CHAPTER 2

Chronologies of cores 905 and MD76-131

Abstract

Two marine cores were sampled and used for thus study. In order to compare these two cores with each other, as well as with additional records of climatic change, it is necessary to develop a chronology allowing time to be the common axis. The chronologies of cores 905 and MD76-131 are based on radiocarbon dating of foraminifera, carbonate secreting organisms that incorporate ^{14}C into their shells. In total 24 AMS ^{14}C dates are used in the 905 chronology and 7 are used the 131 chronology. With the developed chronologies, the Arabian Sea records of monsoon intensity closely correspond to ice core records (GISP2) of northern polar temperature variations over the 35 kyr. The similarity between these records provides the rational for assuming continued coherence in the sediments beyond the capability of radiocarbon dating. Therefore, the Arabian Sea records are "tied" to GISP2 between 35-90 kyr.

Chronology of core 905

The chronology of core 905 is based on 24 radiocarbon (^{14}C) dates from mixed planktonic foraminifera (Table 1). An additional 6 AMS ^{14}C dates agree within the errors of the method but are not directly used in the chronology. The $\delta^{18}O$ record from core 905, which was produced at the Free University of Amsterdam and provided by D. Kroon, supports the age model. The $\delta^{18}O$ record was developed using the planktonic foraminifer *Neogloboquadrina dutertrei* from the sedimentary fraction greater than 250 μm. Transitions between Marine Isotope Stages (MIS) 1-5 and Dansgaard-Oeschger (D-O) events can be identified in the 905 $\delta^{18}O$ record. Measurements of stable oxygen isotopes were performed on about 5 specimens of *N. dutertrei* per sample using a Finnigan MAT 252 mass spectrometer. All isotope results are given relative to the PDB standard in permil. Long term reproducibility of a routinely analysed in-house $CaCO_3$ standard is better than about 0.09 ‰ for oxygen.

The $\delta^{18}O$ and $\delta^{15}N$ records from core 905 were originally used as a guide, from which samples for AMS ^{14}C dating were chosen (Figure 1). Samples thought to relate to specific events previously identified in other marine records, such as Heinrich Events 1-3 (Figure 2) and D-O interstadials were dated, as well as transitions through the Bølling-Ållerød and the Younger Dryas (Table 2). Nine samples were dated in the Holocene with general coverage. Holocene dates were provided by E. Ivanova (2000) and S. Jung et al. (2002a, b).

The age model for core 905 was constructed in two parts: the Holocene (0-11kyr) (Figure 3) and the Last Glacial (11-90 kyr) (Figure 4). As variations in the local reservoir age pose difficulties in transferring radiocarbon ages to Calendar Ages, independently dated records were used as comparative sites. The two components of the 905 chronology are discussed below.

The Holocene

The location of core 905 was chosen to specifically understand variations in monsoon-induced upwelling. The upwelling of deep, nutrient rich water also supplies the surface waters with "old" water that has experienced extensive ^{14}C decay. The reservoir age of the western Arabian Sea is therefore larger than the global average (400 years). It is also understandable that the local reservoir age could change over time with variable

