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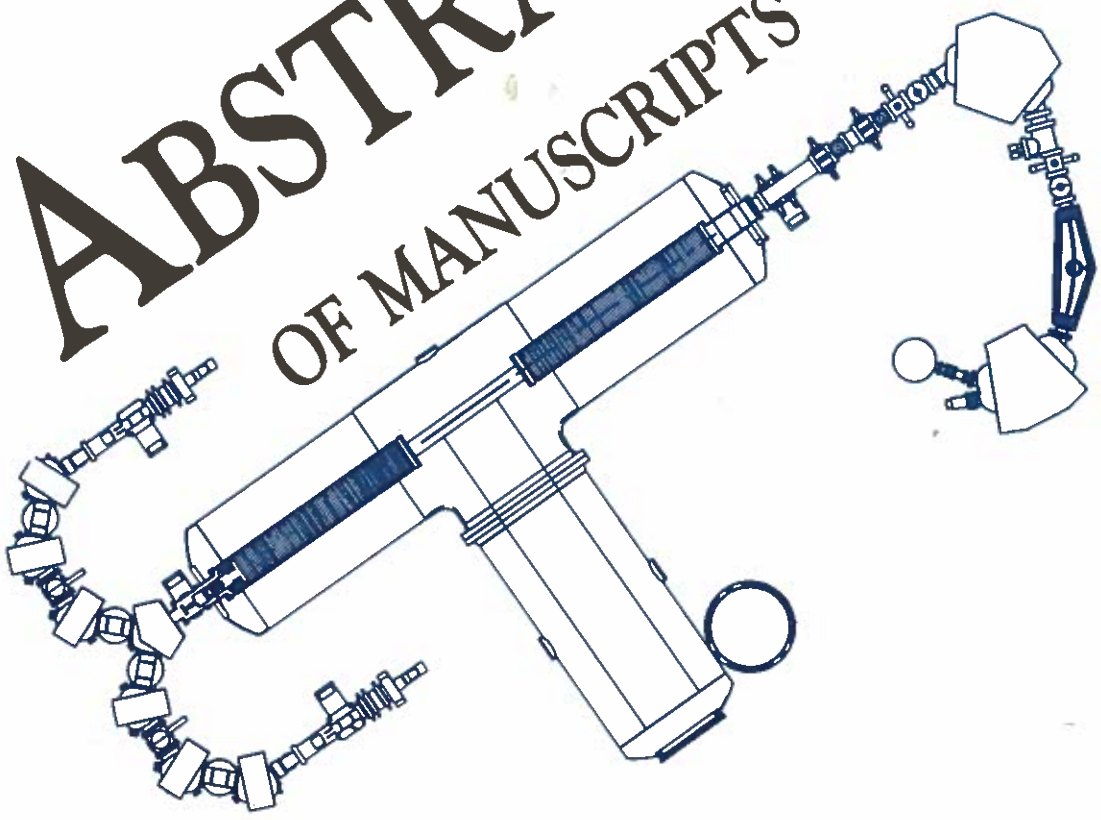
AMS Pulse

The National Ocean Sciences Accelerator Mass Spectrometry Facility Newsletter

ABSTRACTS OF MANUSCRIPTS



Submitted and/or published in 1993

by National Ocean Sciences AMS Facility Staff Members

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Accelerator Mass Spectrometry (AMS) Applications

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Varve calibrated records of carbonate and organic carbon accumulation over the last 2000 years in the Black Sea

M.A. Arthur, W.E. Dean, E.D. Neff, B.J. Hay, J.W. King and G.A. Jones

Sedimentologic and geochemical studies of box and gravity cores recovered from the Black Sea during the first of a multi-leg international Black Sea expedition in 1988 allow reconstruction of the basin wide Holocene environmental history of the Black Sea. In the deep parts of the basin, box cores typically recovered a flocculant surface "fluff" layer, laminated coccolith marls of Unit I (25 to 45 cm thick), and the upper 5 to 10 cm of finely laminated, dark-colored sapropels of Unit II. Fine-grained, homogeneous mud turbidites are interbedded with Units I and II over much of the basin, but the stratigraphic position of these turbidites differs from site to site. The deposition of individual turbidites up to 15 cm thick does not appear to have significantly disturbed underlying laminae.

Organic-carbon accumulation rates in Unit I are somewhat antithetic to those of carbonate, and, on the basis of this and additional constraints placed by pyrolysis and carbon isotopic analyses of organic material, it appears that terrestrial organic matter is an important component (perhaps >25%) of total organic carbon burial in the basin. Unit I in the western basin has a higher terrestrial organic component and higher accumulation rates of terrigenous clastic material than Unit I in the eastern basin, as expected because of the major rivers that empty into the western basin from eastern Europe and the former Soviet Union. Shallower slope sites, but still within anoxic bottom waters, have lower organic carbon accumulation rates and lower pyrolysis hydrogen indices than deep-water basinal sites, suggesting selective resuspension and oxidation of organic matter at basin margins and focusing of organic matter deposition towards the basin center. Comparison of productivity-normalized, organic-carbon accumulation rates from the anoxic Black Sea with open ocean oxic settings at similar water depths and bulk accumulation rates suggests that, although high, organic-carbon accumulation rates are not significantly higher under anoxic conditions than expected for the same bulk accumulation rates under oxic conditions.

