

PS Nature and Timing of Quaternary Carbonate Sediment Drift, Inner Sea of the Maldives Archipelago*

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Abstract

A 150 m-thick deep carbonate sediment drift was first observed on a Shell E-W seismic line north of Gaafaru Falhu atoll in the NE corner of the Maldivian Inner Sea, in a range of water depths from ~325 to 500 m. During the NEOMA 2007 cruise on the RV Meteor lead by Universität Hamburg, the area north of Gaafaru Falhu atoll was extensively surveyed via multibeam bathymetry, 4 kHz sub bottom profilers, and MC seismics. Based on the survey, the drift has been accumulating at the western exit of a deep channel located north of Gaafaru Falhu atoll. Observations of NEOMA/Shell 4 kHz profiles and MCS lines show that a large part of the sedimentary drift, down-lapping on a major unconformity, thins on the toe of its front into 5 to 6 distinct wedge-like subunits into a very recent sequence not much thicker than 15-25 m.

During the NEOMA cruise, one box core, M74-4-1121, was recovered on top of the carbonate drift itself and two 14 m-long piston cores were retrieved on the toe of its front, M74-4-1120 on a proximal location and M74-4-1144 on a more distal position. The box core recovered 20 cm of the very top of the drift. Two third of the carbonate drift sand, made mostly of skeletal angular shell fragments and benthic foraminifers, fell in a size range between 355-1000 μ . The other third of the sand, between 63-355 μ , is a mixture of planktic foraminifers/pteropods, skeletal fragments, and benthic foraminifers. Both piston cores display downcore a clear cyclic pattern in sediment size fraction variability. Interglacial intervals are expended by inclusion of fine (< 63 μ) bank derived material whereas intervening glacial stages are condensed and characterized by high coarse fraction (> 63 μ) proportions ranging between 60-90 % in both cores. Bio-stratigraphic markers help estimate that M74-4-1144 bottomed at the end of Marine Isotope (MIS) 11. The base of core M74-4-1120, displaying lower sedimentation rates than in core M74-4-1144, represents MIS 15. It is probably not a coincidence that the five glacial/interglacial couplets easily identified in M74-4-1121 (from MIS 5 to MIS 15) could correspond to the five small wedge sub-units forming the toe of the carbonate drift front. Based upon this observation, the accumulation of the large and thick carbonate drift north of Gaafaru Falhu atoll was most likely initiated only since the mid-Brunhes, when the atoll top became intermittently re-flooded, after a relative long period of exposure during the early Brunhes.



NATURE AND TIMING OF QUATERNARY CARBONATE SEDIMENT DRIFT, INNER SEA OF THE MALDIVES ARCHIPELAGO

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Abstract

A 200 m-thick deep carbonate sediment drift was first observed on a Shell E-W seismic line north of Gaafaru Falhu atoll in the NE corner of the Maldives Inner Sea, in a range of water depths from ~350 to 500 m (Belopolsky and Droxler, 2004). During the NEOMA 2007 research cruise on the RV Meteor lead by Universität Hamburg, the area north of Gaafaru Falhu atoll was extensively surveyed via 12 kHz multi-beam bathymetry, a 4 kHz sub bottom profiler (Atlas Hydrographics), and multi channel high resolution seismics. Based on these surveys, the drift has been clearly imaged in three dimensions.

The drift has been accumulating at the western exit of a deep channel located north of Gaafaru Falhu atoll (Betzler et al., 2009). The 4 km-wide and as 350 m deep channel, is bounded on its north side by the southern margin of a drowned platform and on its southern side by the northern margin of Gaafaru Falhu atoll. Strength of the westerly current flowing through the channel, illustrated by 10 m high sand waves observed within the channel axis, is tied to the winter Indian monsoon circulation (Betzler et al., 2009).

During the NEOMA cruise, one box core, M74-4-1121, was recovered on top of the carbonate drift itself and two 14 and 13 m-long piston cores were retrieved on the toe of its front, M74-4-1120 on a proximal location and M74-4-1144 on a more distal position.

The box core recovered 20 cm of the very top of the drift. Two third of the carbonate drift sand, made mostly of skeletal angular shell fragments and benthic foraminifers, fell in a size range between 355-1000 μ . The other third of the sand, between 63-355 μ , is a mixture of planktic foraminifers/pteropods, skeletal fragments, and benthic foraminifers. Because the 4 kHz energy source of the sub-bottom profiler could not penetrate the sediment drift, it is assumed that the coarse sand lithology encountered in the box core most likely represents the main lithology of the 200 m-thick sand drift.

Both piston cores display downcore a clear cyclic pattern in sediment size fraction variability. Interglacial intervals are significantly expanded by inclusion of fine (< 63 μ) bank derived argonite and Sr-rich sediments, whereas intervening glacial stages are condensed and characterized by high coarse fraction (> 63 μ) proportions ranging between 60-90 % in both cores. Bio-stratigraphic markers help estimate that M74-4-1144 bottomed at the end of Marine Isotope (MIS) 11. The base of core M74-4-1120, displaying lower sedimentation rates than in core M74-4-1144, represents the middle of MIS 15.