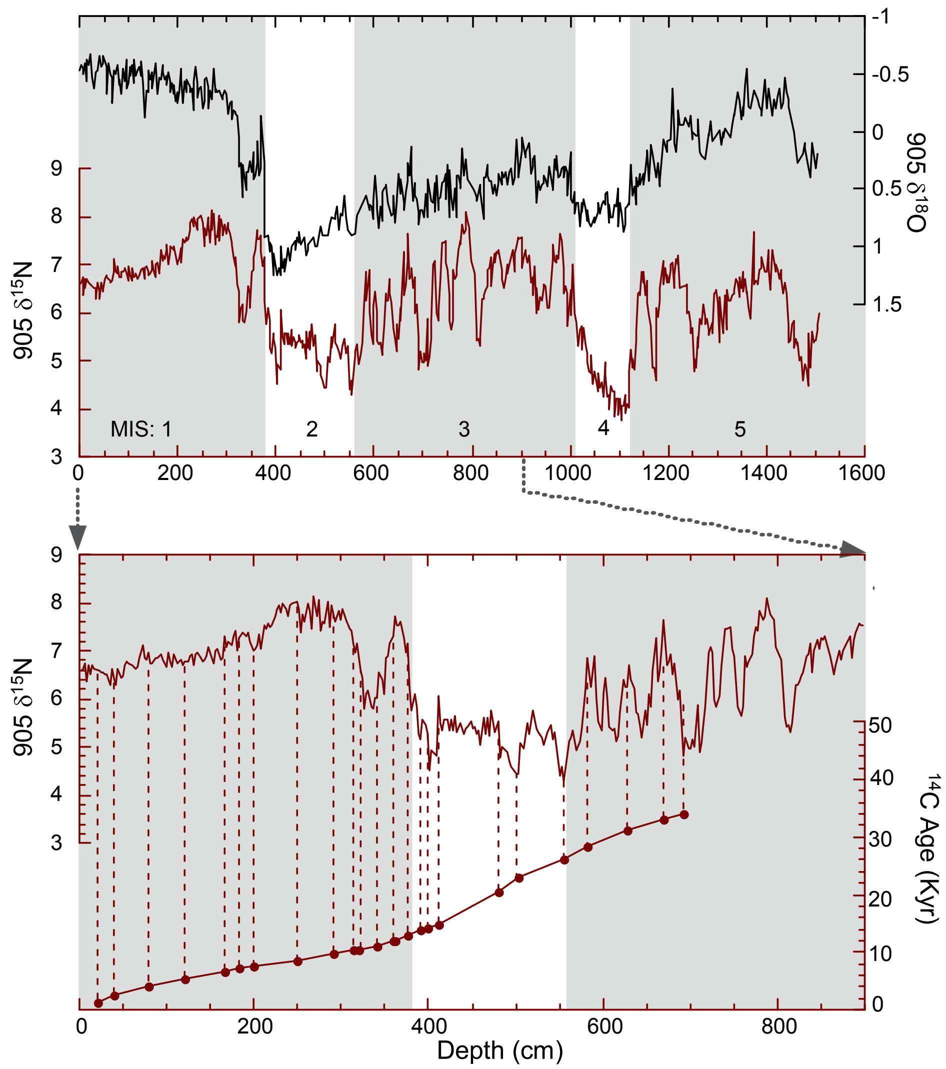

Figure 1. The AMS^{14}C dated samples of core 905. A. A comparison of the δ^{15}N and the δ^{18}O records for the entire 905 core used in this study. Shaded areas indicate Marine Isotope Stages 1,3,5. B. An expanded subset of the core 905 samples. Dashed lines identify the AMS ^{14}C dated samples. The grey arrows are used to identify the portion of the dataset that is expanded.

upwelling. An average reservoir age of 604 years was calculated for the western Arabian Sea, based on ^{14}C measurements of known age mollusc, gastropod and coral samples from 7 sites in the region (Southon et al., 2002). However, a detailed study determined that the reservoir age of the Northern Arabian Sea has varied from 600-1200 years during the Holocene (Staubwasser et al., 2002). This large range in "possible" reservoir results in adding significant uncertainty to any Arabian Sea chronology. Therefore, two preliminary Holocene age models for the 905 site were constructed using Calib 4.4 (Stuiver et al., 1998) to convert AMS ^{14}C ages to calendar ages (years before 1950) and then Analyseries was used to develop the linear interpolation of the ages for the entire core (Figure 3). The first model (Model 1) relied on an average reservoir age of 604 years; the second (Model 2) used the variable reservoir ages from Staubwasser et al. (2002). In order to determine which of these two Holocene age models would be more appropriate for the 905 core, a nearby speleothem record was used as a comparative record of local climatic variation.

