

# High Resolution Sr Records and Late Pleistocene Sea Level Highstands in a Periplatform Sediment Drift (Inner Sea, Republic of Maldives)\*

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## Abstract

High resolution cyclic records of Sr concentrations in the upper 12-14 m of a muddy periplatform drift in the Maldives Inner Sea (cores M74-4-1120, -1143, and -1144 in about 500 m of water depth) reveal high-frequency sea level oscillations during late Pleistocene highstands. Export variations of bank-top produced fine aragonite to adjacent slopes and basin floor faithfully record bank-top flooding and exposure, and therefore sea level.

Here we present the results of a new analytical method based on Sr concentrations, as a proxy for bank-derived fine aragonite content, measured downcore using a X-ray Fluorescence (XRF) Core Scanner. The three piston cores were analyzed for Sr concentration at 1 cm spaced intervals. Large cations, such as Sr, are preferentially substituted for Ca in orthorhombic aragonite, whereas small cations such as Mg are preferentially substituted for Ca in rhombohedral calcite. Based on a calibration curve in core M74-4-1143, Sr concentrations become a valuable proxy for bank-derived fine aragonite content. This new methodology reveals that observed Sr concentration cyclic downcore variations can be correlated to the marine and ice sheet oxygen isotope records and sea level fluctuations at Milankovitch frequencies in addition to millennial frequencies during interglacial stages.

Downcore variations of Sr concentrations in cores 1144 and 1120 mimic well the Lisiecki and Raymo (LR) (2005) stack benthic O isotope record down to the end of Marine Isotope Stage (MIS) 11 and to the beginning of MIS 15, respectively. Planktic O isotope records at 10 to 5 cm spaced intervals are currently being produced in both cores as an assurance that the cyclic downcore variations of Sr concentration are in phase with the LR2005 O isotope stack.

Core 74-4-1144 was scanned for Sr concentration at higher resolution (0.5 cm) for the full MIS 5 interval. Variations of Sr concentrations values at sub-Milankovitch millennial frequencies, since the MIS 5 e/d transition, appear to correlate well with the North GRIP Greenland O isotope ice record and the Red Sea high frequency sea level record. Preliminary interpretation of ultra high resolution Sr analyses during the end of MIS 5, therefore, suggest that sea level fluctuations, between 20 to 60 m below modern sea level, frequently exposed and flooded at millennial time scale the Maldives atoll lagoon floors and were faithfully recorded in the muddy periplatform drift in the Maldives Inner Sea.

### References

Belopolsky, A.V., and A.W. Droxler, 2004, Seismic expressions of prograding carbonate bank margins; middle Miocene, Maldives, Indian Ocean, *in* G.P. Eberli, J.L. Masferro, and J.F.R. Sarg, (eds.), Seismic imaging of carbonate reservoirs and systems: AAPG Memoir 81, p. 267-290.

Chappell, J., 2002, Sea level changes forced ice breakouts in the last glacial cycle; new results from coral terraces, *in* M. Sarnthein, and J.P. Kennett, (eds.), Decadal-to-millennial-scale climate variability: Quaternary Science Reviews: v. 21/10, p. 1229-1240.

Lisiecki, L.E., and M.E. Raymo, 2005, A Pliocene-Pleistocene stack of 57 globally distributed benthic  $\delta^{18}\text{O}$  records: Paleoceanography, v. 20, p. 1-17.

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# High Resolution Sr Records and Late Pleistocene Sea Level Highstands in a Periplatform Sediment Drift (Inner Sea, Republic of Maldives)

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Luedmann, Christian P. Huebscher**



**Long Beach , April 23, 2012**

# Key Research Objectives

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Interpretation of  
high resolution cyclic records of Sr concentrations,  
observed in periplatform ooze  
accumulating in the Maldives Inner Sea,  
as high frequency sea level oscillations  
during late Pleistocene

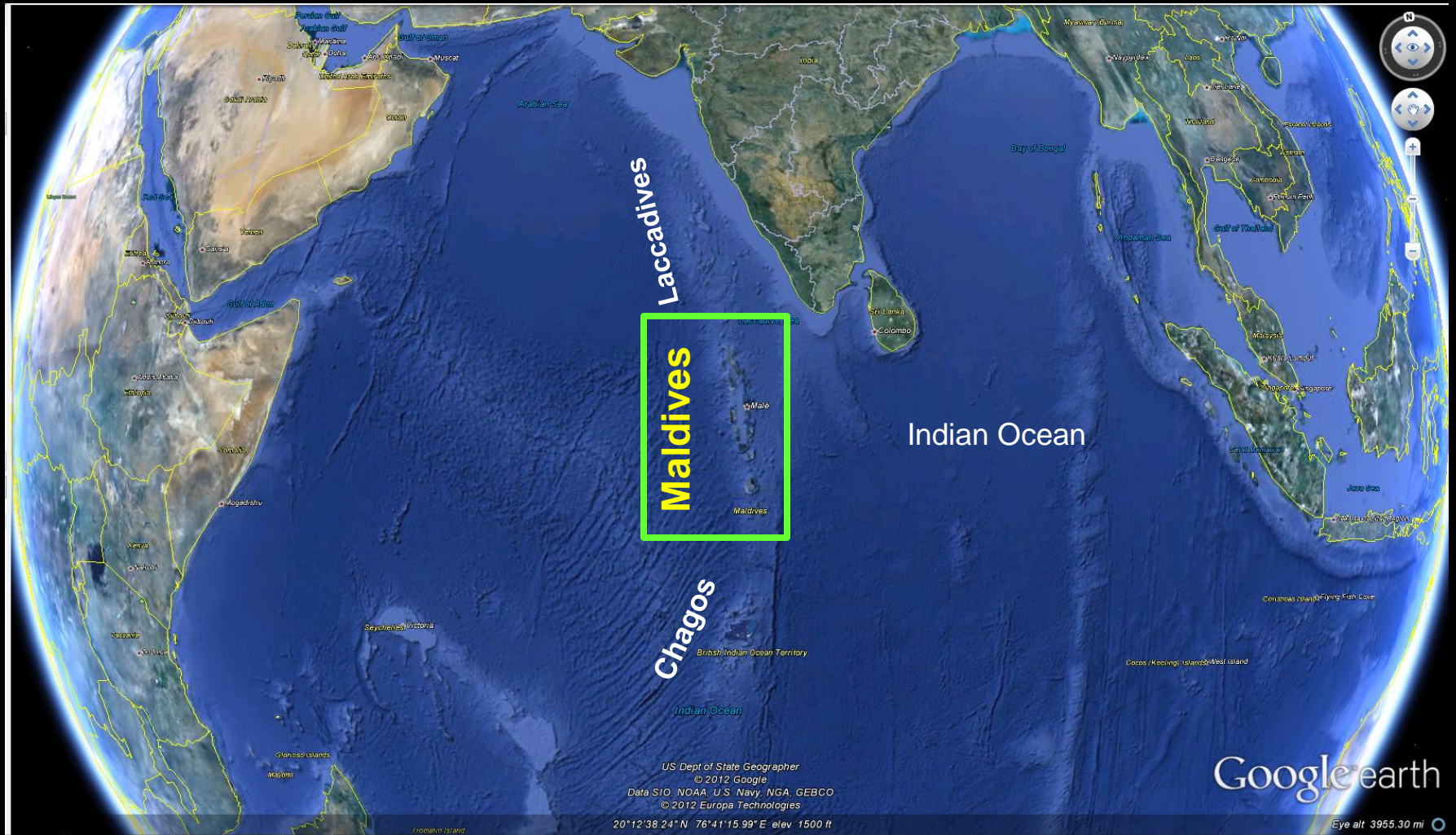
# Presentation Outline

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- Introduction
- Background
- Hypothesis
- Approach and Methodology
- Results and Possible Implications



# Introduction



- This carbonate system is formed on top of the Chagos-Laccadive ridge
- Located on the Indian Plate and therefore is tectonically stable

# Why The Maldives is an Unique Carbonate System?

## Maldives



- The modern part of this carbonate platform, 25 large atolls
- Very small parts of these atolls are exposed (1.5 m average elevation)
- 800-km long and 130 km wide
- 2-3 km thick and established 55 Ma
- This large carbonate isolated platform surrounded by deep water (2500 m)
- Inner Sea with water depths ranging between 200-500 m
- Water Depth of Atoll Lagoon between 40 and 60 m in Central Maldives Archipelago
- Maldives carbonate system an excellent recorder for sea level change, in particular during interglacial times

# Periplatform Carbonates

## Neritic Sources

Green algae (e.g., *Halimeda*)  
Corals (aragonite)  
Mollusks (aragonite)  
Benthic Foraminifers (HMC)  
Echinoderms (HMC), etc.



(Aragonite)

## Pelagic Sources

Coccolithophores (<63  $\mu\text{m}$ )  
Planktic Foraminifers (LMC) (> 63  $\mu\text{m}$ )  
Pteropods (aragonite) (>63  $\mu\text{m}$ )



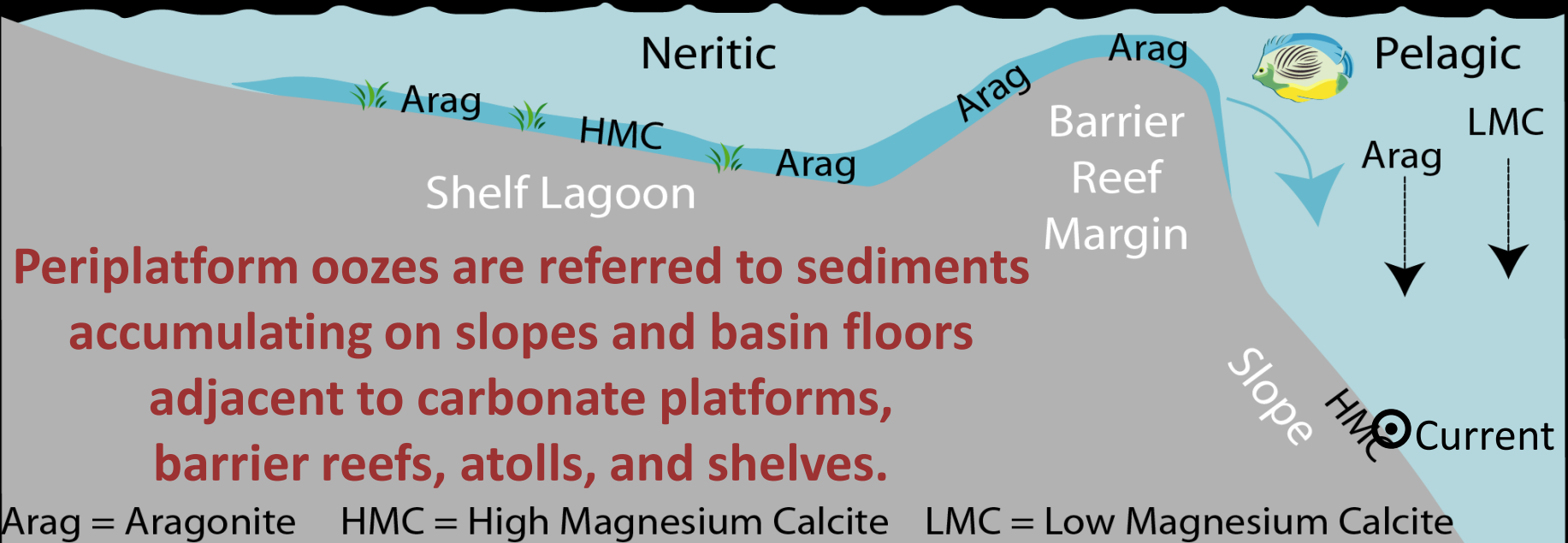
(LMC)

## Sea Floor

Diagenesis  
(High Mg calcite)



(HMC)