Observations of NEOMA high resolution MCS dip and strike lines show that the upper half of the sedimentary drift, composed of three distinct wedge-like main units down-lapping on a series of unconformities, thins on the toe of the drift front into a very recent sequence not much thicker than 30 m. This thin sequence represents the complete Pleistocene based upon the preliminary stratigraphy established on the two NEOMA piston cores 1120 and 1144 and the more distal ODP Site 716. The lower half of the drift thins into an underlying unit not thicker than a few meters assumed to be latest Pliocene in age.

The youngest prograding main unit, made of three subunits, was initiated during the mid Brunhes based upon the stratigraphy developed in the proximal core M74-4-1120. The three subunits, forming the most recent toe of the carbonate drift front, would then correspond to the three main interglacial highstand intervals (MIS-11, MIS-9, and MIS-5). The underlying two main Pleistocene units are interpreted to represent unusually strong interglacial highstand intervals (MIS-31-37) in the mid-Pleistocene and MIS-45-49 in the early-Pleistocene.

Based upon these observations, the accumulation of the large and thick carbonate drift northwest of Gaafaru Falhu atoll was most likely initiated during the latest Pliocene. The lower half of the drift is probably latest Pliocene in age, whereas the upper half of the drift is Pleistocene in age.

Study Area and Objectives

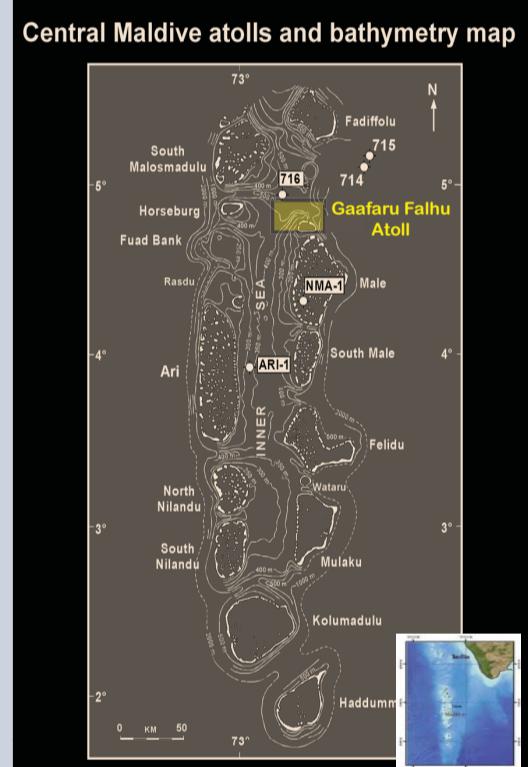


Figure 1. Bathymetric map of the Maldives, main atolls and Inner Sea, where the study area is located.

Modern Physiography: The islands of the Republic of Maldives, with an average elevation of 1.5 m, represent a tiny fraction of the submerged 2-3 km thick and extensive Maldives carbonate mega-platform, particularly in terms of their surface area and overall thickness (Belopolsky and Droxler, 2004). The Maldives Archipelago is clearly visible from space and appears today as a series of 800-km long north-south oriented strings of more than 1200 small atolls in the equatorial Indian Ocean. In the central part of the archipelago, the large atolls form two parallel north-south relatively continuous chains surrounding an internal basin, the Inner Sea, with water depths not exceeding 550 m. Importantly, unlike other large carbonate systems established elsewhere along continental margins, such as the Great Barrier Reef and the Bahamas-Florida platforms, the Maldives mega-carbonate platform has grown since about 55 Ma on top of a slowly subsiding volcanic plateau established on oceanic crust, much larger than the Maldives carbonate mega-platform itself.

This study focuses on the offshore area, immediately northwest of Gaafaru Falhu atoll, located in the North East corner of the Maldives Inner Sea, where a deep water 200 m thick carbonate sand drift has been accumulating. The purpose of the research is to establish a time-stratigraphic framework for this drift. The detailed analyses along, one box core M74-4-1121 (top of the carbonate sand drift) and two piston cores retrieved on the toe of the carbonate sand drift (M74-4-1120 and M74-4-1144), include, downcore size fraction and Sr/Ca variations, bio- and cycle stratigraphy, and high resolution seismic stratigraphy interpretation of the drift itself and toe of slope.

Data and Methods

Geophysical Surveys and Interpretation:

Multi-beam bathymetry, 4kHz sub bottom profiles: Multibeam imaging was performed with a hull-mounted EM120 multibeam echosounder (Kongsberg Maritime). The EM120 is a high-resolution sea-floor-mapping system with 256 simultaneous beams operating in the 12 kHz range, and covering a swath width of up to 5.5 times water depth. Depth resolution is at centimeter to decimeter scale. The beams are stabilized for roll, pitch, and yaw. Data obtained were post-processed using the software package Neptune (Kongsberg Maritime).