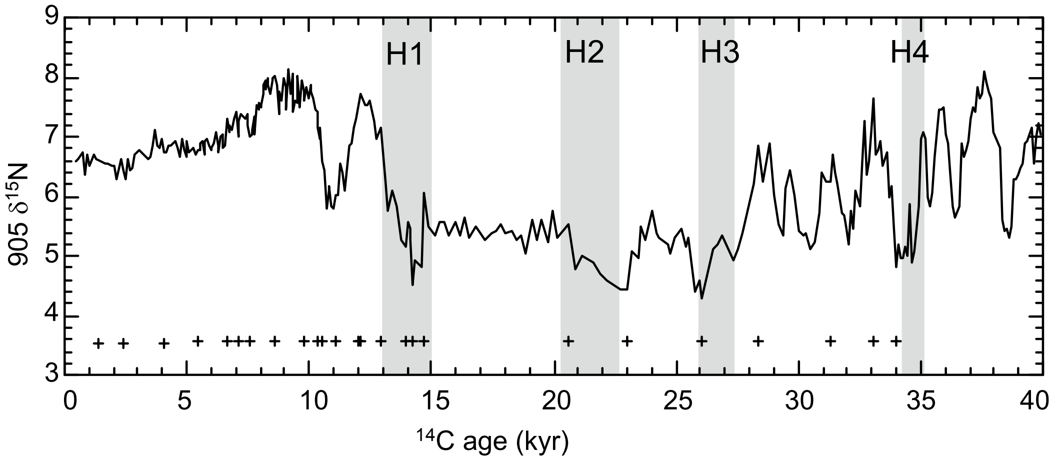

Figure 2. A comparison between the timing of Heinrich Events identified in the North Atlantic Ocean and changes in the Arabian Sea summer monsoon intensity. Shaded bands represent the timing and duration of Heinrich Events (H1-4) as identified by Elliot et al. (1998) and the crosses indicate the position of AMS ^{14}C dated samples from core 905.

The precipitation over Oman is related to the Arabian Sea monsoon intensity (Fleitmann et al., 2003; Neff et al., 2001), as is the upwelling induced at site 905. Therefore, large "events" in the Qunf Cave (Q5) speleothem $\delta^{18}O$ record are assumed to be synchronous with those in the 905 $\delta^{15}N$ (Fleitmann et al., 2003). The most significant variation between the two possible 905 age models occurs between 7-12 kyr (Figure 3). Within this period the "8.2" event is distinct in the Q5 record. A comparison of the timing of this event using the two 905 age models indicates that the constant reservoir age model (604 years) shows the larger degree of similarity with the Q5 record. The extreme reservoir ages of over 1000 years, as seen in the Northern Arabian Sea (Staubwasser et al., 2002) do not appear to be pertinent to the 905 records. The final age model for core 905 has not been tied to Q5 and relies solely on the 11 ^{14}C AMS dates converted to Calendar years using a constant reservoir age of 604 years. The Holocene chronology determined for core 905 by imposing a reservoir age of 604 years is in close agreement with the chronology used by Jung et al., 2004.

			Holocene Model 1		Holocene Model 2	
Depth (cm)	^{14}C age	±error 1σ	Reservoir age	Calendar age	Reservoir Age	Calendar Age
20^	1410	N/A	604	741	640	709
40^	2420	N/A	604	1813	640	1772
80^	4050	N/A	604	3790	640	3749
120^	5410	N/A	604	5569	640	5532
167*	6653	40	604	6924	640	6880
183*	7125	45	604	7427	825	7230
200^	7620	45	604	7869	825	7650
249*	8620	45	604	8914	1010	8459
291*	9748	50	604	10214	780	10034
313.75	10371	47	604	11062	780	10784
320^	10500	N/A	604	11216	780	11004
340^	11100	N/A	604	12260	1070	11373
360^	12000	N/A	604	13269	1070	12904
361.25	12131	62	604	13329	1285	12816
376.25	12895	52	604	14310	-	-
391.25	13975	55	604	15977	-	-
400^	14190	N/A	604	16235	-	-
411.25	14701	61	604	16823	-	-
480.25	20580	114	604	23332	-	-
500^	20940	N/A	604	23752	-	-
502.75	23005	164	604	26164	-	-
510.25	22780	147	604	25902	-	-
555.25	26094	211	604	29772	-	-
582.75	28370	400	604	32431	-	-
590^	27100	N/A	604	30947	-	-
615.25	28694	284	604	32809	-	-
627.75	31312	791	604	35867	-	-
670.25	33105	989	604	37961	-	-
692.75	33963	1103	604	38963	-	-
722.75	36468	1495	604	41889	-	-
785.25	40786	2570	604	46933	-	-
812.75	42701	3264	604	49169	-	-