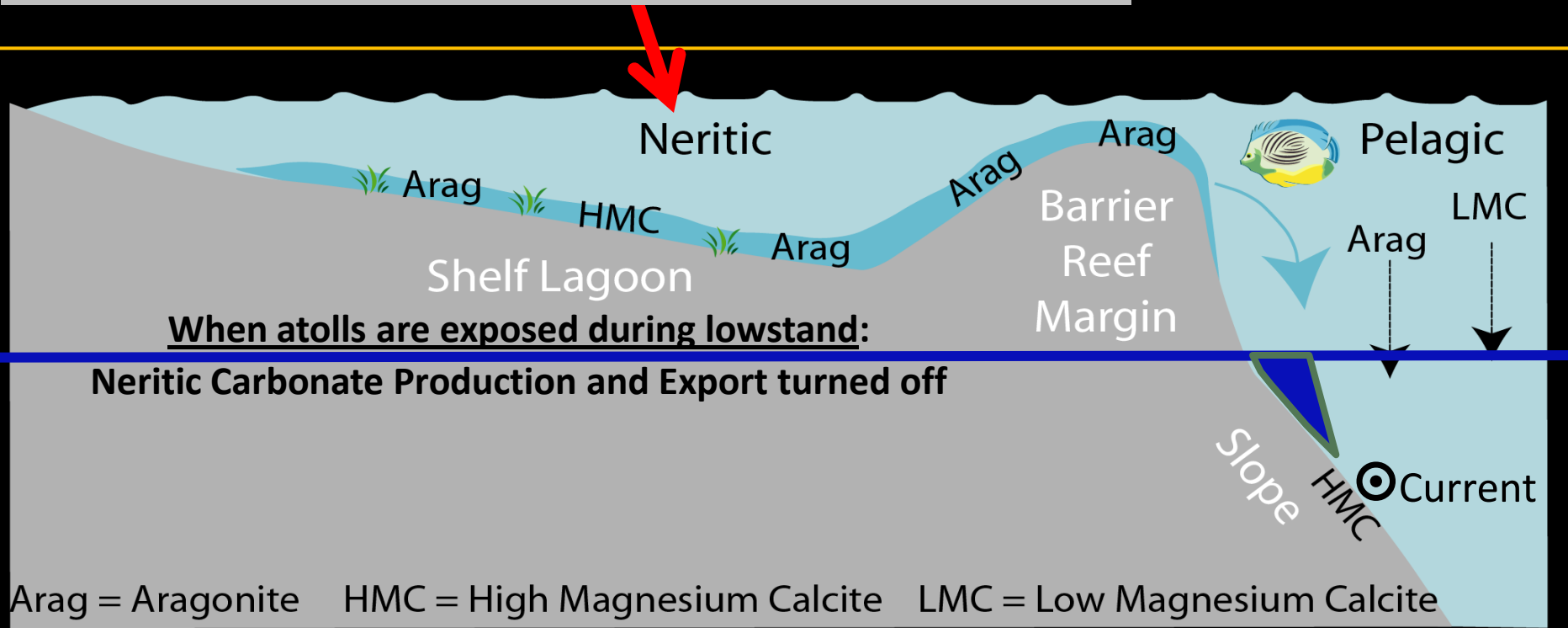




# Periplatform Carbonates

When atolls are flooding during highstand:

Maximum Neritic Carbonate Production and Export turned on



**Fine Bank-Derived Aragonite, Excellent Proxy for Sea Level  
if the Bank Top Bathymetry is known!**

# “Sr Counts” Proxy for Bank-Derived Fine Aragonite

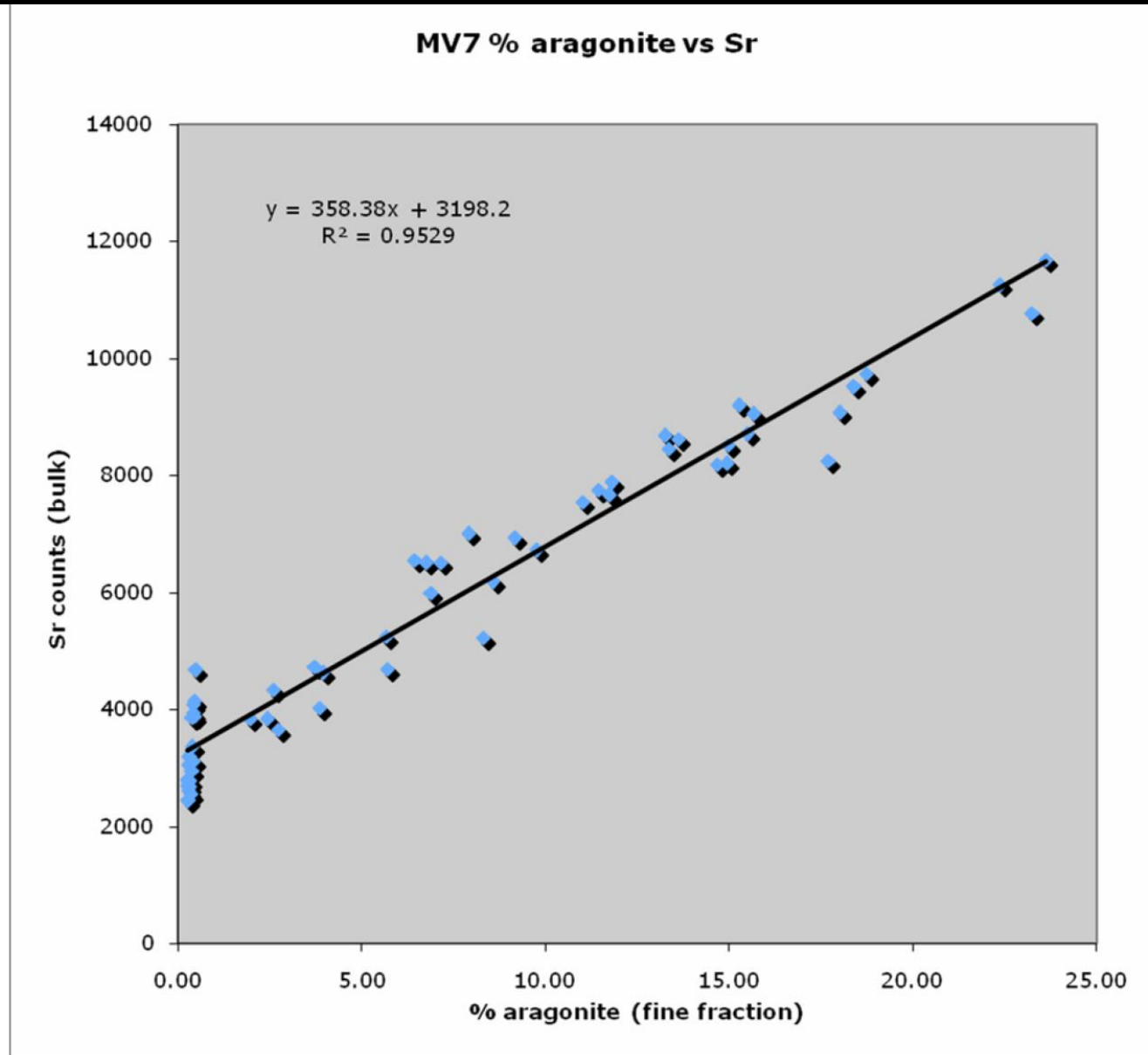
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**Why:** - Large cations, such as Sr are preferentially substituted for Ca in orthorhombic aragonite.  
- Small cations such as Mg are preferentially substituted for Ca in rhombohedral calcite.

**Usually:** Aragonite content is measured by X-ray Diffraction (XRD), a time consuming analysis.

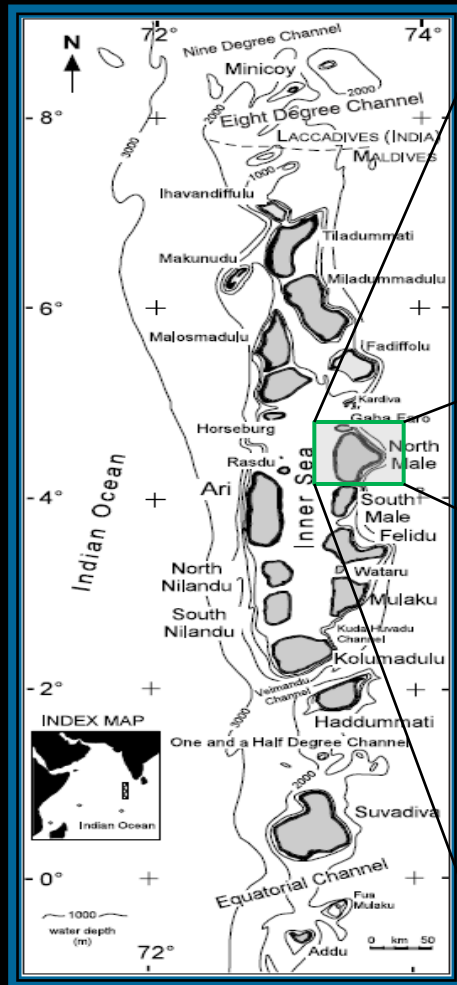
**Now:** Sr counts can easily be determined very quickly and at a very high resolution, using an X-ray Fluorescence (XRF) Core Scanner.

# “Sr Counts” Proxy for Bank-Derived Fine Aragonite

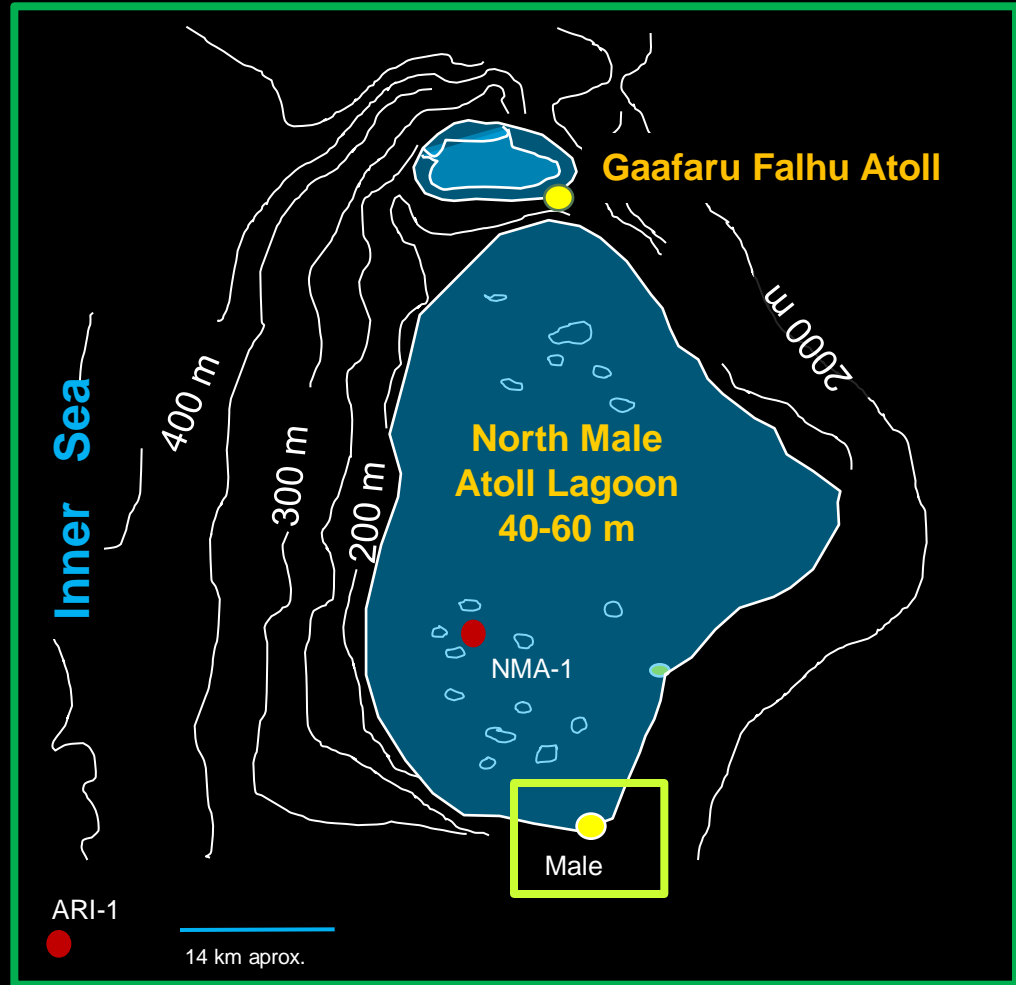


Unpublished Data from Melany McFadden

# Water Depths of Atoll Lagoon Sea Floor



Maldives Archipelago  
(Belopolsky and Droxler, 2004b).