Multi-channel 2D seismic (high resolution): Seismic signals were generated by means of two clustered GI-Guns, each with a volume of 45 in³ for a 105-in³ generated injector volume. A digital 144-channel streamer array with an active length of 600 m and an asymmetric group interval was used. Data were digitized by seven SeaMUX 24 channel 24 bit digitizing modules, configured in six multiple arrays totalling 144 channels. The selected shooting distance during the entire cruise was 12.5 m. The dominant frequencies center around 100–120 Hz. The vertical resolution equals approximately 4–6 m. In the following, depths are approximated using an average sonic velocity of 1600 m/s.

Sub-Bottom Profiler: a hull-mounted 4 kHz sub bottom profiler (Atlas Hydrographics) generated very high resolution seismic images down to maximum 50 m sub-sea-floor. Preliminary seismic line interpretation of lines P4 and P23 Interpretation and visualization were done using the software package Petrel (Schlumberger) at Hamburg University.

Sediment Sampling and Analyses:

Meteor Research Cruise
Box core (20 cm) M74-4-1121
Piston cores M74-4-1120 (14.12 m) and M74-4-1144 (12.86 m)

Laboratory Research (Rice University)

Coarse fraction (>63 μ m) variation with depth
Strontium (Sr) counts variations with depth (XRF analysis) at Marum, University of Bremen
Bio-stratigraphic marker identification (G. ruber pink)
Carbonate preservation recognition, based on percent of whole pteropods