Table 1. AMS ^{14}C dates and the calculated Calendar ages for core 905. Model 1 uses the average reservoir age of the western Arabian Sea from Southon et al., 2002. Model 2 uses the variable reservoir ages from Staubwasser et al., 2002. The symbol ^ indicates dates provided by Ivanova, 2000. Errors are not available (N/A) for these data. The symbol * indicates dates provided by Jung et al., 2002a. Red is used to highlight the age reversals. Blue is used to indicate samples not included directly in the age model but that support the age model within the error of the dates.

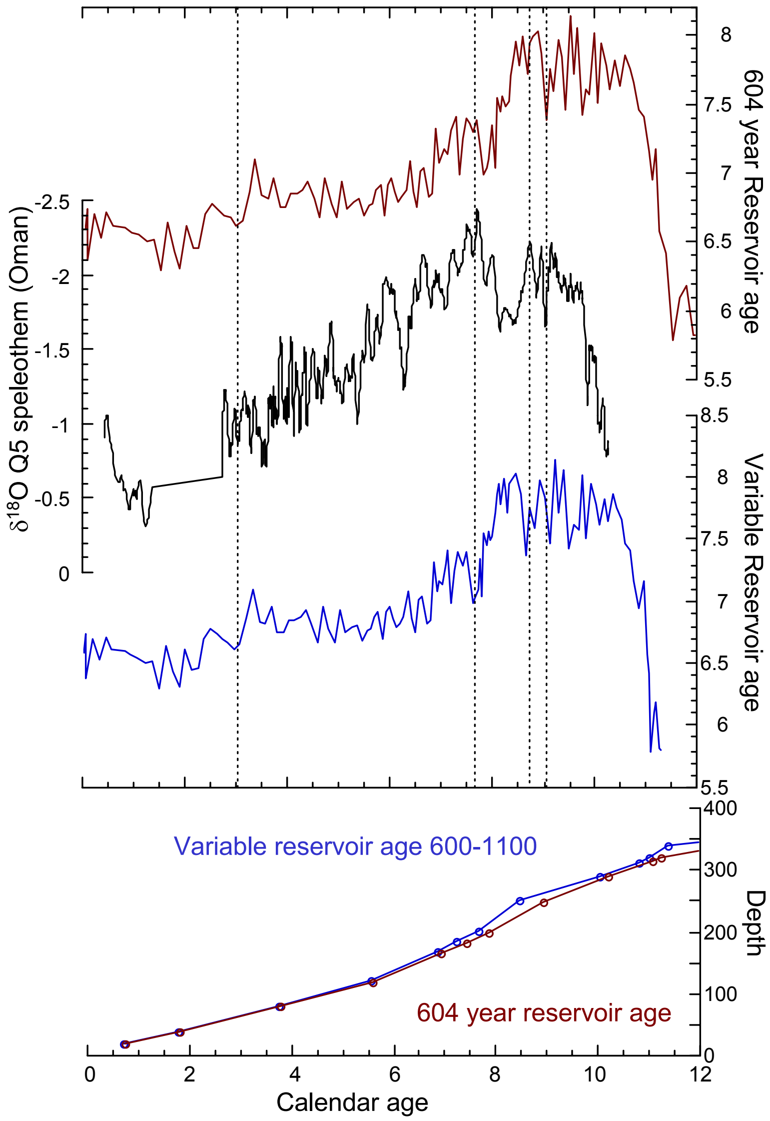

Figure 3. The Holocene chronology for core 905: Comparing two model that use different reservoir ages. Dashed lines are to direct the eye and help compare the onset and termination of the early Holocene event between 9-8 kyr and the transition at 3 kyrs.

