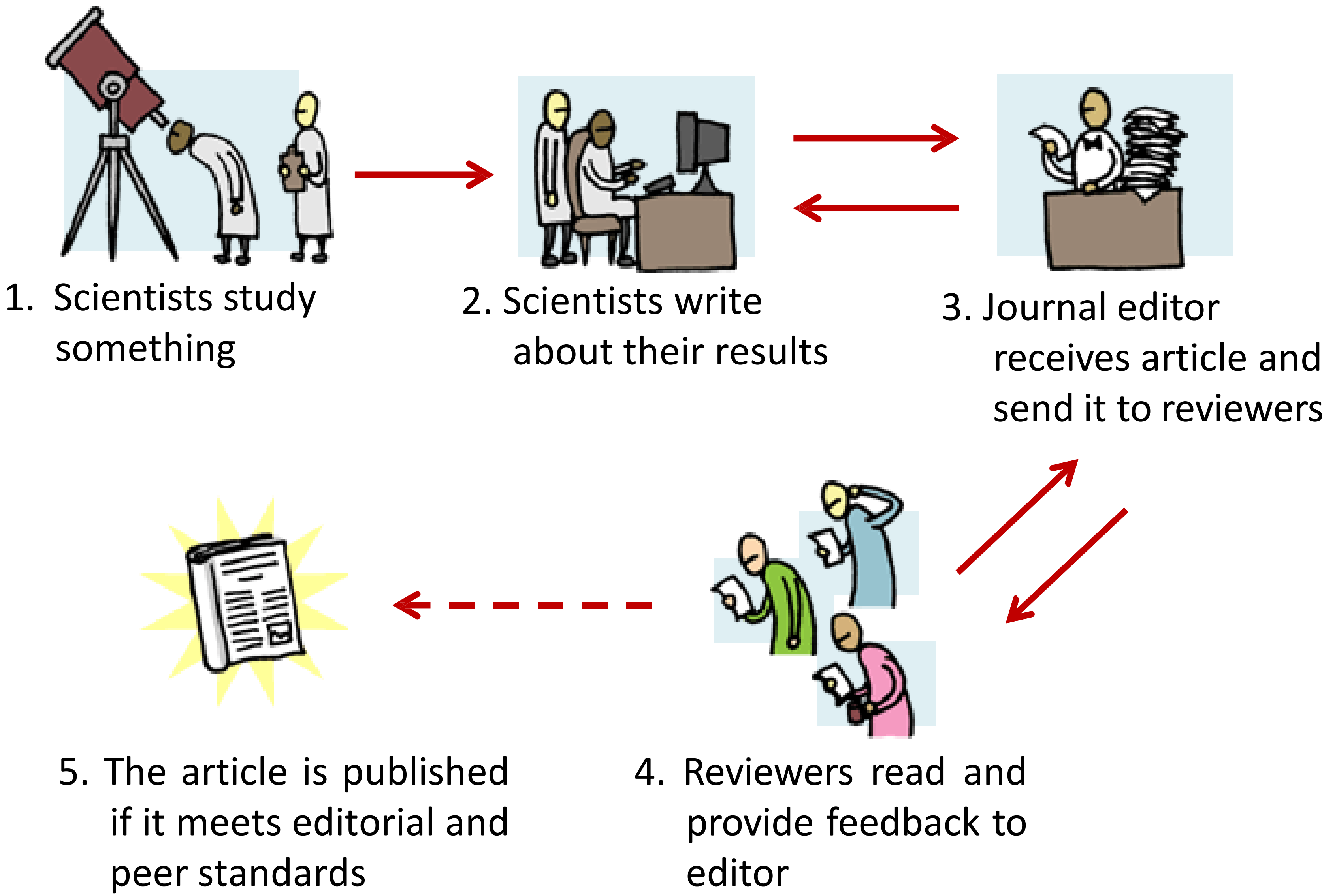
SCIENTIFIC AMERICAN

NewScientist

physicstoday

SCIENCE.fr

The peer review process



http://undsci.berkeley.edu/article/howscienceworks_16

LETTER

https://doi.org/10.1038/s41586-018-0335-4

Rapid glaciation and a two-step sea level plunge into the Last Glacial Maximum

Yusuke Yokoyama[1,2,3*], Tezer M. Esat[4,5], William G. Thompson[6], Alexander L. Thomas[7], Jody M. Webster[8], Yosuke Miyairi[1], Chikako Sawada[1], Takahiro Aze[1], Hiroyuki Matsuzaki[9], Jun'ichi Okuno[10], Stewart Fallon[4], Juan-Carlos Braga[11], Marc Humblet[12], Yasufumi Iryu[13], Donald C. Potts[14], Kazuhiko Fujita[15], Atsushi Suzuki[16] & Hironobu Kan[17]