Results and Interpretation: Seismic lines

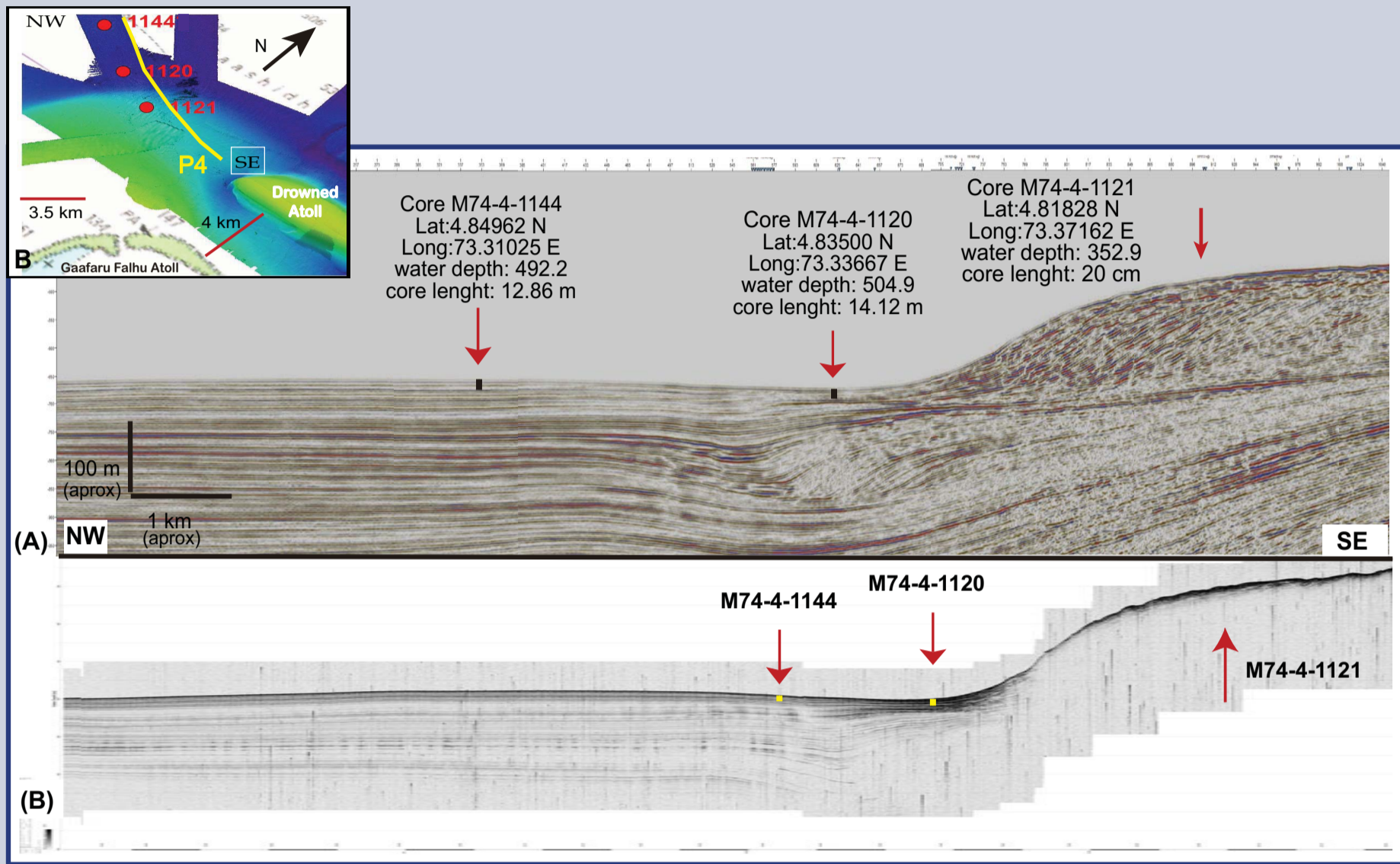


Figure 3. Seismic data acquired during NEOMA Research Cruise 2007. (A) Uninterpreted high resolution multi-channel seismic line P4 segment and (B) uninterpreted sub-bottom profiler P4 segment illustrating the well developed carbonate sediment drift on the southeast side of the lines. Box Core M74-4-1121, piston cores M74-4-1144 and M74-4-1120 are located on the P4 line. Line and cores are located on the inserted map.

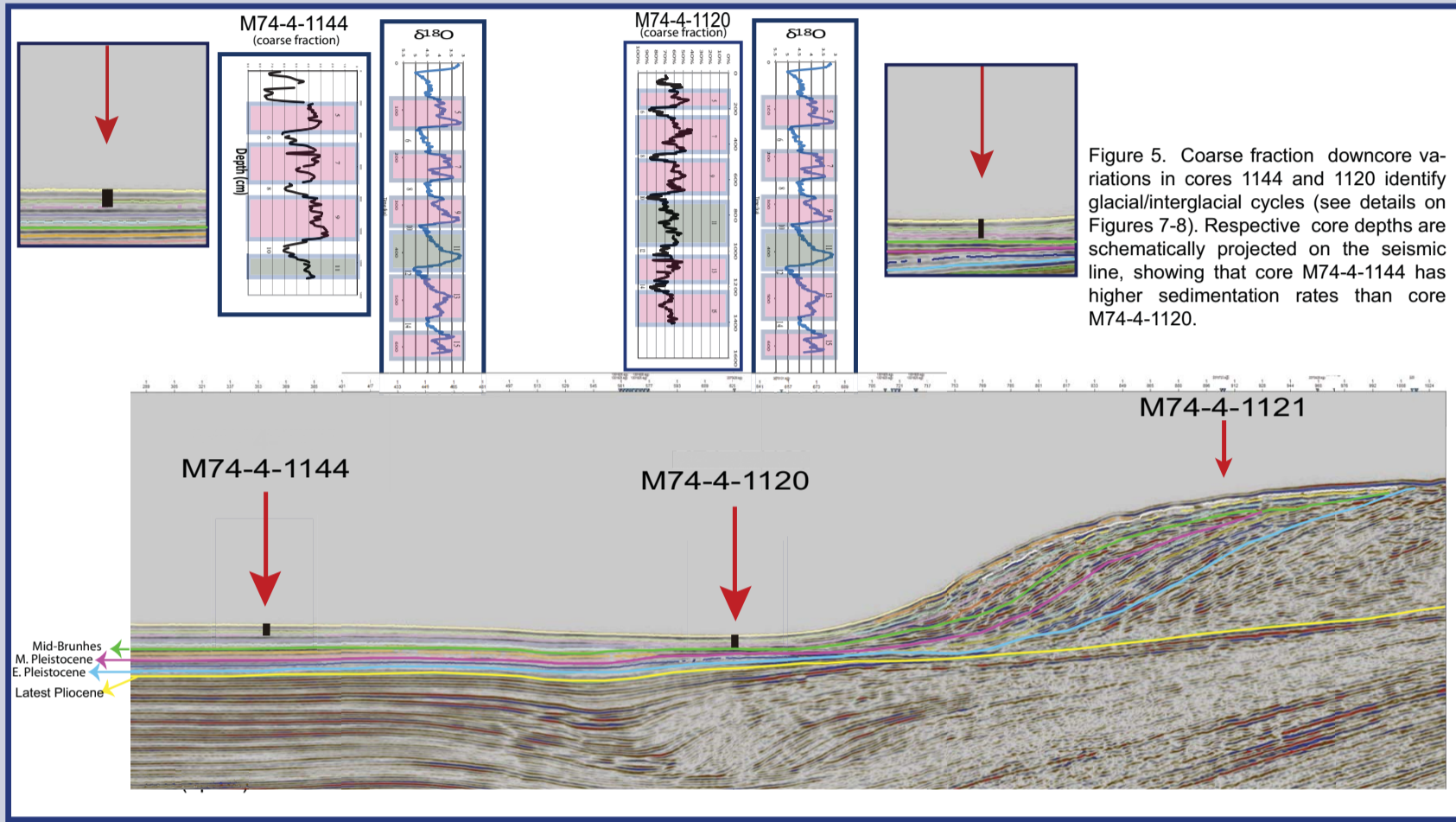


Figure 4. Segment of Seismic line P4 illustrating a preliminary interpretation of the carbonate sand drift. Box core and piston cores are located on the seismic line. The main prograding units of the carbonate sand drift are identified by colored continuous reflectors crossing through the toe front of the drift and into the basin. Time correlations with the stratigraphies developed in piston cores 1120/1144 and ODP Site 716 gave ages for the reflectors from latest Pliocene to mid-Brunhes.