The Last Glacial

Downcore $\delta^{15}N$ measurements from Core 905 reveal 9 periods of extreme low values in the 14 m core (Figure 4). The AMS ^{14}C dates of the first 4 of these periods agree with the ^{14}C ages of Heinrich Events in the North Atlantic (Figure 2). Earlier events are beyond the range of ^{14}C dating techniques. Elliot et al., (1998) determined dates for the onset and termination of Heinrich Events 1-4. These dates are listed in Table 2. The dated samples from core 905 that correspond with minimum $\delta^{15}N$ values fall within the range of dates for Heinrich Events determined by Elliot et al., (1998)((Figure 2). To be consistent with Elliot et al., (1998), interpolated ages for the onset and termination of events identified in the core 905 $\delta^{15}N$ record were calculated using the midpoint of the transitions that lead into and out of an event. The interpolated dates for the onset and termination of the core 905 events are listed in Table 2. The average reservoir age used in the North Atlantic is 400 years and the reservoir age that appears to be appropriate in the Arabian Sea is 604 years. Despite differences in these local reservoir ages and the AMS ^{14}C dating error, which increases with age, the timing of Heinrich Events 1-4 in the North Atlantic and the Arabian Sea correlative event are remarkably similar. The comparison of well-dated Heinrich Events in North Atlantic sediment records with events reflected in the 905 sediment record supports the assumption that global climate changes are occurring synchronously.

		^{14}C age core 905	error 2σ	^{14}C age Elliot (1998)	error 2σ
Younger Dryas	termination	10.58	0.1	-	-
	onset	11.55	0.1	-	-
Bolling-Allerod	termination	11.55	0.1	-	-
	onset	13.07	0.1	-	-
Heinrich 1	termination	13.67	0.1	13	0.1
	onset	14.64	0.1	15	0.2
Heinrich 2	termination	20.6	0.3	20.2	0.2
	onset	23.09	0.3	22.4	0.3
Heinrich 3	termination	25.68	0.4	25.9	0.4
	onset	26.51	0.5	27.4	0.4
Heinrich 4	termination	33.95	2	34.2	0.6
	onset	-	-	35.2	0.6

Table 2. A comparison of AMS ^{14}C dated events defined by $\delta^{15}N$ minima in the Arabian Sea core 905 with Heinrich Events identified in cores from the North Atlantic. Elliot et a., 1998 provide the AMS ^{14}C dates for the onset and termination of Heinrich Events 1-4 determined using four sediment cores from the Irminger Basin and North Atlantic Ocean. Interpolated ages for the core 905 $\delta^{15}N$ minima were calculated as the midpoint of the transition into and out of an event. The error listed is the AMS ^{14}C dating error and does not include error associated with the reservoir ages.

Bond et al., (1995) correlated Heinrich Events in the North Atlantic sediments with temperature variations in the Greenland (GRIP) $\delta^{18}O$ record. Heinrich Events corresponded to cold periods (stadials), which preceded large, rapid transition to warmer temperatures (interstadials) (Bond et al., 1995). The AMS ^{14}C dated intervals in the core 905 record that coincide with Heinrich Events, also correlate with cold periods in the $\delta^{18}O$ Greenland (GISP2) temperature records (Figure 4).