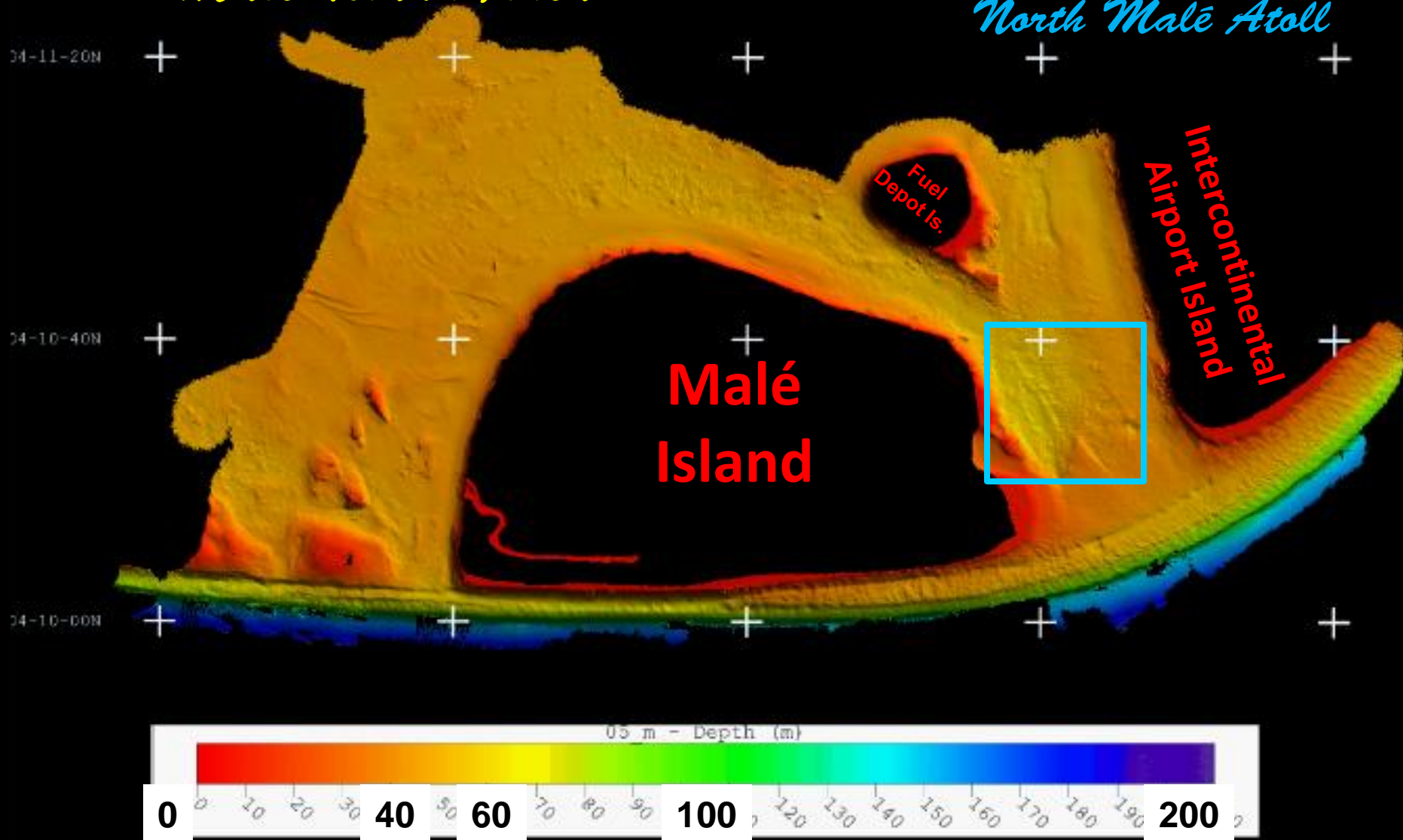


Details of North Male and Gaafaru Falhu Atoll bathymetry and study area location.

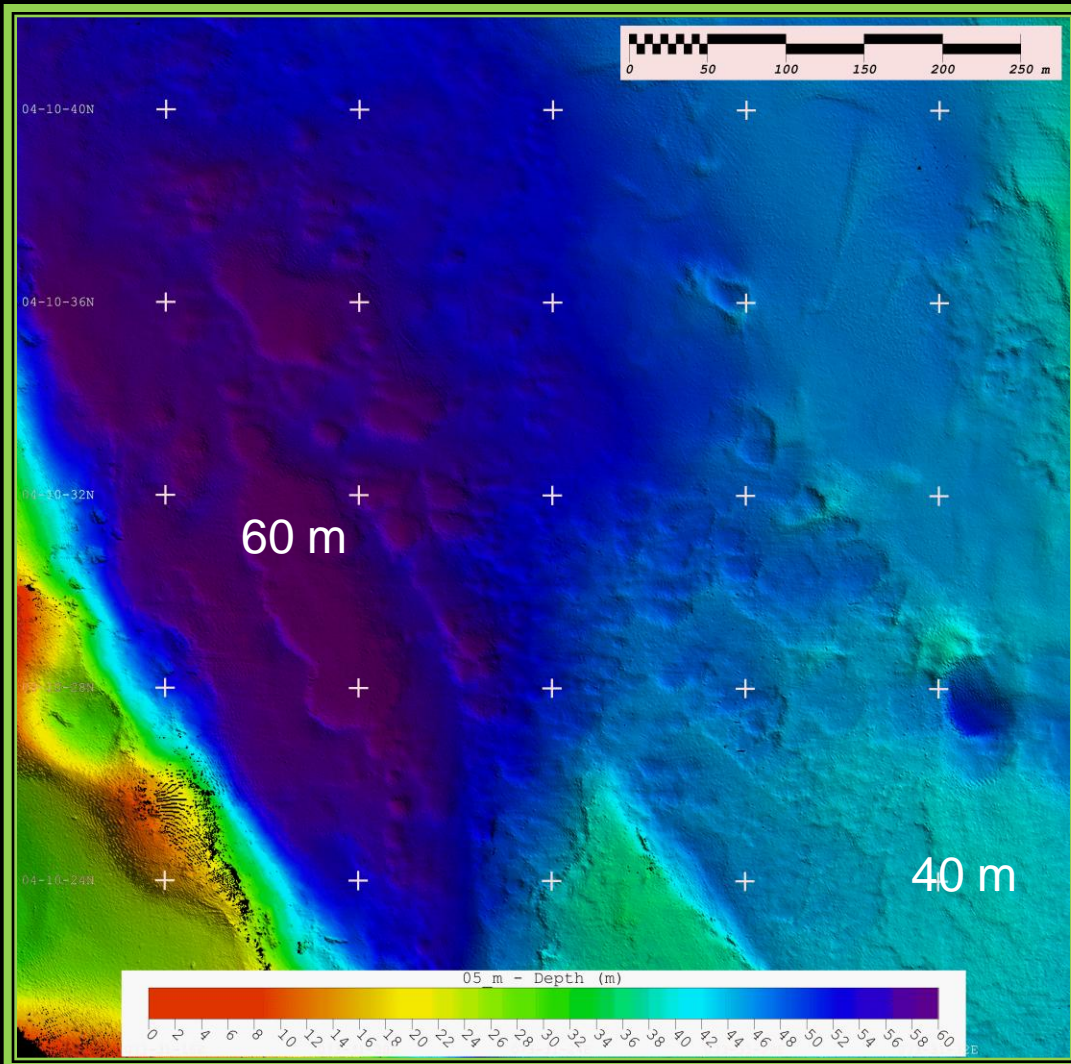


*2008 High Resolution  
Multi-Beam Mapping Survey  
Malé Island Area*

*Exposed Karst  
Morphologies  
on the Lagoon Floor of  
North Malé Atoll*



# North Male Atoll Lagoon Sea Floor

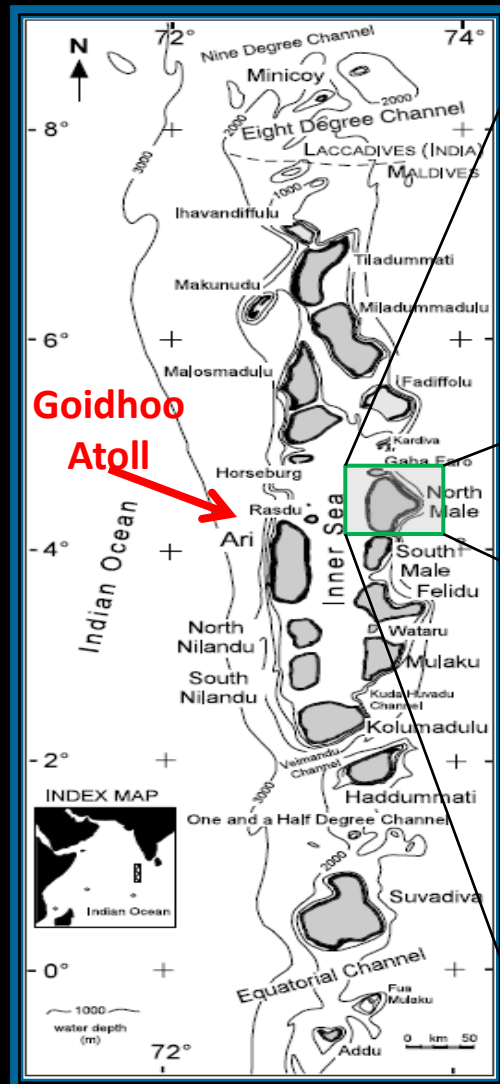


In the channel sea floor: water depths from 40 to 60 m.

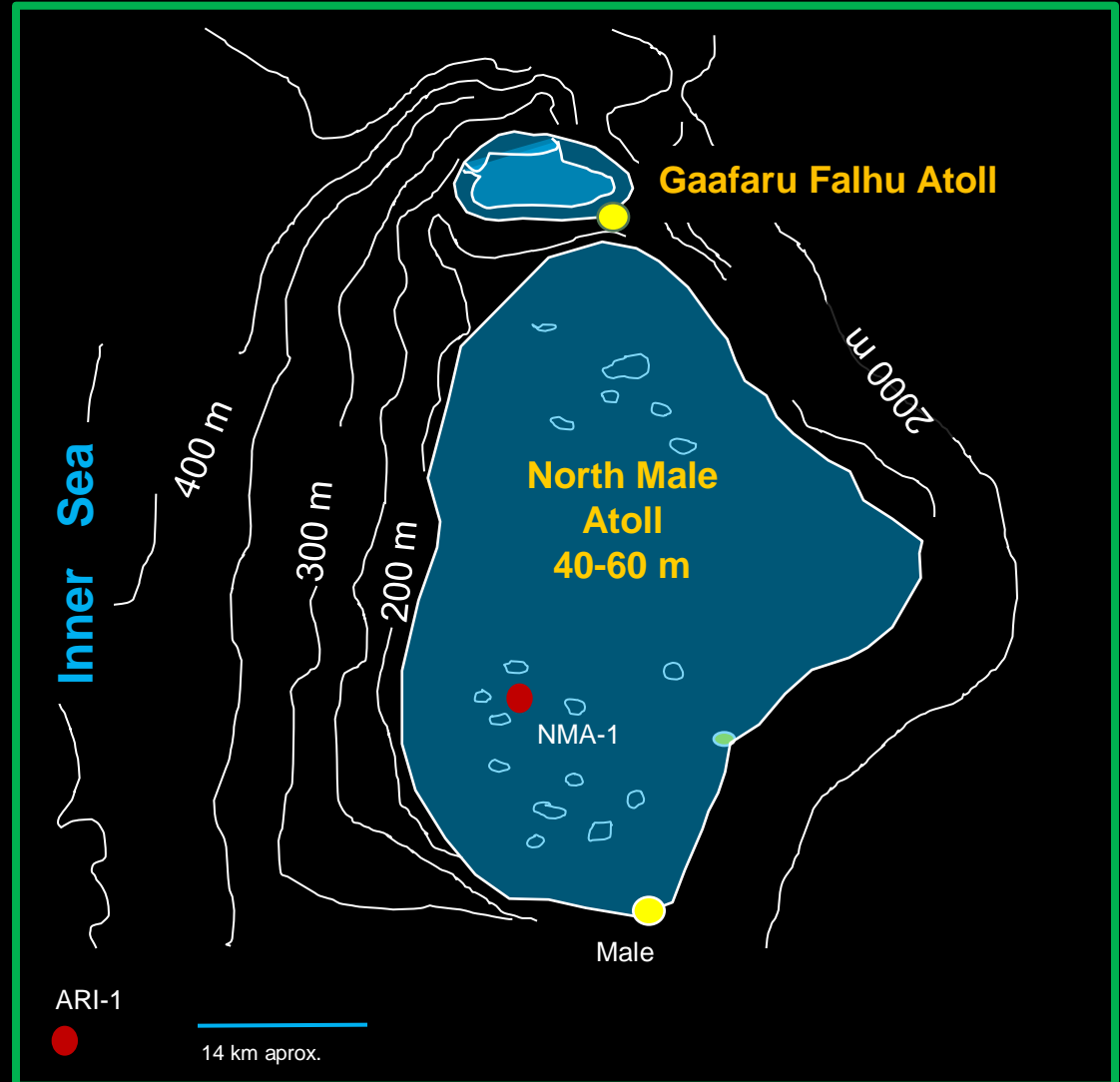
Observed depressions are typical in karst dissolution morphologies.