Results and Interpretation: Core analysis

Lisiecki and Raymo (2005) Benthic Stack $\delta^{18}O$ (‰)

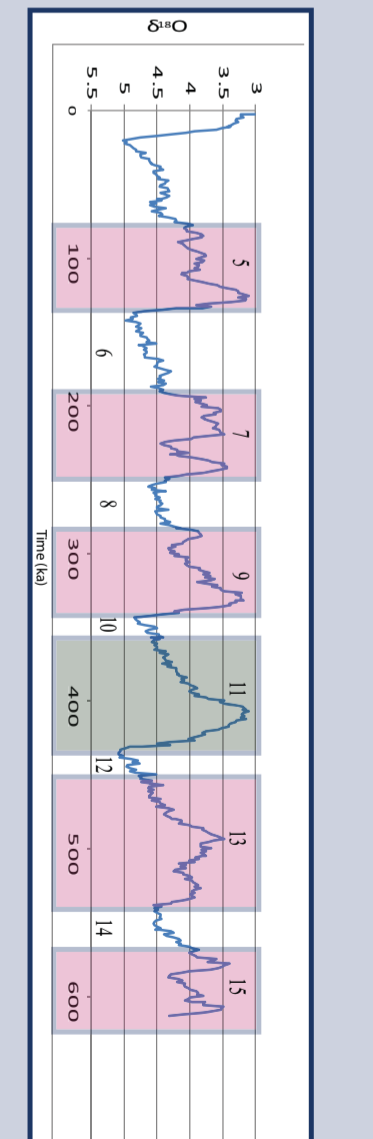


Figure 6. Benthic $\delta^{18}O$ stacked record showing climatic cycles from 621 ky (MIS 15/16 boundary) to present (Lisiecki and Raymo, 2005). Interglacials are represented by pink shaded intervals, the mid-Brunhes interglacial MIS 11 is highlighted by a light green shading.

Core M74-4-1144 Distal location of the carbonate sand drift

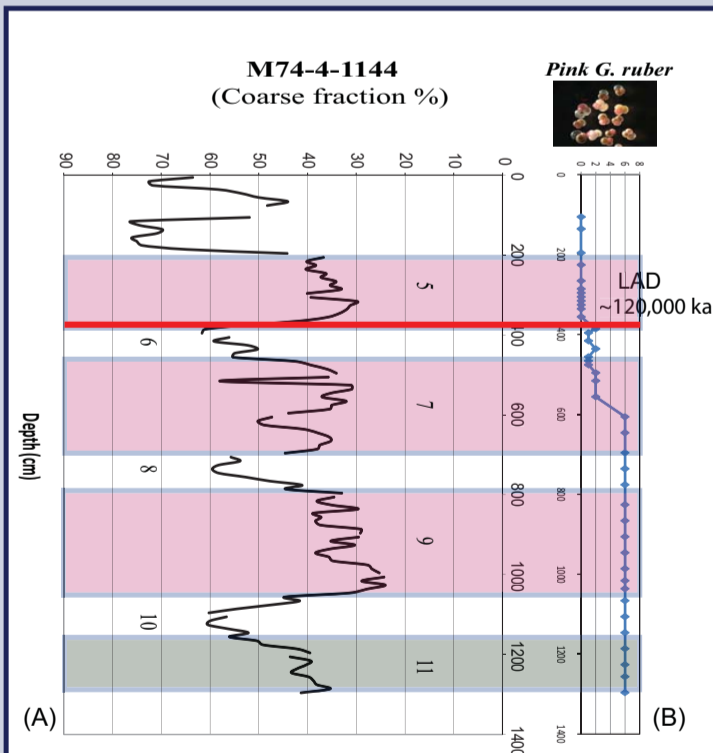


Figure 7. Core M74-4-1144, on a distal location relative to the carbonate drift shows glacial/interglacial cycles down to the end of MIS 11 (highlighted in light green), based on downcore variations of:

(A) % Coarse fraction > 63 μ m. The graphic displays a clear downcore cyclic pattern in sediment size fraction. Interglacial intervals, characterized by low coarse fraction values, are expanded by inclusion of fine argonite (<63 μ m). Glacial stages are condensed and characterized by high coarse fraction (>63 μ m) proportions (60-90%).

(B) % relative abundance of the *Globigerinoides ruber* pink; disappearance of *Globigerinoides ruber* pink marks the initiation of MIS 5.