In press: *Global Biogeochemical Cycles*

Supported by: NSF: OCE-8713181

WHOI Contribution Number: 8561

Lake Miragoane, Haiti (Caribbean)

M. Brenner, J.H. Curtis, A. Higuera-Gundy, D.A. Hodell, G.A. Jones, M.W. Binford and K.T. Dorsey

Lake Miragoane is one of the largest, deepest, freshwater lakes in the Caribbean (area = 7.06 km^2, maximum depth = 41 m, conductivity = 350 µS cm^{-1}). The basin lies in limestone terrain and is situated in a tectonic rift system on the north shore of Haiti's southern peninsula. The lake surface is 20 m above mean sea level. Chronology for a 7.7 m sediment core is based on ^{210}Pb dating, conventional ^{14}C dates on bulk organic matter, and the AMS ^{14}C dates on ostracode shells and terrestrial wood. The core spans the sedimentary record from approximately 10.5 ka BP to present. Geochemical, palynological and stable isotope data elucidate the paleoecology and paleoclimate of this island site.

Published in: Kelts, K. and Gierlowski, E. (eds.), *Global Geological Record of Lake Basins* (IGCP Project 219). Cambridge University Press, Cambridge, 403-405

Supported by: NSF: OCE-8702509

Lake-Level history of Lake Michigan for the past 12,000 years: The record from deep lacustrine sediments

S.M. Colman, R.M. Forester, R.L. Reynolds, D.S. Sweetkind, J.W. King, P. Gangemi, G.A. Jones, L.D. Keigwin and D.S. Foster

Collection and analysis of an extensive set of seismic-reflection profiles and cores from southern Lake Michigan have provided new data that document the history of the lake basin for the past 12,000 years. Analyses of the seismic data, together with dating, magnetic, sedimentologic, isotopic, and paleontologic studies of core samples, have allowed us to reconstruct lake-level changes during this recent part of the lake's history.

The post-glacial history of lake-level changes in the Lake Michigan basin begins about 11.2 ka with the fall from the high Calumet level, caused by the retreat of the Two Rivers glacier, which had blocked the northern outlet of the lake. This lake-level fall was temporarily reversed by a major influx of water from glacial Lake Agassiz (about 10.6 ka), during which deposition of the distinctive gray Wilmette Bed of the Lake Michigan Formation interrupted deposition of red glaciolacustrine sediment. Lake level then continued to fall, culminating in the opening of the North Bay outlet at about 10.3 ka. During the resulting Chippewa low phase, lake level was about 80 m lower than it is today in the southern basin of Lake Michigan.

The rise of the early Holocene lake level, controlled primarily by isostatic rebound of the North Bay outlet, resulted in a prominent, planar, transgressive unconformity that eroded most of the shoreline features below present lake level. Superimposed on this overall rise in lake level, a second influx of water from Lake Agassiz temporarily raised lake levels an unknown amount about 9.1 ka. At about 7 ka, lake level may have fallen below the level of the outlet because of sharply drier climate. Sometime between 6 and 5 ka, the character of the lake changed dramatically, probably due mostly to climatic causes, becoming highly undersaturated with respect to calcium carbonate and returning primary control of lake level to the isostatically rising North Bay outlet. Post-Nipissing (about 5 ka) lake level has fallen about 6 m due to erosion of the Port Huron outlet, a trend around which occurred relatively small (± ~2 m), short-term fluctuations controlled mainly by climatic changes. These cyclic fluctuations are reflected in the sedimentological and sediment-magnetic properties of the sediments.

In Press: *Journal of Great Lakes Research*

Supported by: USGS/WHOI Cooperative Agreement; NSF: OCE-8702509, OCE- 9301015

WHOI Contribution Number: 8536

Radiocarbon dating of Lake Baikal sediments — A progress report

S.M. Colman, V.M. Kuptsov, G.A. Jones, and S.J. Carter

A suite of 34 new accelerator-mass spectrometer (AMS) radiocarbon ages on total organic carbon provides the first reliable chronology for late Quaternary sediments in Lake Baikal. The ages show more than an order of magnitude difference in sediment-accumulation rate among different sedimentary environments in Lake Baikal, from less than 0.03 mm/yr on isolated banks such as Academician Ridge, to nearly 0.3 mm/yr in the turbidite depositional areas beneath the deep basin floors, such as the Central Basin. Rates in the pro-delta area of the Selenga Delta are intermediate between these two extremes. Within each environment, Holocene sediment- accumulation rates appear to be nearly constant, and they are less than late Pleistocene rates. The new AMS ages clearly indicate that the dramatic increase in productivity in the lake, as evidenced by increases in biogenic silica and organic carbon, began before 12 ka, in contrast to previous estimates of the age of this transition (7 ka) based on conventional radiocarbon ages.

Several problems are inherent in the interpretation of these ages. In the Baikal cores, these manifest themselves as (1) the loss of the upper part of the sedimentary section in some cores, (2) apparent ages of the sediment surface that range from 0 to 1700 years, and (3) as stratigraphic reversals of ages in the deeper part of the cores. The first problem can be minimized by correlation to gravity and box cores. The second problem may be partly due to reworked or terrestrial organic carbon, but other factors, such as upward diffusion of bicarbonate, may also be involved; further work is underway to determine the cause of this effect. The last problem is probably due to slight contamination of the carbon in glacial clays, whose very low carbon content (< 0.2 percent) and relatively great age (> 20 ka) make then very susceptible to contamination.