Sea floor morphology illustrate that the North Malé Atoll lagoon floor was exposed when sea level was below 40-60 m.

# Water Depths of Atoll Lagoon Sea Floor

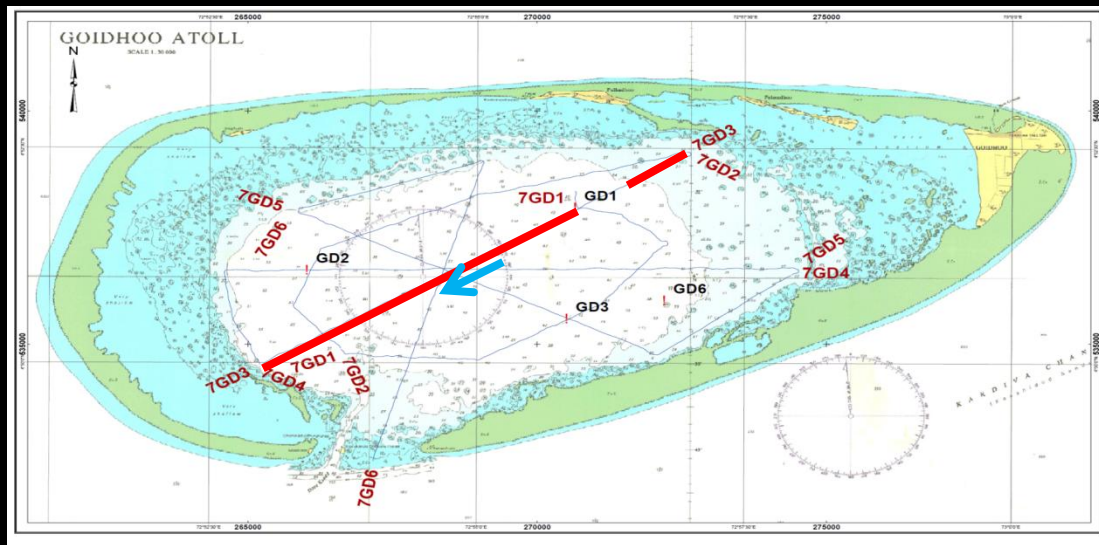


Maldives Archipelago  
(Belopolsky and Droxler, 2004b).



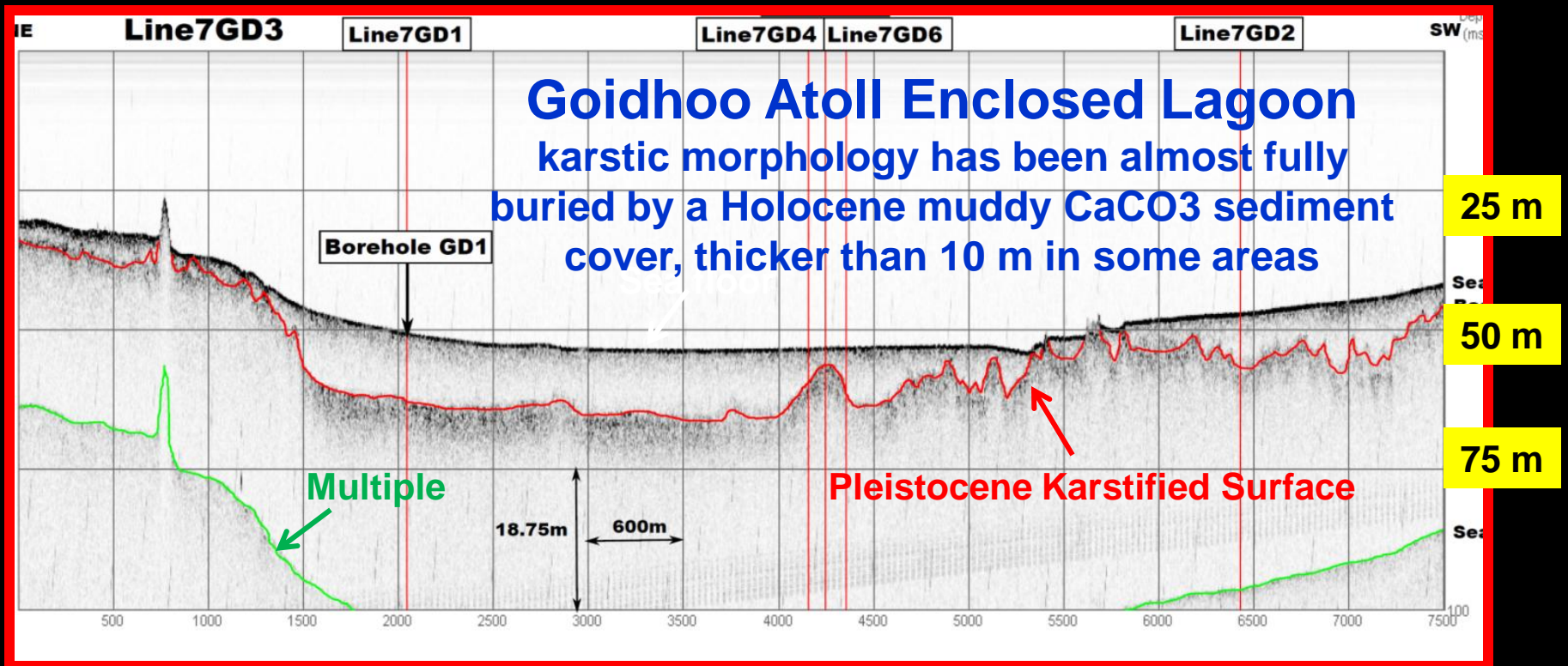
Details of North Male and Gaafaru Falhu Atoll bathymetry and study area location.





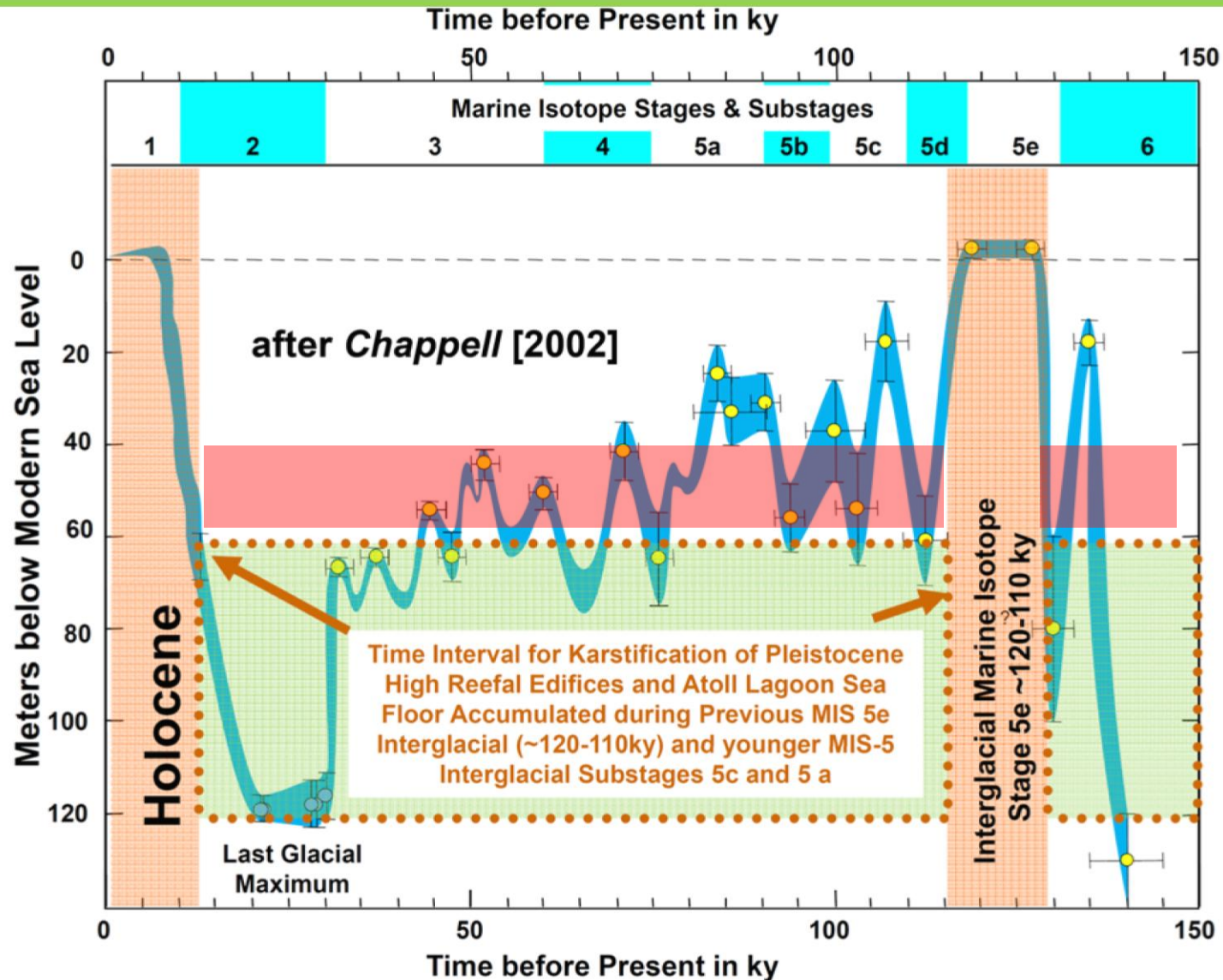
# Goidhoo Atoll Enclosed Lagoon

*A 2010 seismic survey*

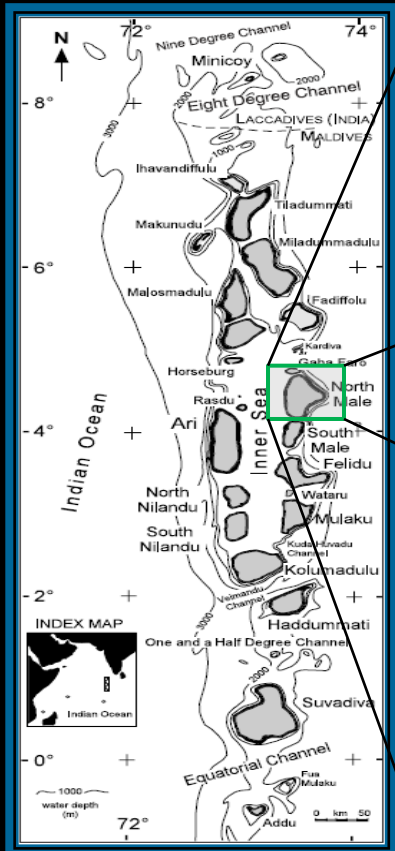




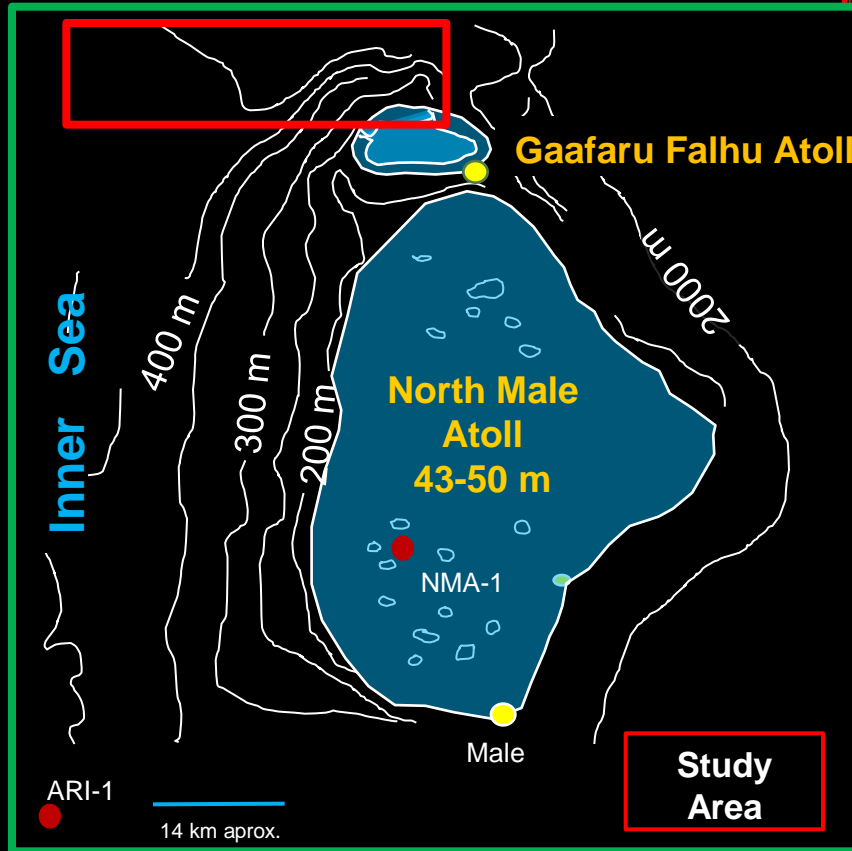
*Atoll lagoon floor was mostly exposed when sea level was below 40-60 m  
as recently as  
during Marine Isotope Stages 3 and 2, 5b, and 5d*