Core M74-4-1120 Proximal location of the carbonate sand drift

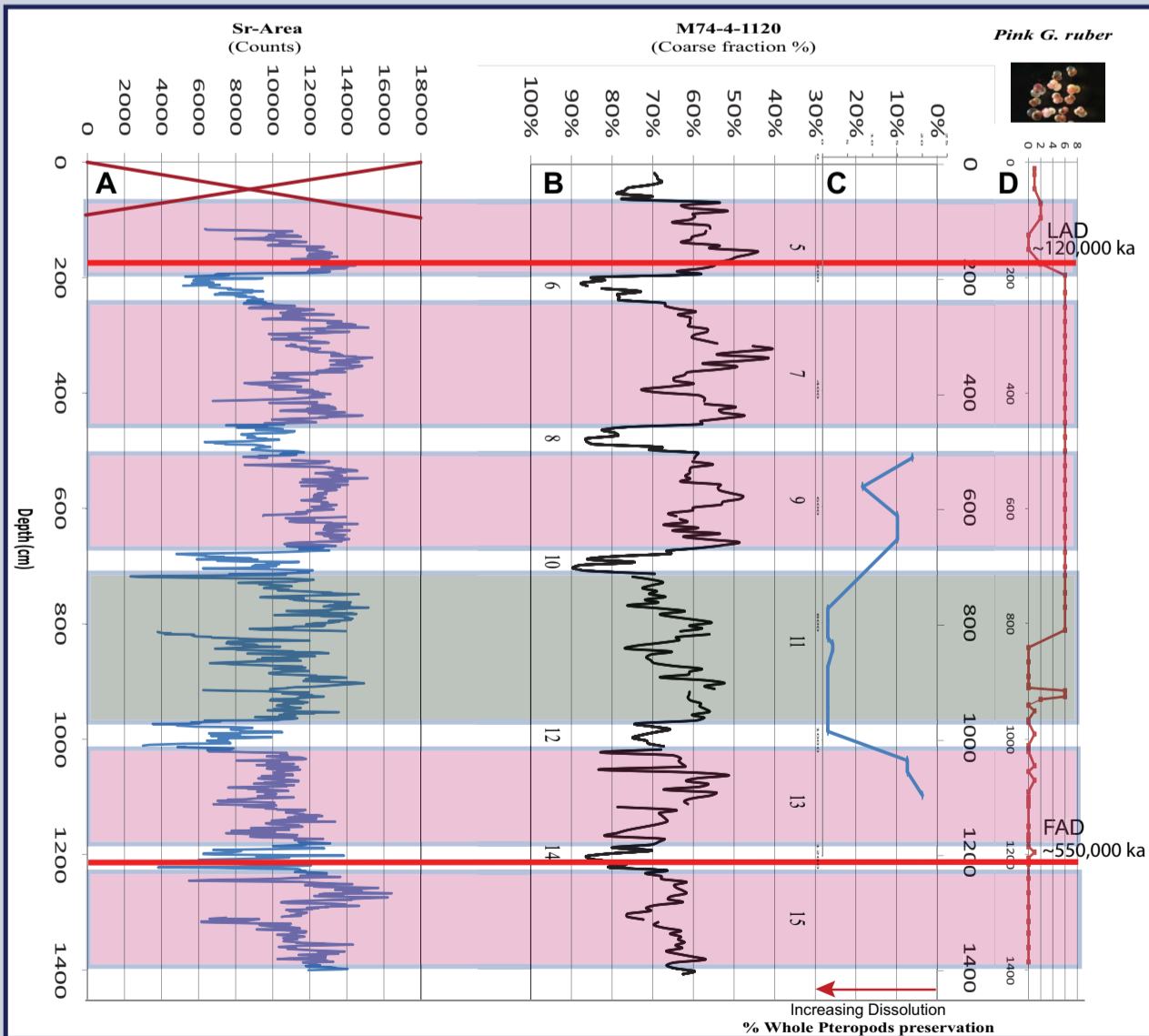


Figure 8. Core M74-4-1120, on a proximal location relative to the carbonate drift shows glacial/interglacial cycles down to the middle of MIS 15. Interglacials are represented by pink shaded intervals, the mid-Brunhes interglacial MIS 11 is highlighted by a light green shading. Core M74-4-1120 displays cyclic of downcore variations of:

(A) Sr counts, an excellent proxy for bank derived fine argonite. Strontium count: greatest values occur during interglacial highstand deposits.

(B) Coarse fraction % (> 63 μ m). Graphic displays a clear downcore cyclic pattern in sediment size fraction. Interglacial intervals, characterized by low coarse fraction values, are expanded by inclusion of fine argonite (<63 μ m) and high strontium contrast. Glacial stages are condensed and characterized by high coarse fraction (>63 μ m) proportions (60-90%).