In press: *Geologie I Geofizica*

Supported by: USGS/WHOI Cooperative Agreement; NSF: OCE- 8702509, OCE-9301015

WHOI Contribution Number: 8555

The Medieval solar activity maximum

J.L. Jirikowic and P.E. Damon

Paleoclimatic studies of the Medieval Solar Maximum (c. AD 1100-1250, corresponding with the span of the Medieval Warm Epoch) may prove useful because it provides a better analog to the present solar forcing than the intervening era. The Medieval Solar Activity Maximum caused the cosmogenic isotope production minimum during the 12th and 13th Centuries AD reflected by $\delta^{14}C$ and ^{10}Be records stored in natural archives. These records suggest solar activity has returned to Medieval Solar Maximum highs after a prolonged period of reduced solar activity. Climate forcing by increased solar activity may explain some of this century's temperature rise without assuming unacceptably high climate sensitivity. By analogy with the Medieval Solar Activity Maximum, the contemporary solar activity maximum may be projected to last for 150 years. The maximum temperature increase forced by increased solar activity stays well below the predicted doubled atmospheric CO_2 greenhouse forcing.

In press: *Climatic Change*

Supported by: NSF: ATM-9012102; Regents Fellow at Univ. Arizona

Tree-ring ^{14}C as a possible indicator of climate change

J.L. Jirikowic, R. Kalin and O. Davis

Analyses of the tree-ring "Calibration" $\Delta^{14}C$ data set shows intermittent high ^{14}C anomalies. During these anomalies, the time series nature of the ^{14}C data set changes markedly. Such non-stationarity suggests ^{14}C variation results from a dynamic, non-linear set of processes. The latest ^{14}C anomaly occurs during the past millennium and coincides with the historic profound solar activity minima. To test the hypothesis of solar modulation of global climate and cosmogenic isotope anomalies, we sought evidence for brief climatic events coincident with major anomalies in a rapid deposition site which had not been previously reported. Using detailed pollen analysis and precise ^{14}C dating, we have studied climatic change during the Homeric-Greek (2830-2550, 2360-2160 cal BP) and Noachan (4880-4660 cal BP) anomalies, at Mission Cross Bog, Elko Co., Nevada. Through "wiggle-matching" with the ^{14}C calibration curve, we could date the precise interval in the sediment record which corresponds to the Homeric and Greek ^{14}C production anomalies. We located the exact age of the Greek anomaly only, corresponding to a wet period in the pollen diagram. We also discovered two wet periods that do not match any cosmogenic isotope anomalies. Hence, the presence of brief climatic episodes cannot be used to date the sequence. By dating and analyzing pollen during the Homeric and Noachan anomalies, we may confirm or refute the climate-cosmogenic isotope anomaly association hypothesis.

Accepted to: Isotopic Indicators of Continental Climate, In: P.K. Swart, K.C. Lohmann, J. McKenzie, and S. Savin (eds.), *Climate Change in Continental Isotopic Records*, Geophysical Monograph # 78, Am. Geophys. Union

Supported by: NSF: SES-9009975

High-precision AMS radiocarbon measurements of central Arctic Ocean seawaters

G.A. Jones, A.R. Gagnon, R.J. Schneider, K.F. von Reden and A.P. McNichol

We report on the first high precision radiocarbon dataset measured on single targets using Accelerator Mass Spectrometry (AMS). Results from a thirteen sample water column profile collected in the Canada Basin (74°N, 150°W, 3850m water depth) of the central Arctic Ocean in September 1992 has been analyzed in duplicate and demonstrates that the average total precision achieved for each of the 26 targets was ±3.22 per mil. The reproducibility of the thirteen paired analyses averaged ±3.66 per mil. Comparison with a recently published AMS ^{14}C profile from the same basin suggests this data is accurate as well. Results suggests that the deep waters of the Canada Basin have a renewal rate of 430 years, in comparison with 250 years estimated for the deep waters of the Eurasian Basin. The major

requirement of the World Ocean Circulation Experiment (WOCE) for a radiocarbon analysis precision of ±3 to 4 per mil for deep water samples has now been met with the AMS technology available at the National Ocean Sciences AMS Facility at the Woods Hole Oceanographic Institution.

In press: *Nuclear Instruments and Methods*

Supported by: NSF: OCE-9301015; DPP- 9024560; NOAA: NAI6RC0074-01

WHOI Contribution Number: 8567

Holocene climate and deep ocean circulation changes: Evidence from AMS radiocarbon-dated sediment drifts of the Argentine Basin (SW Atlantic)

G.A. Jones

Accelerator Mass Spectrometer (AMS) radiocarbon analyses have been made on 51 samples of total organic carbon from four box and two piston cores collected from the "erosional" and "depositional" sides of two central Argentine Basin sediment waves. Throughout the Holocene, sediment from the geomorphically defined "depositional" side of each sediment wave accumulated at rates of 30 to 105 cm/1000 yrs. Sediments from the "erosional" side of each wave accumulated at rates of 2 to 10 cm/1000 yrs in the late and early Holocene, while the mid Holocene is characterized by sedimentation rates less than 1.0 cm/1000 yrs.