A visual comparison of the 905 $\delta^{15}N$ record with the GISP2 $\delta^{18}O_{ice}$ record of polar temperature also reveals that millennial-scale variations, similar to D-O cycles, are reflected in the 905 $\delta^{15}N$ records. Previous studies using AMS ^{14}C dated sediments from the Arabian Sea (Altabet et al., 2002; Schulz et al., 1998) have determined that Greenland temperature excursions are synchronous with variations in the Arabian Sea monsoon records. This conclusion has been supported by the appearance of the Toba ash in northern Arabian Sea sediments (Schulz et al., 2002). The Toba volcanic eruption in the Indonesian Archipelago occurred 71 kyr ago and was used by Schulz et al. (2002) as an independent age marker, visible in both the Arabian Sea sediment record and the Greenland ice core record. The Toba ash falls between D-O interstadials 19 and 20, providing a tie point between the Arabian Sea records and Greenland temperature at a period beyond the capability of AMS ^{14}C dating. Although the Toba ash layer has not yet been identified in core 905, the two large peaks in monsoon intensity identified using productivity proxies in the Northern Arabian Sea sediments are also evident in the 905 $\delta^{15}N$ records. The core 905 AMS ^{14}C dating between 0-35 kyrs correlates variations in monsoon intensity with Heinrich Events in the North Atlantic Ocean and D-O variability in the GISP2 ice core and supports the assumption of continued synchroneity between climate events recorded in Greenland and those recorded in the Arabian Sea sediments between 35-90 kyrs.

The conversion from AMS ^{14}C ages to Calendar Ages of samples 25,000 years and younger was done using Calib 4.4 (Stuiver et al., 1998). Ages older than 25,000 were converted to Calendar Ages using the equation of Bard et al, (1993). A constant reservoir age of 604 years (discussed above) was applied to samples older than 11,000 years. Two age reversals were noted in core 905 at 510.25 and 590 cm depth. The deeper reversal appears anomalously young, being 2000 years younger that the previous sample. The shallower reversal is small can possibly be explained by the error of the dating method. The two dates relating to the reversals were excluded from the final chronology. Four additional dates (marked in blue in Table 1) were not used directly in the chronology. These dates agree with the constructed chronology within the error of the AMS ^{14}C dating method (Figure 4).

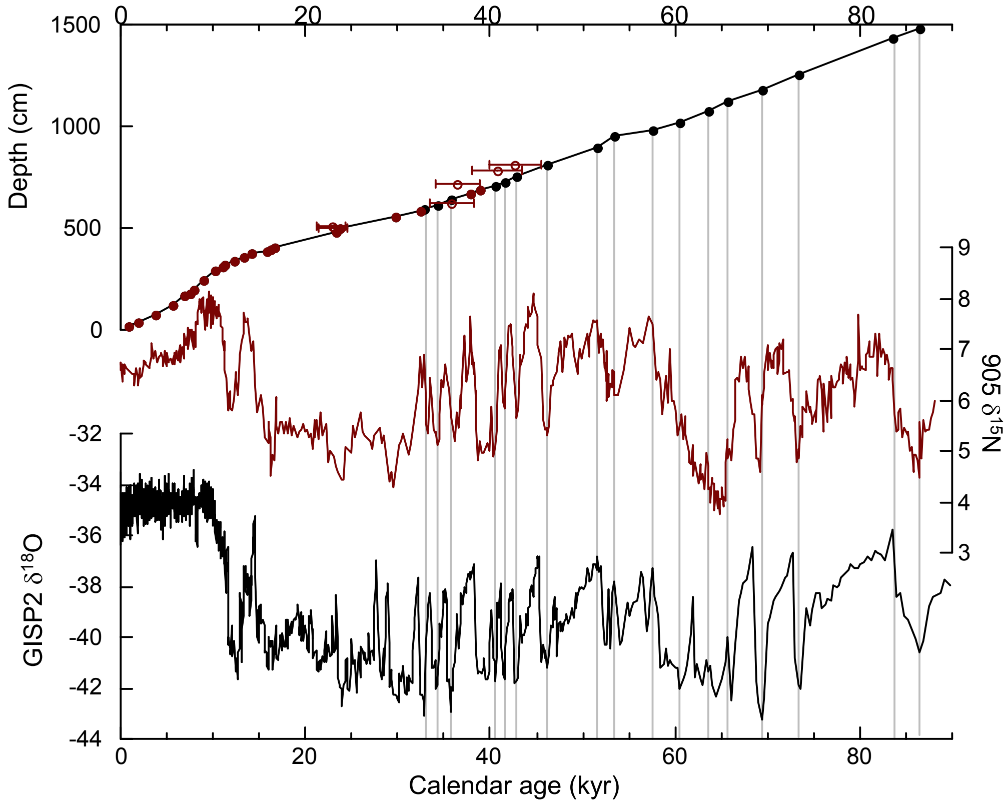

Figure 4. Developing the pre-Holocene chronology for core 905. The open circles with error bars represent dates that support the age model but were not used in the final chronology. Black circles between 35-90 kyr indicate the position of tie points between the 905 core and GISP2. The grey lines highlight the core 905 samples that were tied to the GISP2 $\delta^{18}O_{ice}$ record.