(C) Proxy for carbonate dissolution, based on pteropods preservation. Results show a strong interval of dissolution centered in interglacial MIS 11 as globally observed (Droxler et al., 1990)

(D) % relative abundance of the *Globigerinoides ruber* pink; disappearance of *Globigerinoides ruber* pink marks the initiation of MIS 5 (Thompson et al., 1979) and the first appearance of *Globigerinoides ruber* pink identifies the beginning of MIS 14 (Zheng et al., 2005)

Latest Pliocene-Pleistocene Carbonate Sand Drift Evolution

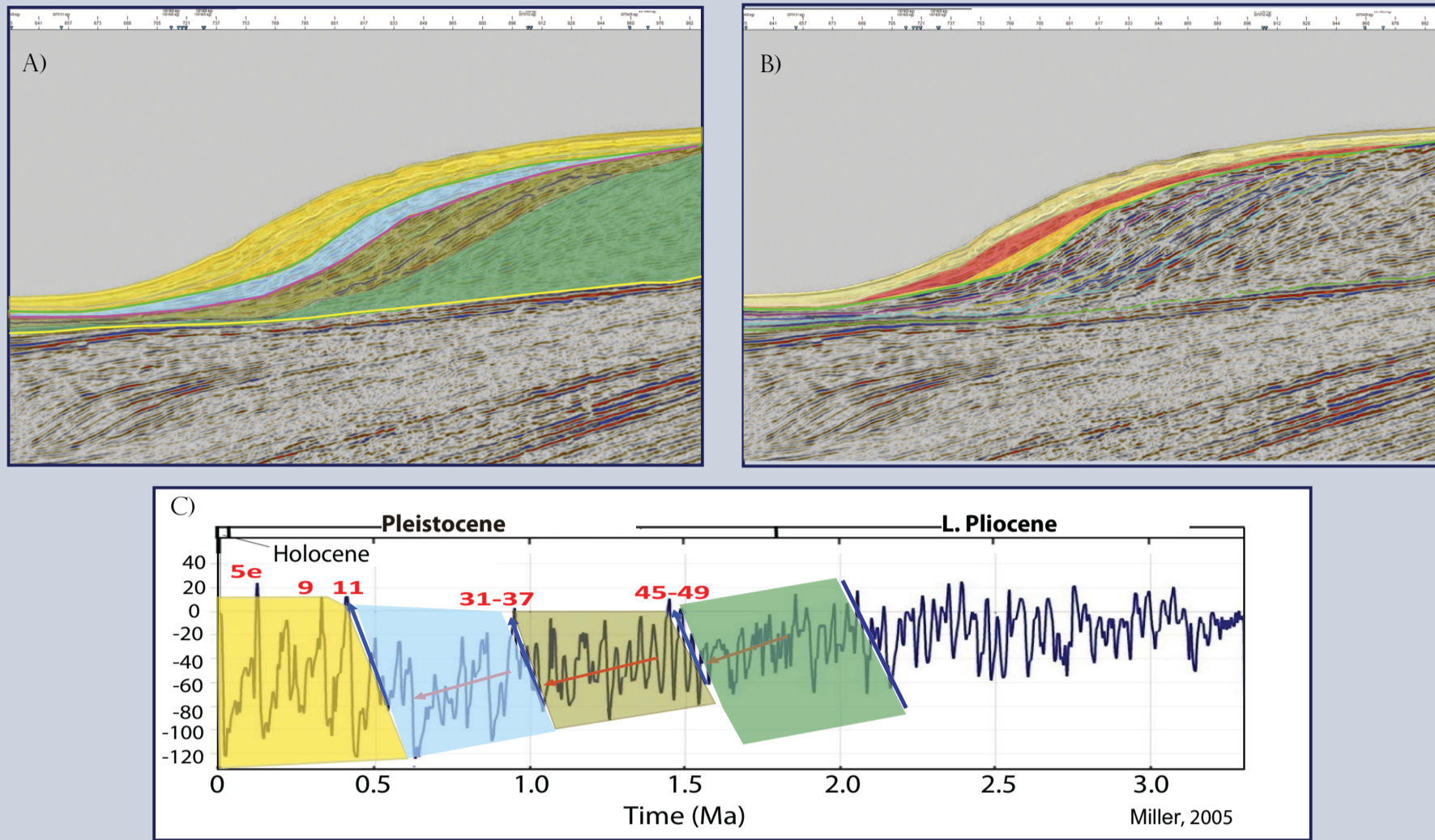


Figure 10. A) Three main units compose the Pleistocene younger half of the carbonate drift; the older half apparently is latest Pliocene in age. B) The youngest prograding main unit, made of three subunits, was initiated during the mid Brunhes based upon the stratigraphy developed in the proximal core M74-4-1120. The three subunits, forming the most recent toe of the carbonate drift front, would then correspond to the three main interglacial highstand intervals (MIS-11, MIS-9, and MIS-5, as shown in C). The underlying two main Pleistocene units (shown in A) are interpreted to represent unusually strong interglacial highstand intervals (MIS-31-37) in the mid-Pleistocene and MIS-45-49 in the early-Pleistocene as shown in C. The lower half of the drift is probably latest Pliocene in age, whereas the upper half of the drift is Pleistocene in age.