During the mid-Holocene, increased aridity reduced chemical weathering and the flow of the rivers draining to the continental shelf, causing a concomitant decrease in fine-grained terrigenous input to the basin as evidenced by decreased sedimentation rates, lower N/C ratios, and depleted $\delta^{13}C_{org}$ values. Bottom water flow speeds in the late Holocene averaged 14 cm/1000 yrs, and are in agreement with 10 cm/sec mean and 15-20 cm/sec maximum flow speeds measured by current meter. Flow speeds in the Argentine Basin were 10% higher than today from 8000 to 2000 yBP, and are consistent with a general invigoration of thermohaline circulation that began between 9000 and 8000 yBP. The introduction of warm, salty Indian Ocean water into the northern North Atlantic at 9000 yBP was the mechanism that provided the excess salt needed to stabilize the North Atlantic Deep Water (NADW) thermohaline circulation system in its present mode.

Accepted to: *Paleoceanography*

Supported by: NSF: OCE-8511386, OCE- 9301015; ONR: N00014-87- K-0007; NOAA: NAI6RC0074-01

WHOI Contribution Number: 8552

A new hypothesis for the Holocene appearance of coccolithophores in the Black Sea

G.A. Jones

A recent accelerator mass spectrometer (AMS) radiocarbon study of Black Sea Holocene sediments has resolved a long standing chronology controversy involving radioisotope and varve counting methodologies. The revised chronology combined with model results of the salinity evolution of the Black Sea since the last glacial maximum does not support the hypothesis of a salinity-controlled Holocene invasion of the Black Sea by coccolithophores, a planktonic golden-brown unicellular marine algae. Rather, evidence presented here suggests these organisms were inadvertently transported from the Mediterranean Sea by sailing vessels during the Greek exploration and colonization of the Black Sea in the 7th and 8th centuries B.C. As such this may be one of the earliest examples of anthropogenic transport of marine organisms between ocean basins, and a good example of the difficulties inherent in distinguishing natural from anthropogenic effects when studying Holocene biological systems.

In press: *The Holocene*

Supported by: NSF: OCE-8712181

WHOI Contribution Number: 8470

Radiocarbon chronology of Black Sea sediments

G.A. Jones and A.R. Gagnon

Accelerator Mass Spectrometer (AMS) radiocarbon analyses have been made on 102 samples from twelve sediment cores and 23 samples from two water column profiles. These materials, collected during the first leg of the 1988 joint U.S.-Turkish Black Sea Expedition, provide the most comprehensive radiocarbon chronology of Black Sea sediments yet attempted. Radiocarbon analyses from carefully collected box cores and a mollusc shell collected live in 1931 suggest the pre-bomb surface waters had a $\Delta^{14}C$ value of -56‰ (460 yrs) and that the maximum detrital correction for radiocarbon ages of Unit I sediments is 580 years for the organic carbon and 260 years for the carbonate fractions. Evidence does not support the 1430-to-2000 year pre-bomb surface water and/or detrital corrections argued for in past studies. The best estimates for the age of the beginning of the final invasion of the coccolithophore *Emiliania huxleyi* (Unit 1/2 boundary of Ross and Degens, 1974, *The Black Sea—Geology, Chemistry and Biology*, PP. 183-199) and the age of the first invasion of *E. huxleyi* (Unit I/II boundary of Hay *et al.*, 1991, *Deep-Sea Research*, 38, S1211-S1235) are 1635 ±60 and 2720 ±160 yBP, respectively. Sapropel formation began at approximately 7540 ±130 yBP at all depths in the basin, a pattern in disagreement with those predicted by existing time-evolution models of sapropel formation for this basin. Our data suggest that the oxic/anoxic interface has remained relatively stable throughout the Holocene, is controlled largely by the physical oceanography of the basin, and has not evolved as assumed by previous workers.

In Press: *Deep-Sea Research*

Supported by: NSF: OCE-8712181; OCE- 8702509

WHOI Contribution Number: 8174

Timing of the Holocene repopulation of the Atlantic Ocean by *G. menardii* and *G. tumida* and implications for surface watermass paleoceanography

G.A. Jones

The most recent repopulation of the Atlantic Ocean by the menardiform foraminiferal species *Globorotalia menardii* (d'Orbigny) and *Globorotalia tumida* (Brady) has been widely accepted as occurring at approximately 11,000 yBP (Ericson and Wollin, 1956, *Micropaleontology*, 2, 257-270) and used exten-