The core 905 $\delta^{15}N$ record was then plotted using Calendar Ages and compared to the GISP2 $\delta^{18}O_{ice}$ record of temperature changes in the northern polar region. The calculated Calendar Ages for events younger than 40 kyr indicate a strong correlation with the D-O cycles evident in the GISP2 temperature record (Figure 4). The three dates older than 40 kyr are not in as close agreement with the GISP2 $\delta^{18}O_{ice}$ record. However, these dates are at the very limit of effective ^{14}C dating and the associated errors (2σ) are up to 7000 years, therefore, within the error associated with the dating method, these three dates do support the correlation with GISP2 $\delta^{18}O_{ice}$ (Table 1). The strong resemblance between dated events in the core 905 $\delta^{15}N$ record and GISP2 D-O stadial/interstadials provides the rational for "tying" the deeper section of the 905 record to the GISP2 $\delta^{18}O_{ice}$ record (samples beyond AMS ^{14}C dating capability). This was achieved using AnalySeries (Paillard et al., 1996). The final chronology for core 905 is based on 24 AMS ^{14}C dates and 17 ties to the GISP2 $\delta^{18}O_{ice}$ record.

Sedimentation Rate at Site 905

The constructed age model for core 905 indicates a near-linear sedimentation rate of approximately 16.5 cm/kyr from 90-30 kyr (Figure 4). This decreased to approximately 13 cm/kyr during the LGM. The sedimentation rate during the Holocene increased to ~21cm/ky between 10-6 kyr and 19 cm/ky from 6-0.4 kyr. The transition at ~6 kyr from a high sedimentation regime to a lower sedimentation regime coincides with the end of the Early Holocene "Humid period" (deMenocal et al., 2000; Gasse, 2000) It also occurs at the beginning of a plateaux in the $\delta^{15}N$ record following a 4000 year decline. Therefore it likely represents a decrease in the biological productivity at this site resulting from a decline in the strength of the SW Monsoon. Consequently, the sample resolution of the data presented ranges from 75-150 years.

Chronology of core MD76-131

Depth (cm)	^{14}C age	error ±	Cal age (kyr)
9	4.146	0.35	3.986
68	10.142	0.36	10.781
103	11.246	0.39	12.632
140	12.799	0.44	14.211
154	12.405	0.39	13.647
174	14.118	0.41	16.173
204	15.425	0.65	17.681
360	24.732	0.86	28.410

Table 3. AMS ^{14}C dates for core MD76-131. The sample in red is an age reversal. This sample was not used in the final chronology of core MD76-131.

The chronology of core MD76-131 is based on 7 AMS radiocarbon ages providing independent age control between 4-28 kyr BP (Figure 5). AMS ^{14}C ages were converted to Calendar Age by Calib 4.4 using a reservoir age of 640 years for this site near Goa, as determined by Southon et al (2002) (Table 3). A minor age reversal occurred at 154 cm. This age was not included in the final chronology but is not in conflict with the derived age model of core MD76-131 within the error of the dating method. In the near future, additional ^{14}C dates will be added for the period between 30-35 kyr BP. The $\delta^{18}O$ record of core MD76-131(Ganeshram et al., 2000) provides a tie point for the MIS 3/ 4 transition. Additional control for the lower section of the core was determined by comparing the $\delta^{15}N$ record of MD76-131 with the 905 $\delta^{15}N$ record.