Conclusions

- During the NEOMA cruise, a 200 m-thick deep carbonate sediment drift in the area north of Gaafaru Falhu atoll (northeast Maldives Inner Sea) was extensively surveyed via 12 kHz multi-beam bathymetry, a 4 kHz sub bottom profiler (Atlas Hydrographics), and multi-channel high resolution seismics. Based on these surveys, the drift has been clearly imaged in three dimensions.
- One box core, M74-4-1121, was recovered on top of the carbonate drift itself and two 14 and 13 m-long piston cores were retrieved on the toe of its front, M74-4-1120 on a proximal location and M74-4-1144 on a more distal position.
- Because the 4 kHz energy source of the sub-bottom profiler could not penetrate the sediment drift, it is assumed that the coarse sand lithology encountered in the box core most likely represents the main lithology of the 200 m-thick sand drift.
- Both piston cores display downcore a clear cyclic pattern in sediment size fraction variability. Interglacial intervals are significantly expanded by inclusion of fine (< 63 μ) bank derived argonite and Sr-rich sediments, whereas intervening glacial stages are condensed and characterized by high coarse fraction (> 63 μ) proportions ranging between 60-90 % in both cores. Bio-stratigraphic markers help estimate that M74-4-1144 bottomed at the end of Marine Isotope (MIS) 11. The base of core M74-4-1120, displaying lower sedimentation rates than in core M74-4-1144, represents the middle of MIS 15.
- Observations of NEOMA high resolution MCS dip and strike lines in the area of the drift show that the upper half of the sedimentary drift, composed of three distinct wedge-like main units down-lapping on a series of unconformities, thins on the toe of the drift front into a very recent sequence not much thicker than 30 m. This thin sequence represents the complete Pleistocene based upon the preliminary stratigraphy established on the two NEOMA piston cores 1120 and 1144 and the more distal ODP Site 716. The lower half of the drift thins into an underlying unit not thicker than a few meters assumed to be latest Pliocene in age.
- The youngest prograding main unit, made of three subunits, was initiated during the mid Brunhes based upon the stratigraphy developed in the proximal core M74-4-1120. The three subunits, forming the most recent toe of the carbonate drift front, would then correspond to the three main interglacial highstand intervals (MIS-11, MIS-9, and MIS-5). The underlying two main Pleistocene units are interpreted to represent unusually strong interglacial highstand intervals (MIS-31-37) in the mid-Pleistocene and MIS-45-49 in the early-Pleistocene.
- Based upon these observations, the accumulation of the large and thick carbonate drift northwest of Gaafaru Falhu atoll was most likely initiated during the latest Pliocene. The lower half of the drift is probably latest Pliocene in age, whereas the upper half of the drift is Pleistocene in age.

References

- Belopolsky, A.V., and Droxler, A.W., 2004, Seismic expressions and interpretations of carbonate sequences: The Maldives carbonate platform, equatorial Indian Ocean: American Association of Petroleum Geologists Studies in Geology 49, 46 p.
- Betzler, C., Hubscher, C., Lindhorst, S., Reijmer, J.J.G., Romer, M., Droxler, A. W., Furstenau, F., and T. Ludmann, 2009, Monsoon-induced partial carbonate platform drowning (Maldives, Indian Ocean). *Geology* 2009;37:867-870, doi:10.1130/G25702A.1
- Cullen, J. L., and A.W. Droxler, 1990, Late Quaternary Variations in Planktonic Foraminifer Faunas and Pteropod Preservation in the Equatorial Indian Ocean, *Proceedings of the Ocean Drilling Program, Scientific Results*, Vol.115
- Lisiecki, L., & Raymo, M. E. (2005), A Pliocene-Pleistocene stack of 57 globally distributed benthic $\delta^{18}O$ records. *Paleoclimatology*.
- Miller, K.G., Komiz, M.A., Browning, J.V., Wright, J.D., Mountain, G.S., Katz, M.E., Sugarman, P.J., Cramer, B.S., Christie-Blick, N., and Pekar, S.F., 2005, The Phanerozoic record of global sea-level change: *Science*, v. 310, p. 1293-1298, doi:10.1126/science.1116412
- Thompson, P.R., Be, A. W. H., Duplessy, J.C., and N. J. Shackleton, 1979, Disappearance of pink-pigmented *Globigerinoides ruber* at 120,000 yr BP in the Indian and Pacific Oceans, *Nature* 280, 554 - 559 (16 August 1979); doi:10.1038/280554a0
- Zheng, F., Li, Q., Li, B., Chen, M., Tu, X., Tian, J., and Z. Jian, 2005, A millennial scale planktonic foraminifer record of the mid-Pleistocene climate transition from the northern South China Sea, *Paleogeography*, v. 223, Issues 3-4, 349-363.

Acknowledgments

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