sively to biostratigraphically define the boundary between Holocene and glacial sediments in the Atlantic Ocean. Accelerator mass spectrometer (AMS) radiocarbon dating of mixed planktonic foraminifera and monospecific samples of these two species have been made on a total of 188 samples from 3 Indian Ocean and 10 Atlantic Ocean cores. Both species were continuously present in the Indian Ocean during the last 30,000 years. The low abundances of *G. menardii* found throughout the late glacial section of southeastern South Atlantic core, RC17-43, suggests that the Agulhas Retroflection was still shedding warm-core rings containing Indian Ocean planktonic assemblages into the southeastern South Atlantic during that time. *G. menardii* was found to isochronously repopulate the rest of the Atlantic Ocean at 6350±100 yBP. In contrast, the pattern of Atlantic Ocean repopulation for *G. tumida* was found to be time-transgressive, averaging 9020±220 yBP in the equatorial and western North Atlantic Ocean and 7310 yBP in the eastern North Atlantic. *G. tumida* was not found to occur in the South Atlantic during the last glacial or the Holocene. The data presented here do not support the assumed isochroneity or long accepted age of the *G. menardii-tumida* Z/Y biostratigraphic datum. Not only does each species demonstrate a distinct and different mode of repopulating the Atlantic Ocean, but the timing of these events as a biostratigraphic tool must be interpreted in light of bioturbation modeling. *G. menardii-tumida* specimens are bioturbated downward into older sediments containing no specimens of these species, and it is the radiocarbon dating of the bulk sediments and not the individual specimens of *G. menardii-tumida*, that have resulted in the previous anomalously old age estimates. The maximum change in abundance should be used for defining a biostratigraphic datum, and not the first appearance, or 1% abundance levels as is common. It is further suggested that warm, salty Indian Ocean waters did not make it into the North Atlantic via the Agulhas- Benguela Current system until approximately 9000 yBP. This warm, salty water is the catalyst by which the atmospheric and oceanic climate of the northern North Atlantic, and North Atlantic Deep Water stabilized in their present modes.

Accepted to: *Deep-Sea Research*

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WHOI Contribution Number: 8532

Western North Atlantic evidence for millennial-scale changes in ocean circulation and climate

L.D. Keigwin and G.A. Jones

Two late Quaternary series of high resolution percent carbonate data from western North Atlantic sediment drifts (Bermuda Rise and Bahama Outer Ridge) show millennial-scale oscillations superimposed on the familiar, longer-period oscillations of orbital origin. The dominant high frequency oscillation in these records has a quasi period of about 4000 yrs. These % $CaCO_3$ changes most likely result from the influence of climate change on the flux of terrigenous material from eastern Canada, the resuspension of continental margin sediment by deep eddy kinetic energy, and carbonate dissolution. Sediment is transported to the Bermuda Rise by deep recirculating gyres and to the Bahama Outer Ridge by the deep western boundary current system. Stable isotope results on foraminifera across several of these oscillations from interstadial climate conditions and from a glacial inception display variability similar to that of % $CaCO_3$. Oxygen isotope ratios of planktonic foraminifera suggest large variations in near-surface temperature and/or salinity, and carbon isotope ratios of benthic foraminifera indicate that there were significant oscillations in the flux of North Atlantic Deep Water (NADW). These data support models which couple surface ocean conditions in the North Atlantic, production of NADW, North Atlantic heat flux, and evidence for temperature oscillations in ice cores.

In press: *Journal of Geophysical Research*

Supported by: NSF: OCE-8702509, ATM- 8706617; NOAA: NA16RC0074-01

WHOI Contribution Number: 8530

Radiocarbon ages from two submerged strandline features in the Western Gulf of Maine and a modified sea-level curve for the Northeastern Massachusetts coastal region

R.N. Oldale, S.M. Colman and G.A. Jones

New radiocarbon dates provide ages for two submerged strandline features on the Massachusetts inner shelf. These ages provide limited control on a relative sea-level (RSL) curve for the late Wisconsinan and Holocene. The curve indicates a late Wisconsinan high stand of RSL of +33 m about 14,000 yr ago and a very short-lived relative low stand of about -43 m at about 12,000 yr ago followed by a rise to present sea level. Rapid changes of RSL about 12,000 yr ago may be related to changes in global glacial meltwater discharge and eustatic sea-level change shown by dated corals of Barbados. Variations in the magnitude and timing of RSL change from south to north along the coast of the western Gulf of Maine are due to greater crustal depression and later deglaciation to the north.

Published in: *Quaternary Research*, 40:38-45

Supported by: USGS/WHOI Cooperative Agreement; NSF: OCE- 8702509

Accelerator Mass Spectrometry, tracking carbon in the marine environment

R.J. Schneider and G.A. Jones

This paper discusses the origin of the different carbon isotopes and their use in the ocean sciences. In addition, AMS and beta- decay methods of radiocarbon dating are compared and the advantages of AMS in many ocean sciences projects are outlined.

Published in: *Oceanus*, 35: 93-95

Supported by: NSF: OCE-8702509

Development of the mollusc *Arctica islandica* as a paleoceanographic tool for reconstructing annual and seasonal records of $\Delta^{14}C$ and $\delta^{18}O$ in the mid-to high-latitude North Atlantic Ocean

C.R. Weidman and G.A. Jones

Corals have been used, previously, to reconstruct high-resolution geochemical records of the surface subtropical oceans,

but no comparable tools have been developed for the colder, higher latitude oceans. We report that the application of accelerator mass spectrometry and micro-sampling techniques now allows the carbonate shell of the long- lived (~200 yr) mollusc (Bivalvia) *Arctica islandica* to be used to fulfill this role for the mid- and high-latitude North Atlantic Ocean. We describe the sampling methods used to produce the first time histories of bomb-^{14}C in the northern North Atlantic Ocean from Georges Bank (41°N, 67°W) and the North Sea (54°N, 6°E), and a record of seasonal bottom temperatures derived from the $\delta^{18}O$ profile of a shell collected on Nantucket Shoals (41°N, 69°W).