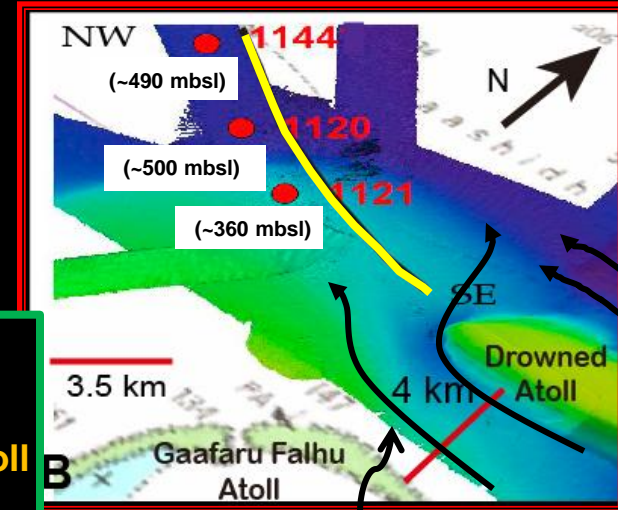
# Study Area



Maldives Archipelago  
(Belopolsky and Droxler, 2004b).

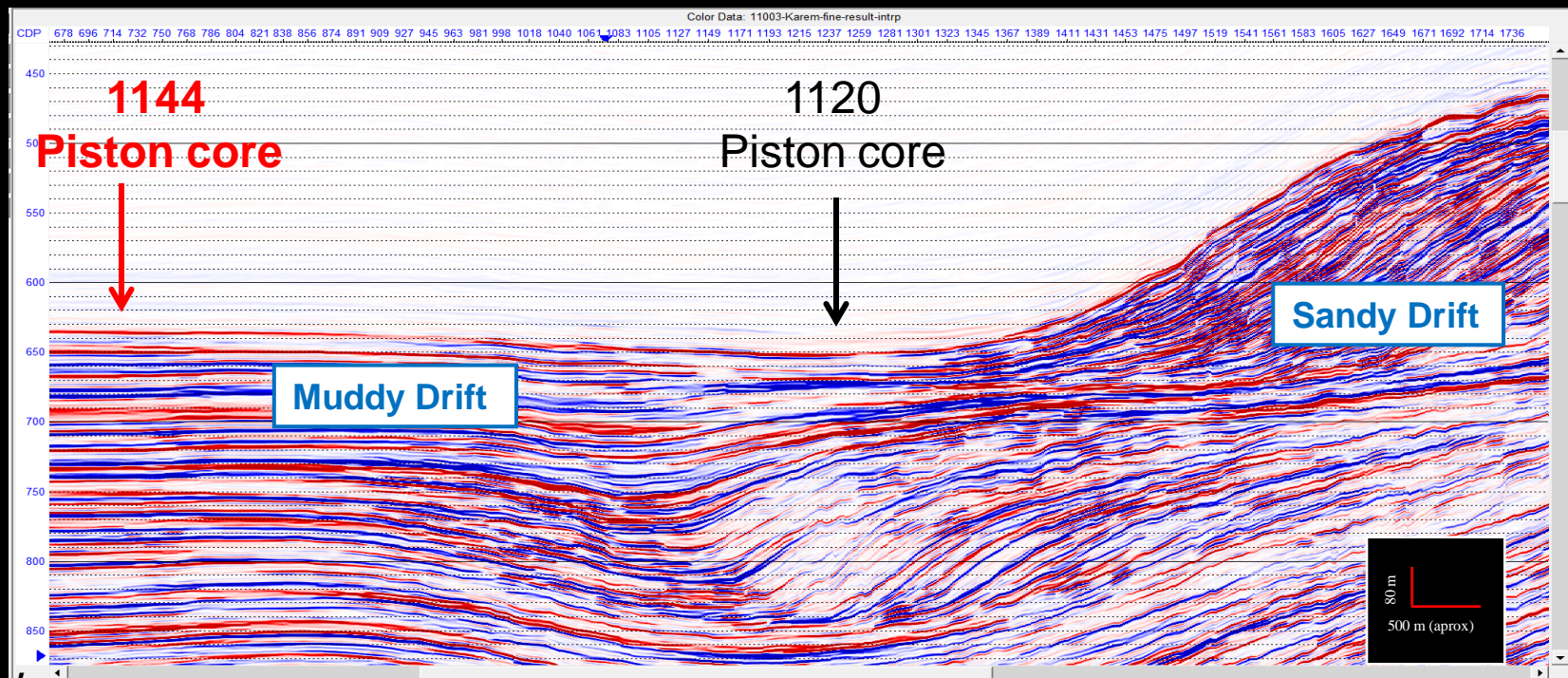


Details of North Male and Gaafaru Falhu Atoll bathymetry and study area location.



# Opportunity

## Deep Water Carbonate Deposits in the Inner Sea Excellent Recorder of the Maldives Evolution



Input seismic University of Hamburg (Germany)

Ultra additional processing (Lumina Geophysical, LLC)

# Sample Processing and Analysis

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**Laboratory Research (Rice University):  
total of 416 samples**

- **X-ray Fluorescence analysis , high resolution downcore variation of Sr counts**



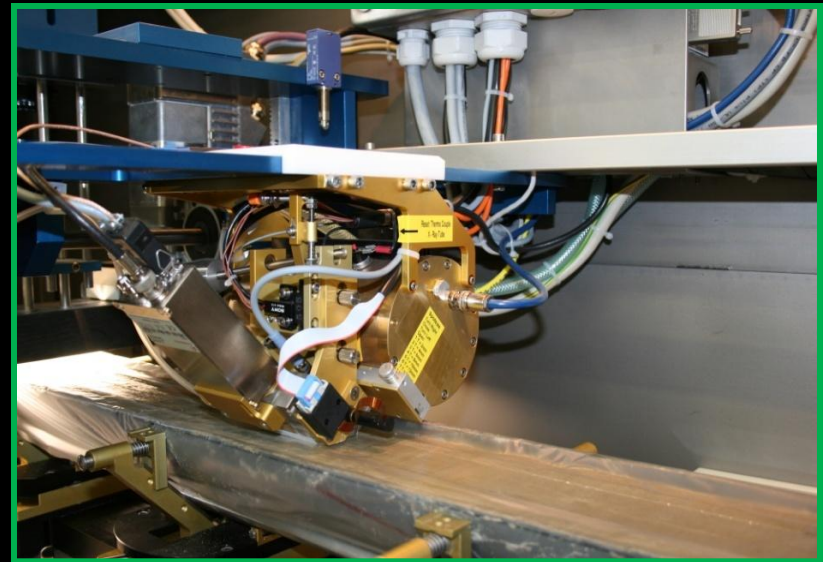
# Sample Processing and Analysis

## High resolution downcore variation of Sr counts (XRF analysis)



- Data were collected every 1 cm to 5 mm downcore
- The resulting data are elements intensities in count per seconds.

It is designed for rapid and non-destructive determination of chemical composition of marine bottom sediments.

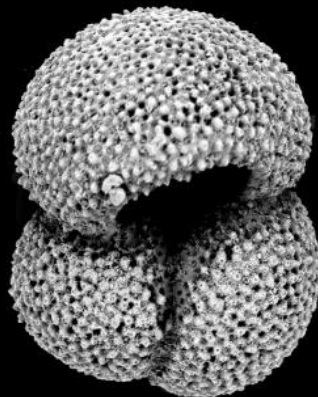


The analysis of major and trace elements by x-ray fluorescence is made possible by the behavior of atoms when they interact with radiation

# Sample Processing and Analysis

Laboratory Research (Rice University):  
total of 416 samples

- X-ray Fluorescence analysis , high resolution downcore variation of Sr counts
- Planktic stable isotope analysis , for developing a high resolution chronostratigraphy



200  $\mu$ m

*Globigerinoides ruber*

# Hypothesis

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Evolution of these drifts was influenced by the interaction of high frequency and high amplitude Quaternary sea level fluctuations partially (?) modified by monsoonal bottom currents

Atolls are the sources for the drift sediments, their production highly influenced by sea level

When atolls are flooding during highstand:

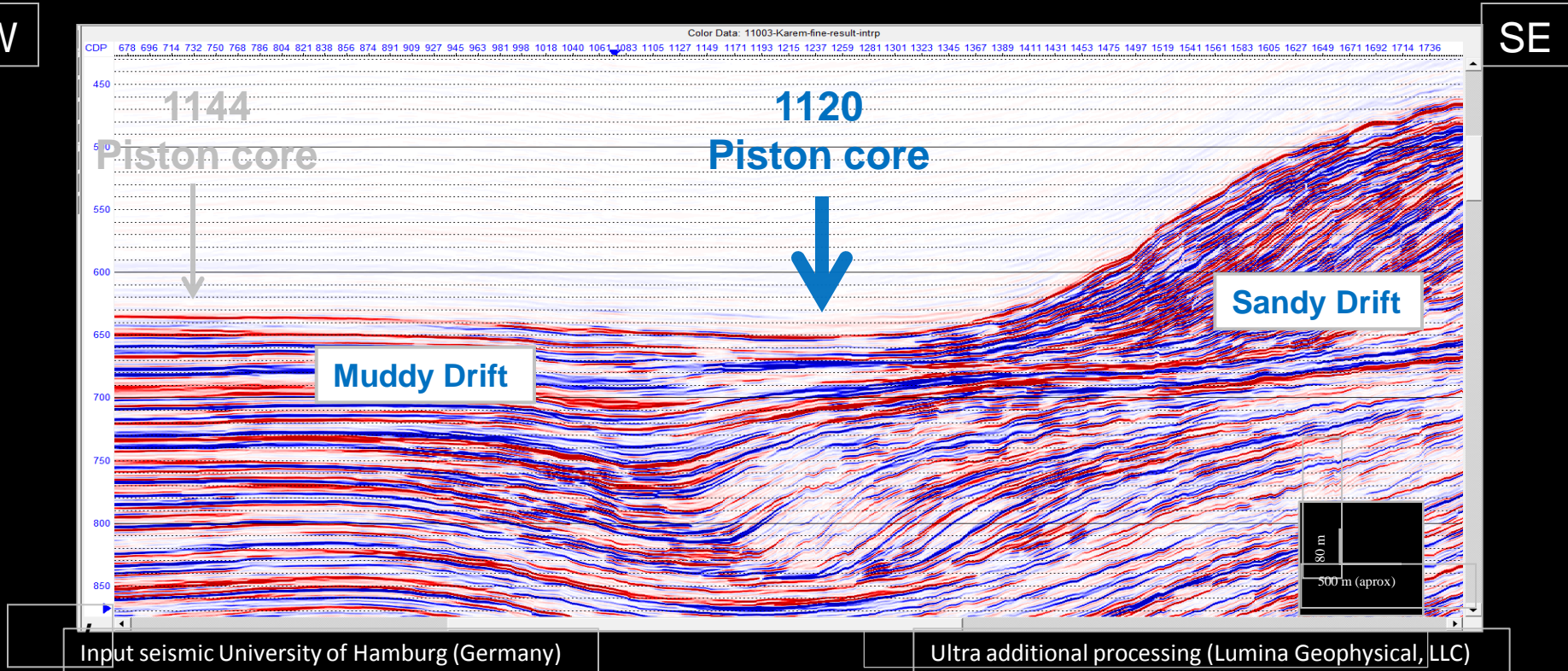
Neritic Carbonate Production and Export turned on

When atolls are exposed during lowstand:

Neritic Carbonate Production and Export turned off

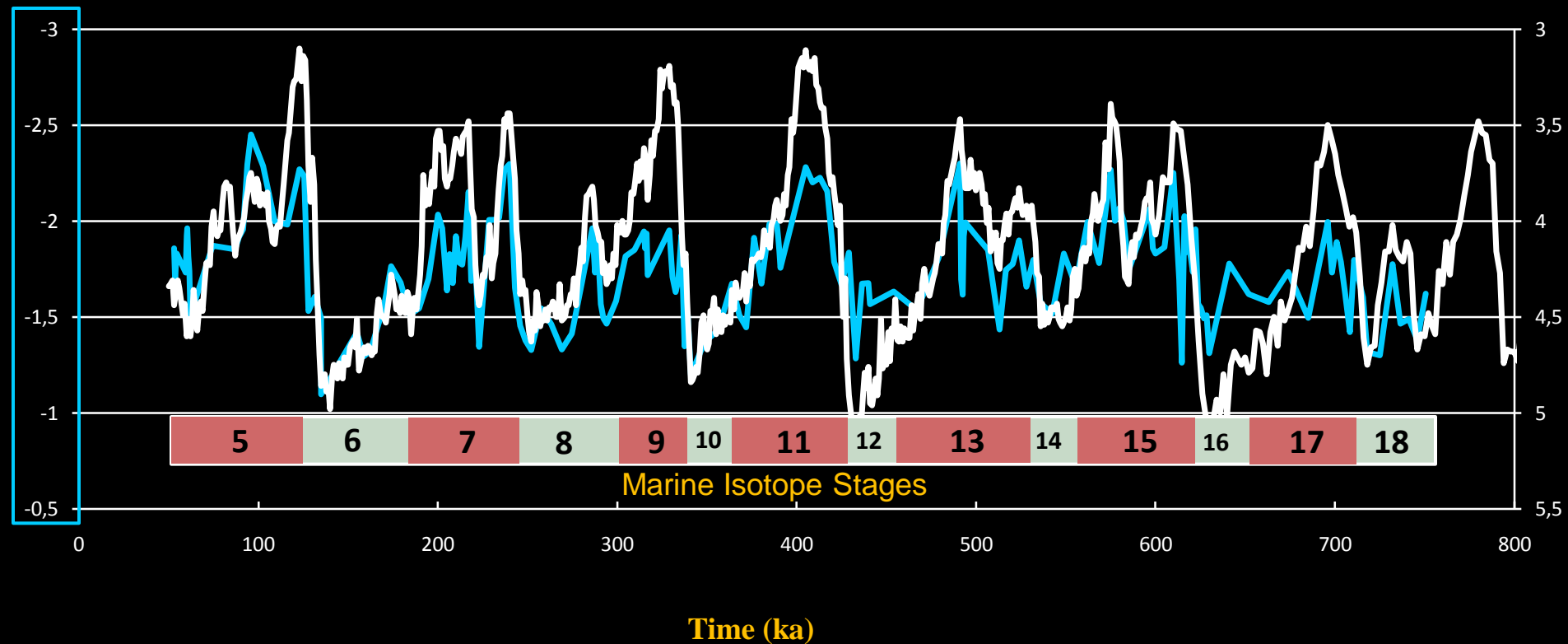
# Opportunity

## Deep Water Carbonate Deposits in the Inner Sea Excellent Recorder of the Maldives Evolution



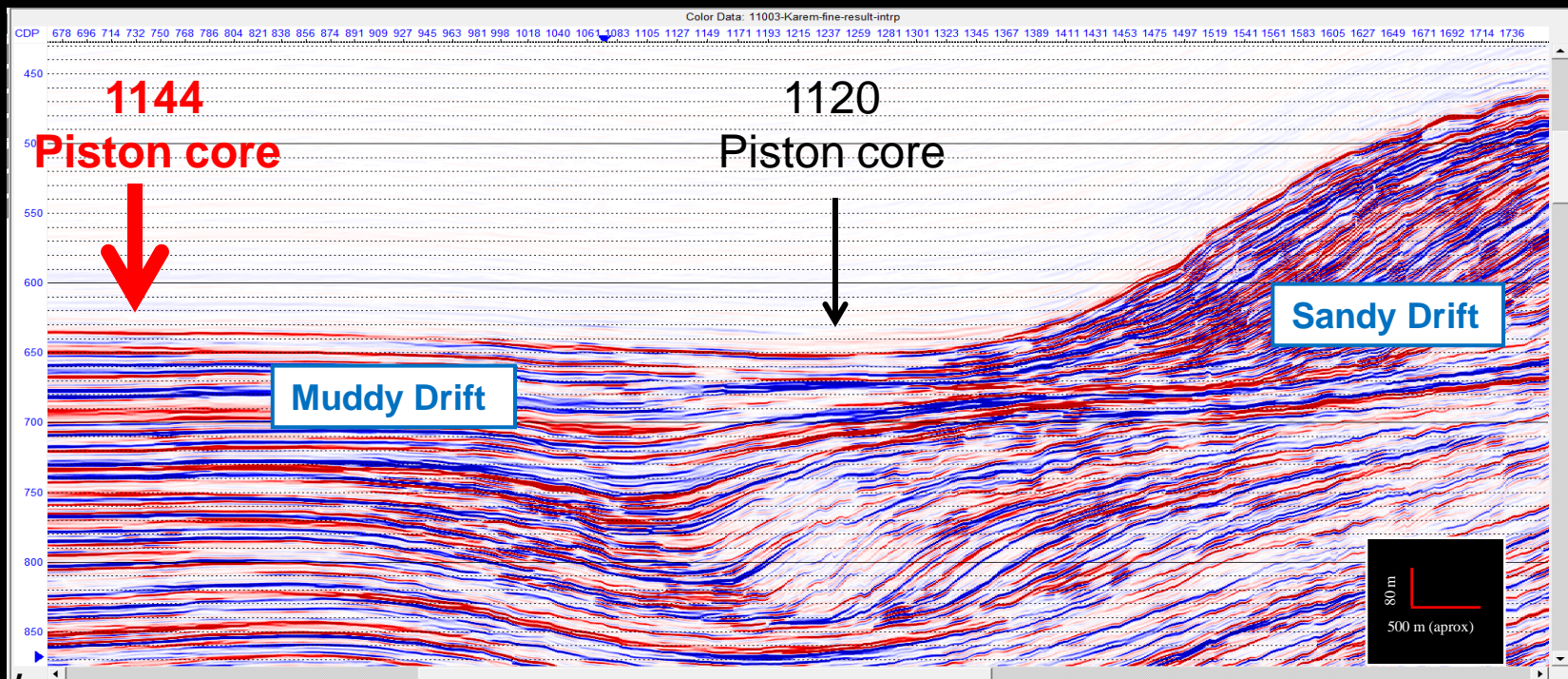


# Comparison between **1120 Planktic 18-O Record** and Benthic Stacked Record of Lisiecki and Raymo (2005)



# Opportunity

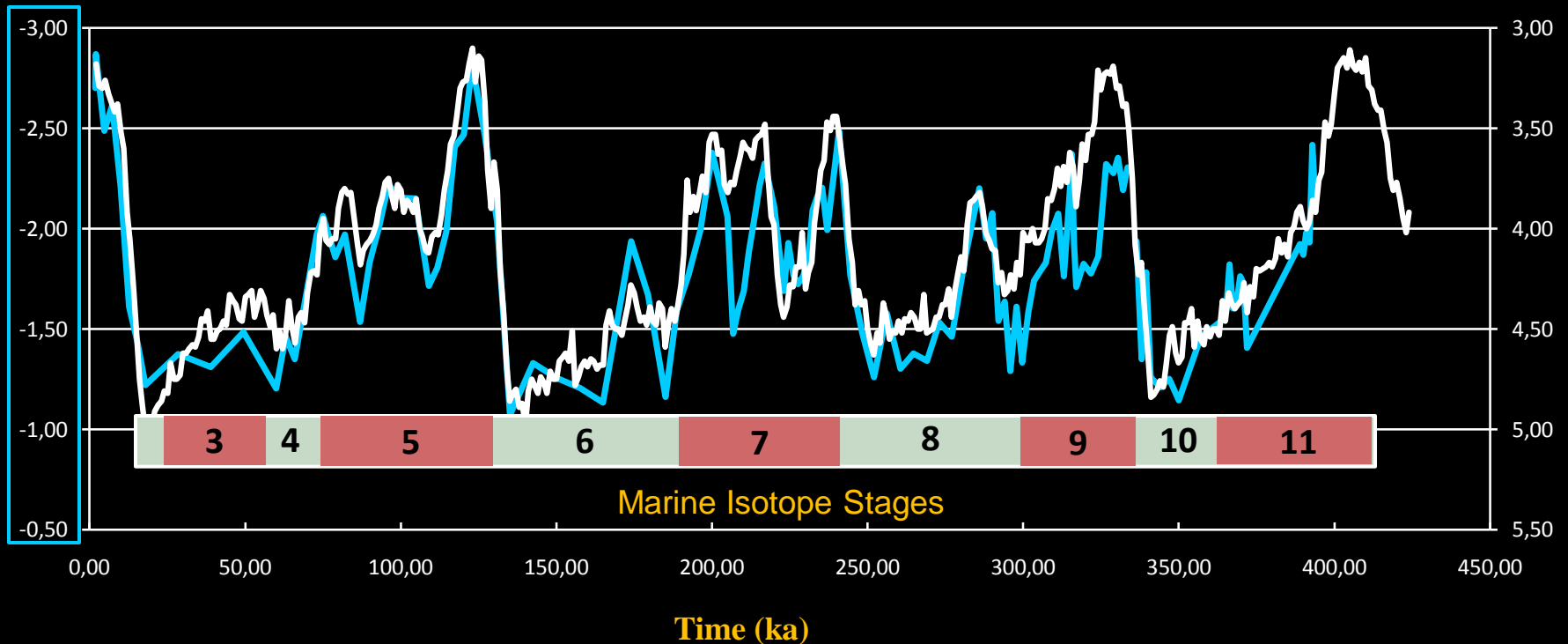
## Deep Water Carbonate Deposits in the Inner Sea Excellent Recorder of the Maldives Evolution



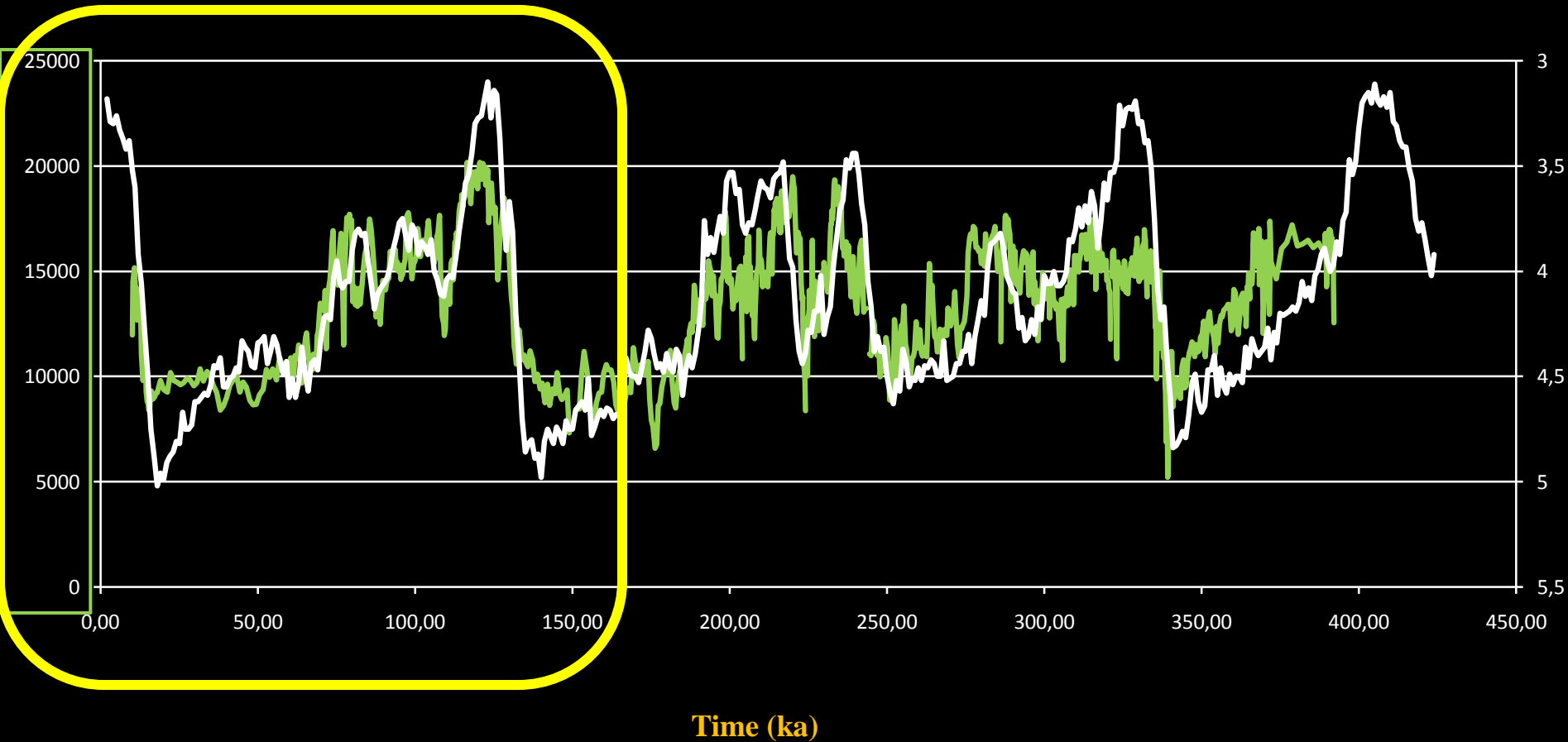
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Ultra additional processing (Lumina Geophysical, LLC)