The approximately 10,000-year-long Last Glacial Maximum, before the termination of the last ice age, was the coldest period in Earth's recent climate history[1]. Relative to the Holocene epoch, atmospheric carbon dioxide was about 100 parts per million lower and tropical sea surface temperatures were about 3 to 5 degrees Celsius lower[2,3]. The Last Glacial Maximum began when global mean sea level (GMSL) abruptly dropped by about 40 metres around 31,000 years ago[4] and was followed by about 10,000 years of rapid deglaciation into the Holocene[1]. The masses of the melting polar ice sheets and the change in ocean volume, and hence in GMSL, are primary constraints for climate models constructed to describe the transition between the Last Glacial Maximum and the Holocene, and future changes; but the rate, timing and magnitude of this transition remain uncertain. Here we show that sea level at the shelf edge of the Great Barrier Reef dropped by around 20 metres between 21,900 and 20,500 years ago, to −118 metres relative to the modern level. Our findings are based

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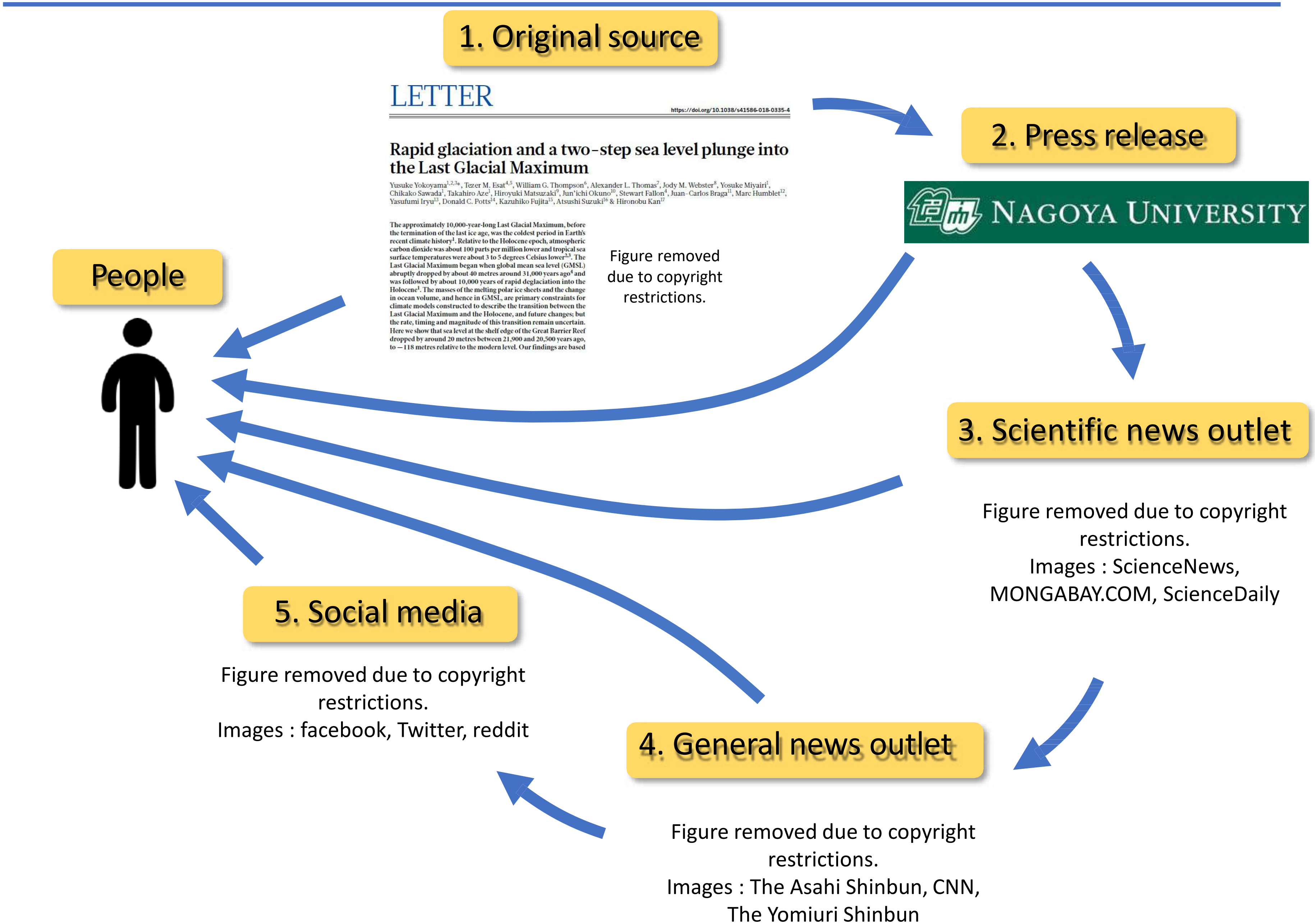
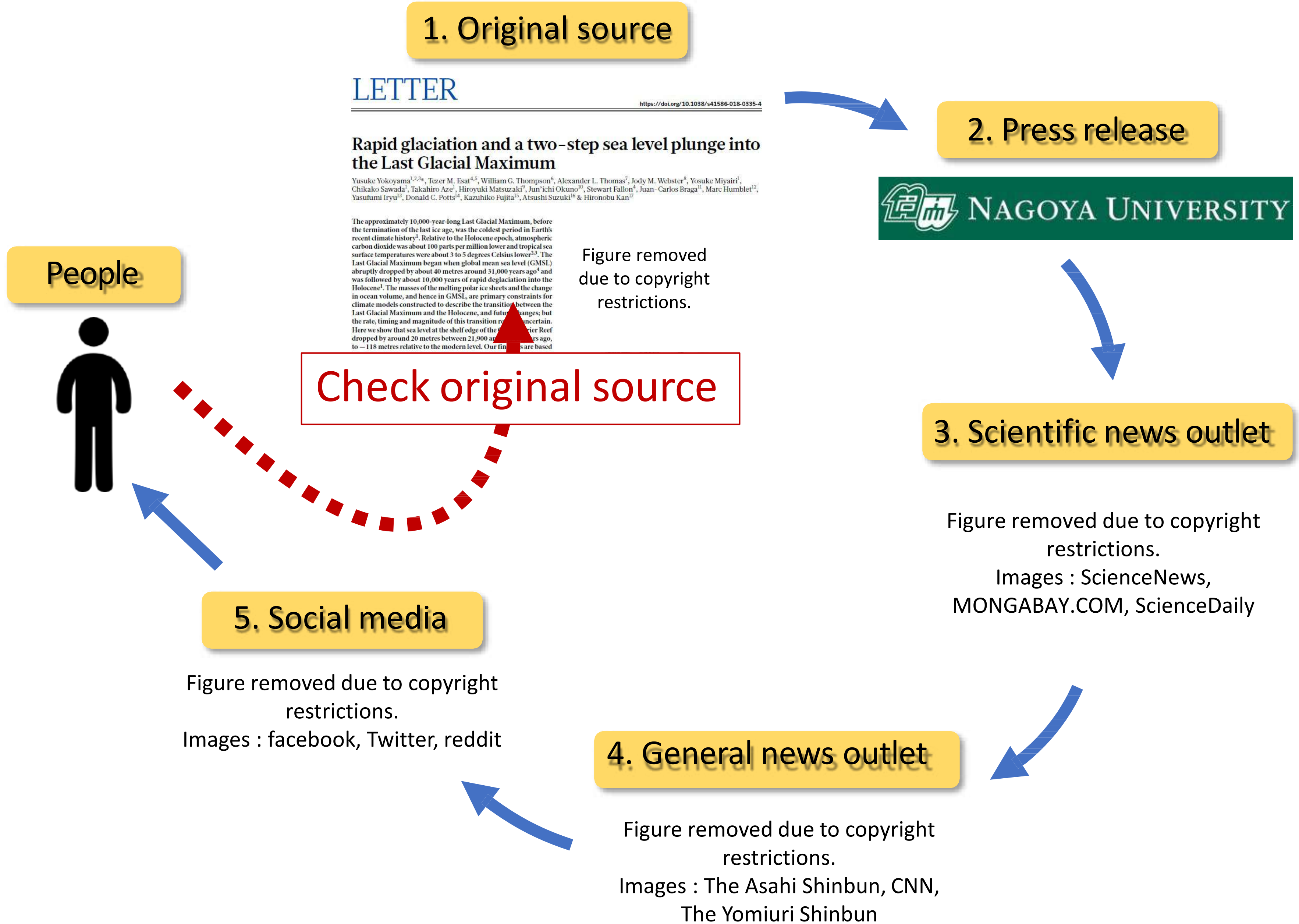
Information flow



Information flow



In the Internet Age, in which we are confronted to a flood of information on a regular basis, it is necessary to analyze information carefully and verify its source in order to take correct decisions

Thank you for your attention!