In Press: In: Rozanski, K. (ed.), *Applications of isotope techniques in studying past and current environmental changes in the hydrosphere and atmosphere.* International Atomic Energy-SM- 329/56/XX

Supported by: WHOI Ocean Ventures Fund: 25008530; NOAA: NA36GPO291; NSF: OCE- 9301015

WHOI Contribution Number: 8534

The long-lived mollusc; *Arctica islandica*: A new paleoceanographic tool for the reconstruction of maximum bottom temperatures for the continental shelves of the northern North Atlantic Ocean

C.R. Weidman and G.A. Jones

The carbonate shell of the bivalve *Arctica islandica* has been recognized, for more than a decade, as a potentially important marine geochemical bio-recorder owing to this species' great longevity (200+ years) and wide geographic distribution throughout the northern North Atlantic Ocean — a region vital to global climate and ocean circulation. However, until now, this potential has not been realized due to the difficulty of precisely sampling the shell of this slow growing species. Using newly available automated micro-sampling techniques combined with micro-mass stable isotope mass spectrometry, a stable oxygen isotope record (1956-1957 and 1961-1970) has been obtained from a live- captured 38-year old *A. islandica* specimen collected near the former position of the Nantucket Lightship (41°N, 69°W). The shell's $\delta^{18}O$ signal; 1) is in phase with its growth banding, confirming the annual periodicity of this species' growth bands, 2) is in isotopic equilibrium with the ambient seawater and faithfully records the seasonal maximum bottom temperature, and 3) shows a consistent shell growth shutdown temperature of ~7-8° C, which translates into a 7-month, June-December, shell growth period at this location. These results add important information on the life history of this commercially important shellfish species and demonstrate that *A. islandica* shells can be used to reconstruct interannual records of the maximum bottom temperature.

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Supported by: WHOI Ocean Ventures Fund: 25008530; NOAA: NA16RC0080-01; NSF: OCE931015

WHOI Contribution Number: 8520

A new high-temporal resolution paleoceanographic tool for the northern North Atlantic: the mollusc *Arctica islandica*

C.R. Weidman and G.A. Jones

Annual and seasonal geochemical records of the surface subtropical oceans have been previously obtained from corals, but no comparable tools have been developed for the colder, higher latitude oceans — regions critical to the regulation of global climate and ocean circulation. The carbonate shell of the mollusc (Bivalvia) *Arctica islandica* offers tremendous potential as a long term monitor of ocean conditions on the continental shelves in the mid- to high-latitude North Atlantic due to this species' great longevity (>200 years), abundance, and wide latitudinal (35°N-70°N) and bathymetric (10-200 m) distribution. The slow growth rate of this long-lived mollusc thwarted earlier attempts to exploit this potential, but now the application of micro-mass stable isotope mass spectrometry, automated micro-sampling technology, and accelerator mass spectrometry (AMS) have overcome this obstacle.

Our efforts have produced a $\delta^{18}O$ profile from a 38-year old *A. islandica* specimen collected from near the position of the former Nantucket Lightship (41°N, 69°W) for the annual band years 1956 to 1957 and 1961 to 1971. This record is in good agreement with the predicted $\delta^{18}O$ record derived from bottom temperature and salinity measurements taken at this lightship during this same period. In addition, we have obtained the first time- histories of bomb-^{14}C in the higher latitudes of the North Atlantic from Georges Bank (41°N, 67°W) and the North Sea (54°N, 6°E). Both of these results: 1) contribute new information on the life history of *A. islandica*, an important commercially harvested shellfish species in the U.S., confirming a consistent annual banding pattern for this species and showing a consistent shell growth shutdown temperature of ~8°C; and 2) demonstrate that *A. islandica's* shell can be used to help determine the annual maximum bottom temperature, shelf water origin, and the interannual variability of these parameters for the past two centuries.

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WHOI Contribution Number: 8535

A shell-derived time history of bomb-^{14}C on Georges Bank and its Labrador Sea implications

C.R. Weidman and G.A. Jones

Bomb-produced radiocarbon has been used in the past as an important tracer of ocean circulation and as a valuable tool for calculating CO_2 air-sea exchange. However, previous studies of the ocean's time-varying bomb ^{14}C record have been confined exclusively to analyzing banded corals, and thus their application has been limited to the lower latitudes. The first time history of bomb ^{14}C from the high-latitude North Atlantic Ocean is obtained from a 54-year-old mollusc specimen, (Bivalvia) *Arctica islandica*, which was collected live from Georges Bank (41°N) in 1990. The annual growth bands of its shell were analyzed for $\Delta^{14}C$ using accelerator mass spectrometry, producing a $\Delta^{14}C$ time history from 1939 to 1990. The depleted condition of the Georges Bank bomb ^{14}C signal relative to two coral-derived