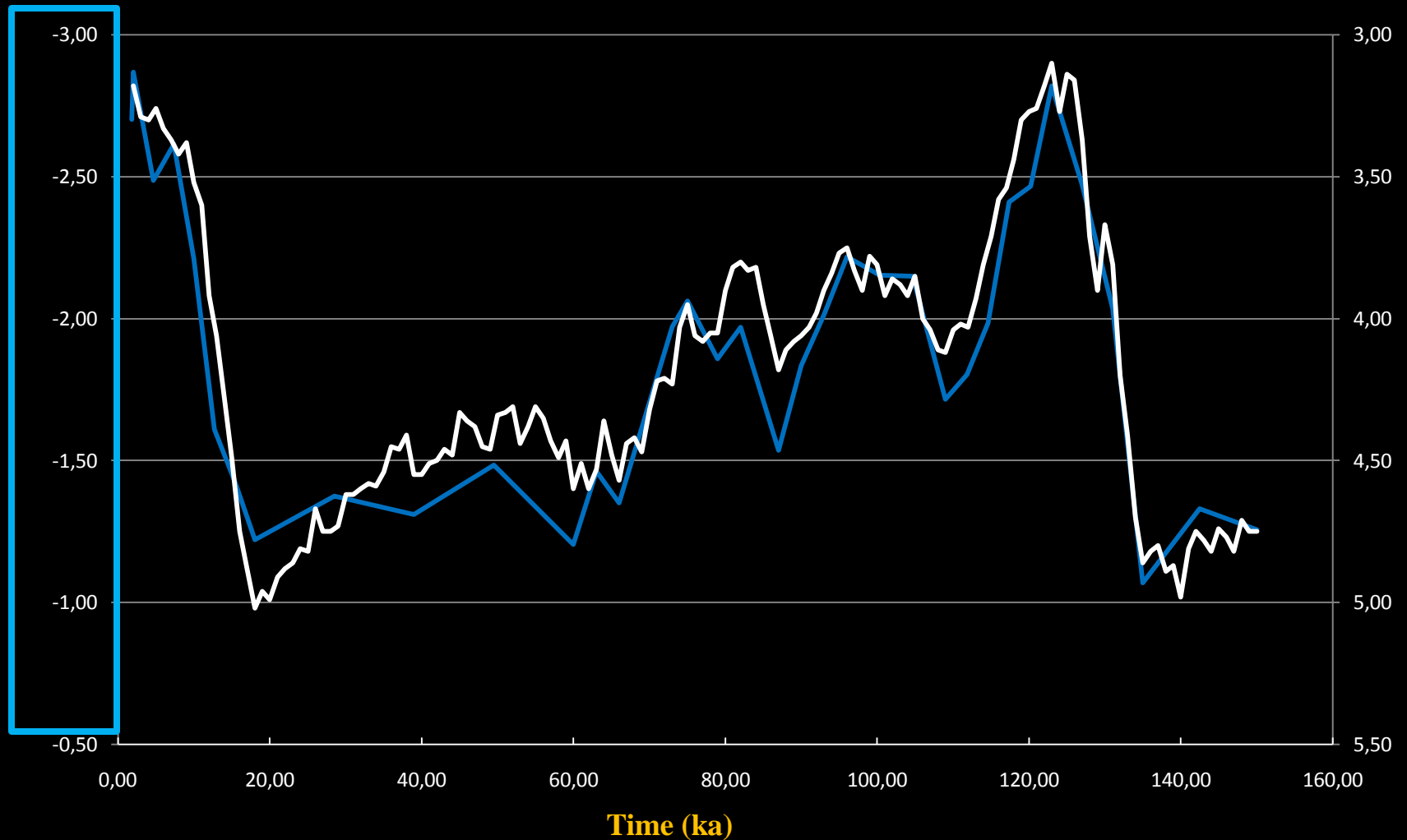
# Comparison between 1144 Planktic 18-O Record and Benthic Stacked Record of Lisiecki and Raymo (2005)