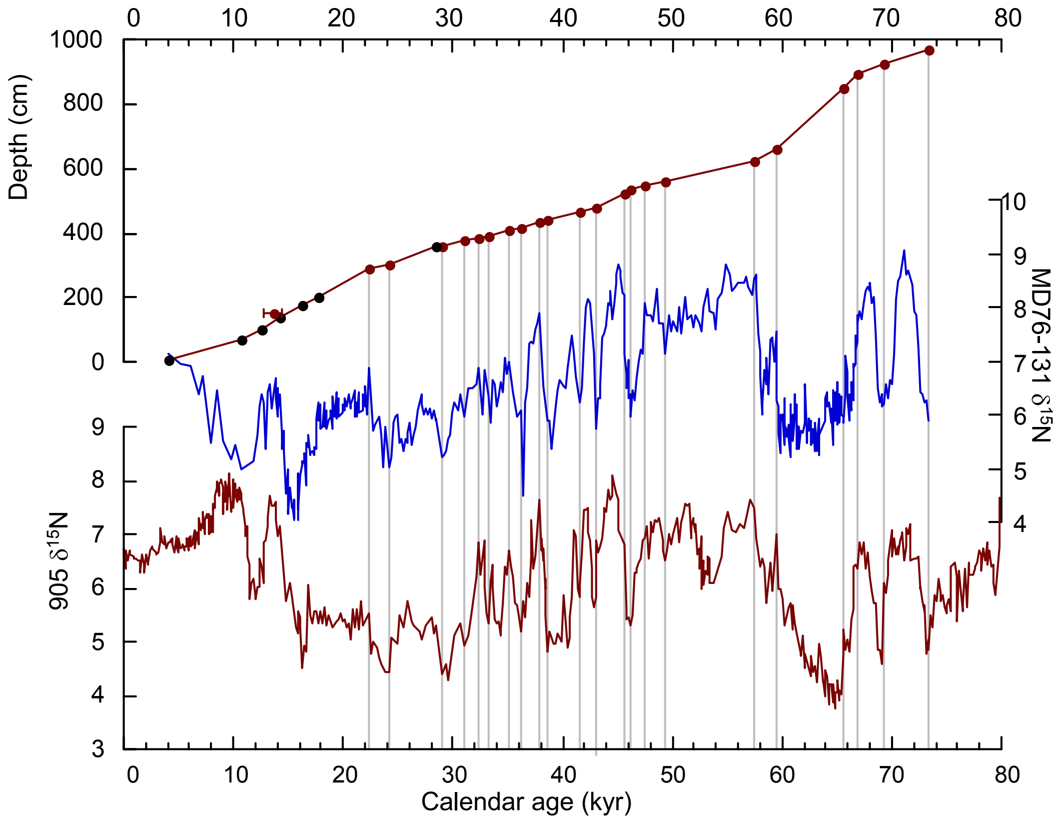

Figure 5. The development of the core MD76-131 chronology. Samples from the MD76-131 core that were dated using AMS ^{14}C techniques are identified by black circles. One minor age reversal occurred at approximately 12 kyr. That age was not included in the chronology and is signified by the marker with error bars attached. The tie points to the 905 core are represented by the red circles and grey lines between 24-75 kyrs.

Today a basin-wide Oxygen Minimum Zone (OMZ) is maintained in the Arabian Sea between 150-1250 m water depth by the high flux of organic matter through the water column and by moderate ventilation of the intermediate waters (Calvert et al., 1995; Reichart et al., 1998). The $\delta^{15}N$ paleo-record of the Arabian Sea reflects changes in the intensity of the OMZ (Altabet et al., 2002; Ganeshram et al., 2000; Naqvi et al., 1998). Therefore the basin-wide nature of the $\delta^{15}N$ signal can be used to compare the 905 core and MD76-131 core (Figure 5). Tie points were placed to constrain millennial scale transitions in the record.

In contrast to the sedimentation rates determined for the Somali Margin, the lowest sedimentation rates, ~ 8.7 and 9.8 cm/kyr, on the Indian margin occur during the Holocene and MIS 3 respectively (Figure 5). During the last glacial period the sedimentation rate increased to ~ 18 cm/kyr. The highest sedimentation rate of 24 cm/kyr corresponds to MIS 4.

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