North Atlantic $\Delta^{14}C$ time histories suggests a significant deepwater source for the waters on Georges Bank. Supported by previous work linking the origin of waters on Georges Bank to the Labrador Sea, the $\Delta^{14}C$ budget on Georges Bank is modeled as Labrador Sea water, which largely becomes confined to the shelf and partially equilibrates with the atmosphere during a 1-year transit time from the Labrador Sea to Georges Bank. This model is also used to estimate a time history of bomb ^{14}C for the Labrador Sea. Prebomb $\Delta^{14}C$ values calculated for the surface Labrador Sea suggest that a greater inventory of bomb ^{14}C has accumulated here than has previously been reported. However, the estimated prebomb average $\Delta^{14}C$ (-70.6‰) for this period is nearly identical to the -70‰ previously calculated for the prebomb source of North Atlantic Deep Water and is in agreement with Transient Tracers in the Ocean subsurface tritium data from the central Labrador Sea. Deduced variations in the ventilation and/or $^{14}CO_2$ uptake rates in the Labrador Sea correspond with observed changes in surface salinity of the Labrador Sea, suggesting a reduction in deepwater formation during the late 1960s and 1970s.

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Supported by: NOAA: NA36GPO0291

WHOI Contribution Number: 8152

AMS Methods, Instrumentation, & NOSAMS Facility Description

Automated sample processing at the National Ocean Sciences AMS Facility

G.J. Cohen, D.L. Hutton, K.F. von Reden, E.A. Osborne, A.P. McNichol and G.A. Jones

The high throughput and high-precision requirements for the NOSAMS Facility have made it essential to automate many of the stages in sample processing. These automated procedures increase the sample capacity for the lab while reducing errors in sample preparation. Automation has also allowed sample histories to be recorded and saved in Sybase, a relational database.

In press: *Nuclear Instruments and Methods*

Supported by: NSF: OCE-9301015

WHOI Contribution Number: 8564

Comparative study of Fe-C bead and graphite target performance with the NOSAMS Facility recombinator ion source. Part II: Small sample performance evaluation

L.A. Currie, D.B. Klinedinst, A.P. McNichol, R.J. Schneider, K.F. von Reden, G.A. Jones, G.A. Klouda and R.M. Verkouteren

A designed AMS experiment was carried out to investigate ^{14}C target performance for two target types and over a range of isotopic compositions ("age") and sample sizes, with a special focus on the ability to measure ^{14}C in environmental samples having only microgram amounts of organic matter. The findings were positive, showing that precision, accuracy, and stability were adequate to determine ^{14}C to 1% or better in samples containing as little as 25 µg carbon. Satisfactory Poisson precision and target stability were demonstrated down to a level of 7 µg carbon, but experimental data showed that accurate measurements at that level required detailed knowledge of blank variability and mass dependence of the modern carbon calibration factor.

Submitted to: *Nuclear Instruments and Methods*

Supported by: NSF: OCE-9301015

WHOI Contribution Number: 8579

AMS radiocarbon results obtained from graphite targets produced at the Woods Hole Oceanographic Institution between 1986 and 1991

A.R. Gagnon and G.A. Jones

In July 1986 an AMS radiocarbon target preparation laboratory was established at the Woods Hole Oceanographic Institution to produce graphite to be analyzed at the NSF- Accelerator Facility for Radioisotope Analysis at the University of Arizona (Tucson). By June 1991, 923 graphite targets had been prepared and 847 analyzed. Our lab procedures during this time included the careful documentation of weights of all starting samples, catalysts and final graphite yields, as well as the volume of CO_2 gas evolved during $CaCO_3$ hydrolysis or closed-tube organic carbon combustions. From these data, we evaluate the methods used in general and in our lab.

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The National Ocean Sciences Accelerator Mass Spectrometry Facility

G.A. Jones, A.P. McNichol, K.F. von Reden and R.J. Schneider

This article outlines the progress made at the National Ocean Sciences AMS Facility from being little more than a concept in 1988 to an operational facility in 1992. The special features incorporated into the design and construction of this facility are discussed in light of the requirements of the ocean sciences community in general and the World Ocean Circulation Experiment (WOCE) in particular. The present precision limitations are discussed and a plan for continued improvement outlined.

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Comparative study of AMS target performance using the NOSAMS recombinator ion source. Part I: Experimental design, sample preparation, and analysis protocol

D.B. Klinedinst, A.P. McNichol, L.A. Currie, G.A. Jones, G.A. Klouda, K.F. von Reden, R.M. Verkouteren and R.J. Schneider

Using the National Ocean Sciences Accelerator Mass Spectrometer (NOSAMS) located at the Woods Hole Oceanographic Institution, a collaborative study was undertaken to compare the performance of two ^{14}C AMS target types: the Fe-C bead developed at the National Institute of Standards and Technology (NIST) and the more commonly used graphite powder.

Targets were prepared according to a partial factorial design. A total of 29 targets that spanned a mass range of 7 to 1680 µg carbon and fraction of modern carbon range of 0 to 1.3 were analyzed. The study took place in order to compare the performance of the two target types, with a special view toward the limits of stability, sample size, and precision.

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Rapid analysis of seawater samples at the National Ocean Sciences Accelerator Mass Spectrometry Facility, Woods Hole, MA

A.P. McNichol, G.A. Jones, D.L. Hutton, A.R. Gagnon and R.M. Key

We have established a laboratory for extracting ΣCO_2 from seawater samples for AMS analysis of the radiocarbon content. The seawater samples are collected at sea, poisoned, and stored until analysis on land. Each sample is acidified, the inorganic carbon is stripped out as CO_2 with an inert carrier gas and then converted to graphite. In this paper we demonstrate our precision and accuracy in the analysis of seawater samples.