# Comparison between **1144 Strontium Count Record** and Benthic Stacked Record of Lisiecki and Raymo (2005)

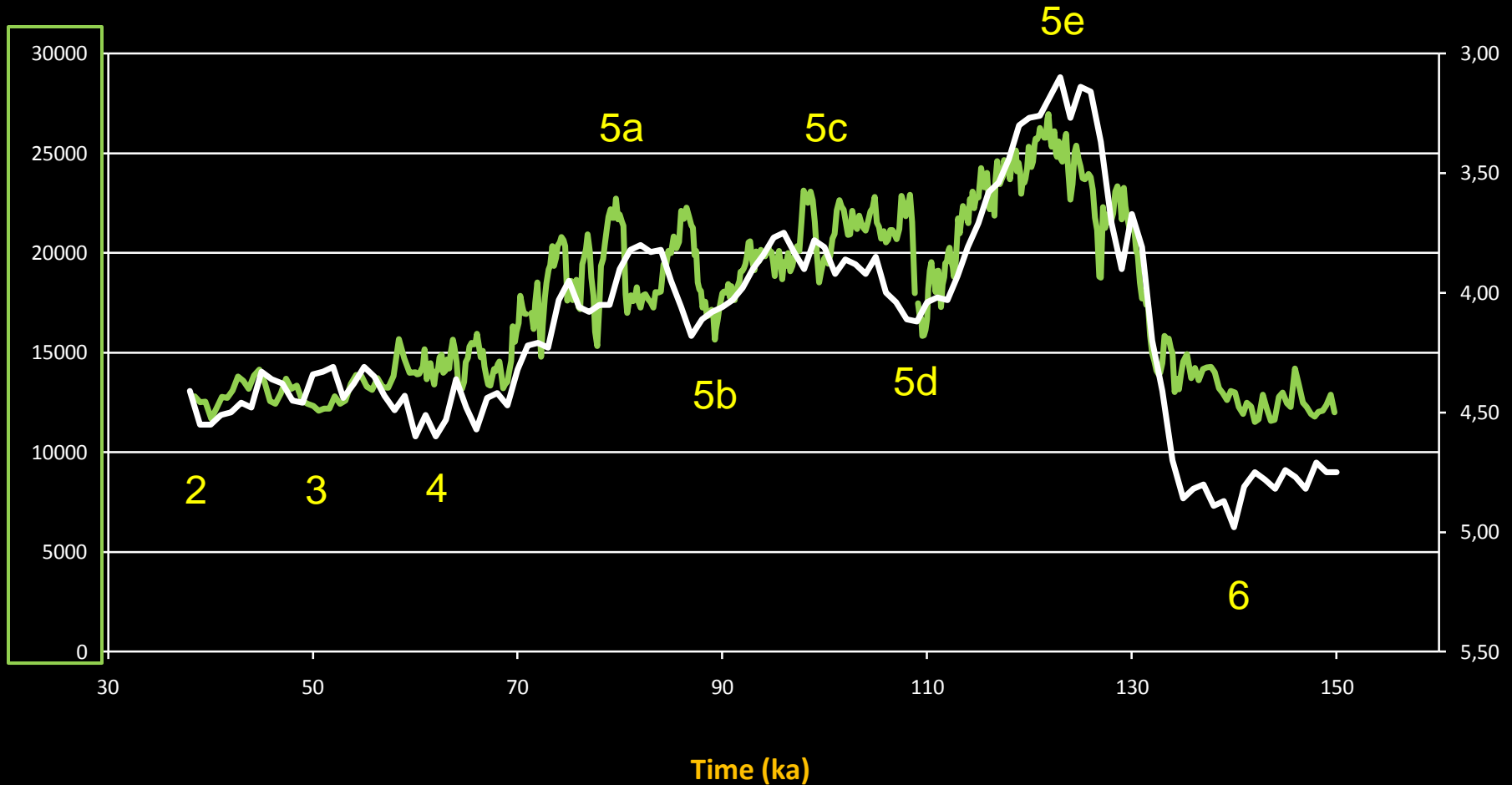


# Comparison between **1144 Planktic 18-O Record** and Benthic Stacked Record of Lisiecki and Raymo (2005)

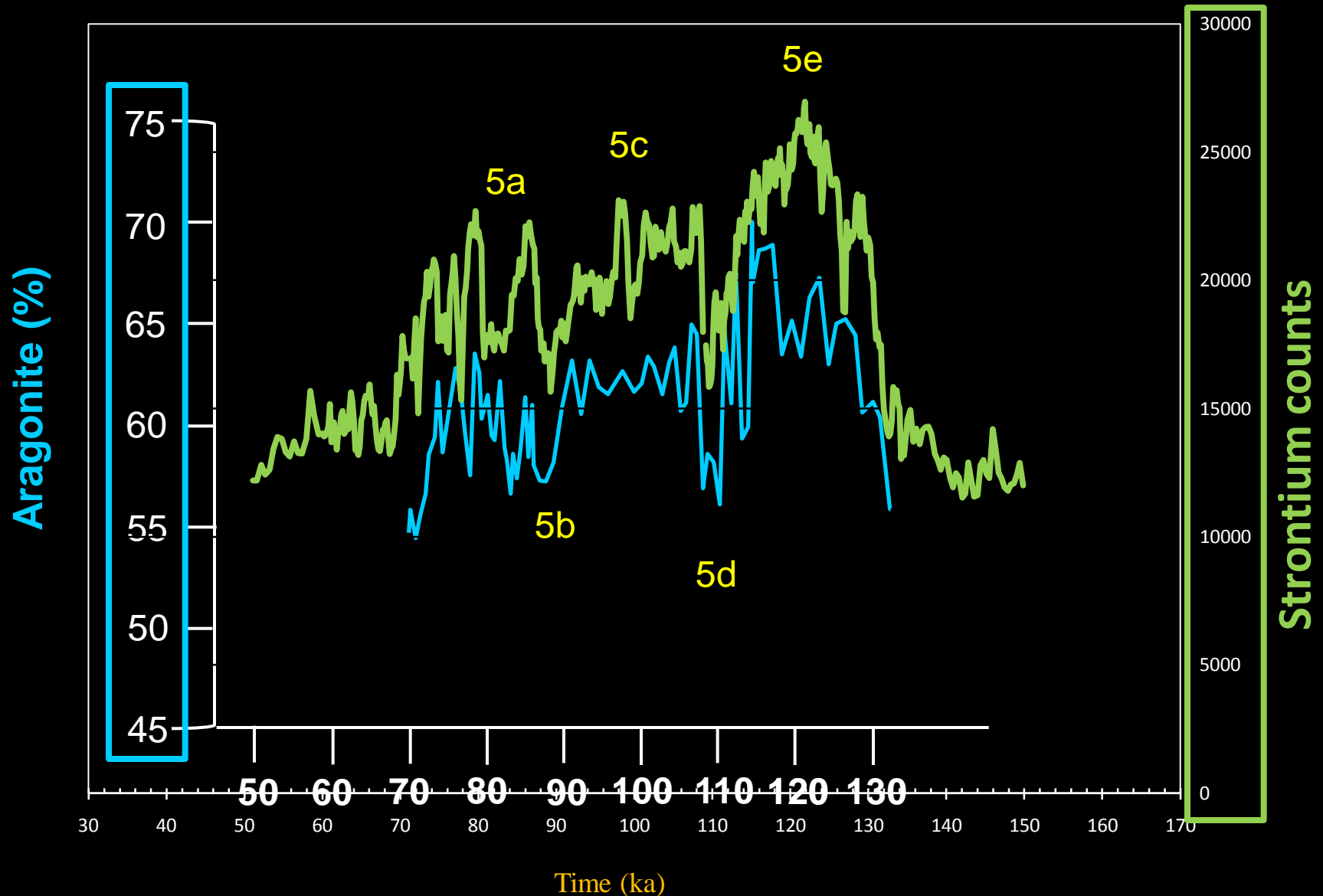




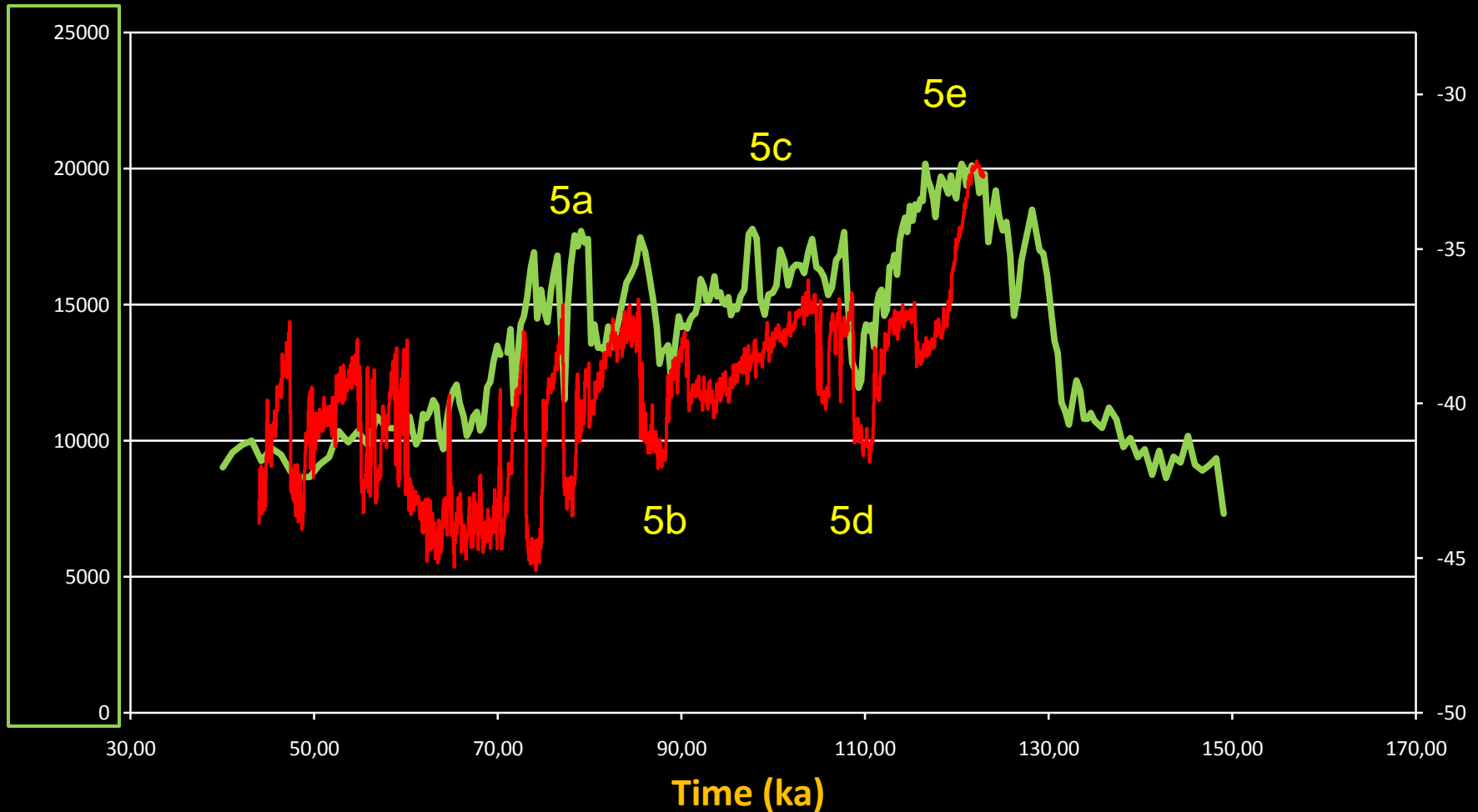
# Comparison between **1144 Strontium Count Record at 0.5 cm-spaced samples** and Benthic Stacked Record of Lisiecki and Raymo (2005)



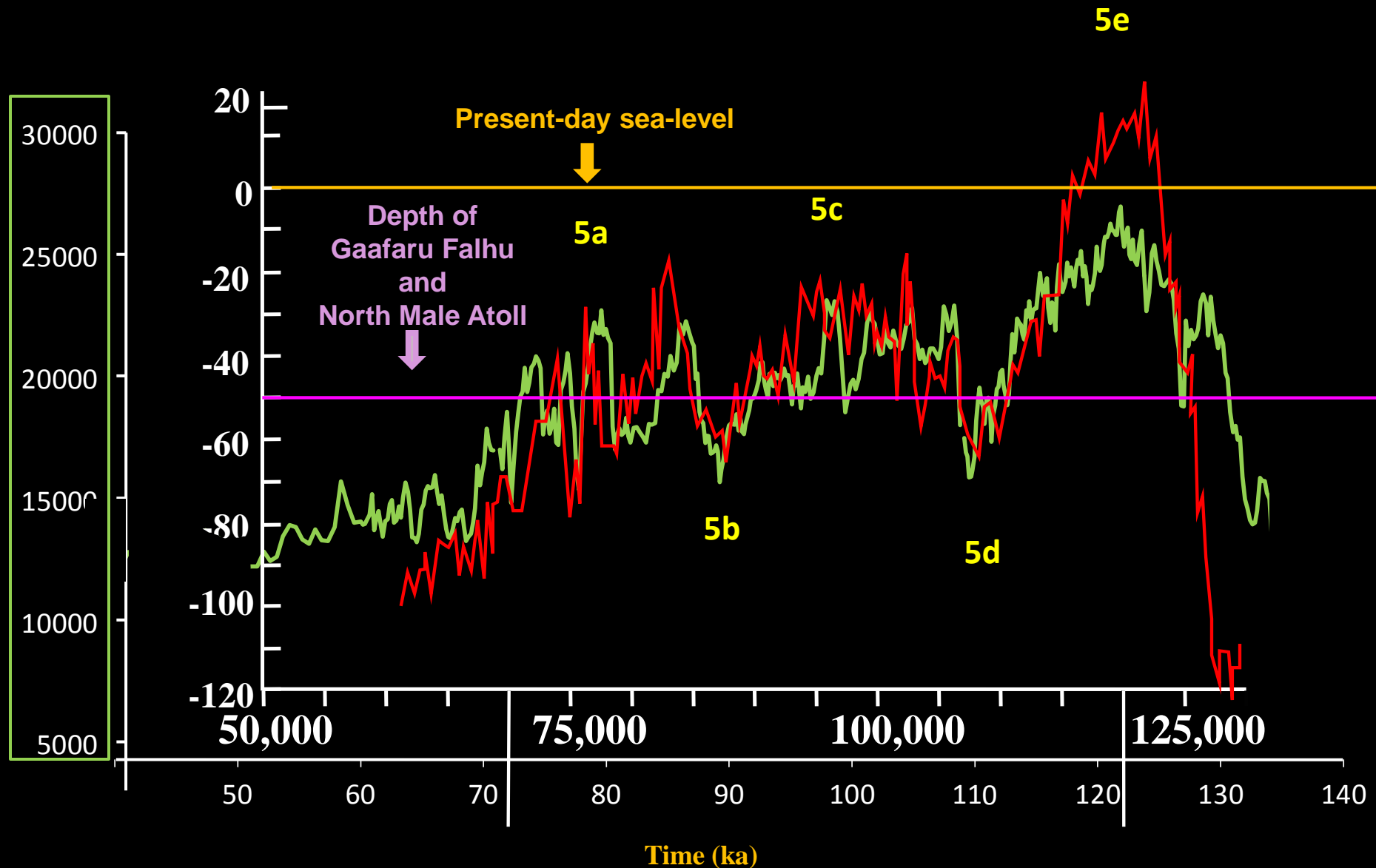
# Comparison between 1144 Strontium Count Record (5mm) and Aragonite record, Paul et al. (2011)



# Comparison between 1144 Strontium Count Record (5mm) and NGRIP 18-O Ice Record



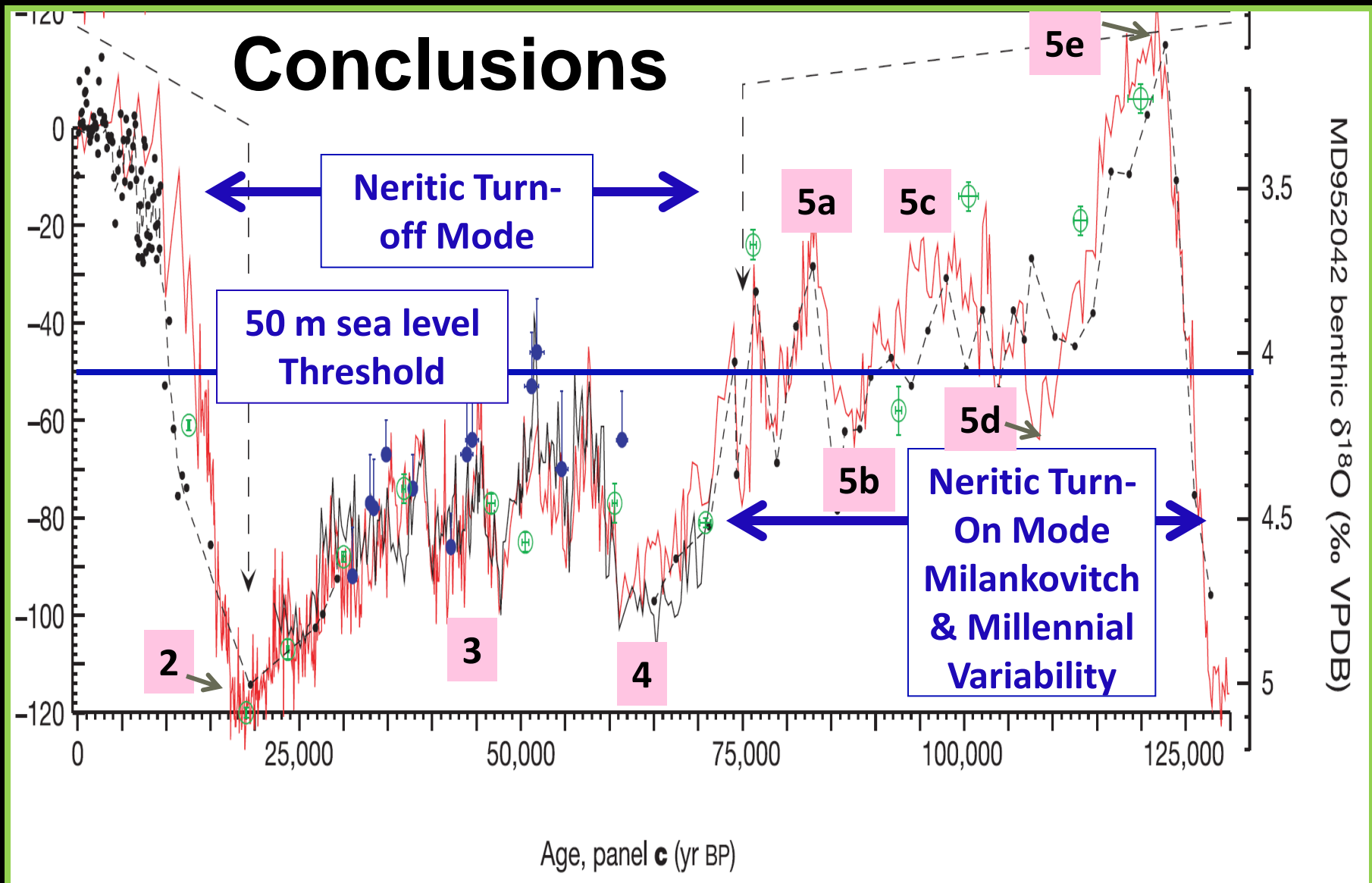
# Comparison between 1144 Strontium Count Record (5mm) and Sea-level, Siddall et al., 2003 (m)





# Sea-level fluctuations during the last glacial cycle

Siddall et al., 2003



# Thanks!!