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TIC, TOC, DIC, DOC, PIC, POC - Unique aspects in the preparation of oceanographic samples for ^{14}C-AMS

A.P. McNichol, E.A. Osborne, A.R. Gagnon, D.L. Hutton, B. Fry and G.A. Jones

The radiocarbon content of discrete carbon pools (total (T), dissolved (D), and particulate (P) inorganic (I) and organic (O) carbon (C)) is a useful tracer of carbon cycling within the modern and past ocean. The isolation of different carbon pools in the ocean environment and conversion to CO_2 presents unique analytical problems for the radiocarbon chemist. In general, isolation and preparation of inorganic carbon presents few problems; dissolved carbon is easily extracted by acidifying the sample and stripping with an inert gas. Carbon is also readily isolated from particulate carbonate samples; in this case, CO_2 is prepared by hydrolysis of the substrate with phosphoric acid. The isolation and preparation of organic carbon presents a much greater problem. Dissolved organic carbon (DOC) must first be isolated from DIC and then oxidized in the presence of very high salt concentrations. We present results from a closed-tube combustion method in which the DIC-free seawater is evaporated to dryness, transferred to a clean combustion tube, and oxidized overnight at 550°C. Combustion of total organic carbon (TOC) in sediments with a high inorganic carbon content is also difficult. Removal of $CaCO_3$ with acid leaves severely deliquescent salts which, if not thoroughly dried, cause combustion tubes to explode. Removal of the salts by rinsing can also remove significant amounts of organic matter. Finally, we present results from a local coastal region.

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Electric dissociation of negative ions- II

M-J. Nadeau, A.E. Litherland, M.A. Garwan and X-L. Zhao

As an alternative to naturally occurring negative ion discrimination, we have used electric dissociation to discriminate between isobars, thereby destroying the weaker negative ion of a pair. This technique also permits the determination of the properties of the quantum states and the binding energy of some weakly bound negative ions (Ca, Tm, Dy and Yb) some of which had not been studied previously (Tm, Dy, Yb). During the course of this study, it was also established that some very weakly bound negative ions (Dy and Yb) are destroyed by weak electric fields such as those in tandem accelerators. This fact was used to verify the theory of electric dissociation by the comparison of the dissociation probability under different field configurations and gradients. The results regarding the lanthanide elements indicate that in all three cases that the extra electron occupies a *p*-orbital which does not follow the "natural" filling of the periodic table. The study of Ca- concluded that the lowest states are the $4s^24p\ ^2P\ J=1/2,3/2$ states with binding energy of 21.0 ±2.5 meV and a spin-orbit splitting in the range 0.4-2.5 meV with a maximum probability at 0.75 meV. The ordering of the levels has not been established yet.

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Internal and external checks in the NOSAMS Facility Sample Preparation Laboratory for target quality and homogeneity

E.A. Osborne, A.P. McNichol, A.R. Gagnon, D.L. Hutton and G.A. Jones

When a sample reaches the NOSAMS facility, there are two sources that contribute to decreases in precision and accuracy of an analysis—the stability and cleanliness of the AMS and the cleanliness and reproducibility of the chemical procedures used to convert a sample to graphite. In the NOSAMS sample preparation laboratory (SPL) we have developed rigorous internal procedures aimed at ensuring that sample preparation introduces as little error into our analyses as possible and identifying problems rapidly. These procedures and standard laboratory practices are all documented and procedure numbers are stored for all samples processed in the SPL.

Our three major CO_2 preparation procedures are stripping inorganic carbon from seawater, hydrolyzing $CaCO_3$, and oxidizing organic matter. For seawater, approximately 10% of our analyses are standards or blanks which we use to demonstrate extraction of virtually all the inorganic carbon. Analysis of the stable carbon isotopic composition of the CO_2 extracted from our standards indicates a precision of better than 0.15‰. We

also routinely process ^{14}C-free CO_2 in our stripping lines to demonstrate the absence of a significant process-dependent blank. For organic combustions and $CaCO_3$ hydrolyses, we use the carbon yield (%OC or %$CaCO_3$ by weight) as a check on our sample procedures. For organic carbon analyses in sediments, we have found through experience that it is important to have a reliable estimate of the amount of organic carbon present before proceeding with our combustions. We have analyzed the blank contribution of these procedures as a function of sample size. Our organic carbon blank is constant at approximately 0.4% modern for samples containing greater than 1 mg C and our carbonate blank is less than 0.2% modern for samples containing more than 0.5 mg C.

We use a standard Fe/H_2 catalytic reduction to prepare graphite from CO_2. We check the completeness of our reactions with the pressure data stored during the reaction as well as use a robot to determine a gravimetric yield. All graphite undergoes a visual inspection and is rejected if any heterogeneities are present. We have recombusted graphite made from CO_2 with $\delta^{13}C$ values ranging from -42‰ to 1‰ and determined that the $\delta^{13}C$ of the recombusted carbon agrees with that from the pure gas to within 0.5‰, demonstrating little or no fractionation during the treatment of the sample. The $\delta^{13}C$ we measure on the CO_2 generated from more than 75% of our samples is compared to the $\delta^{13}C$ measured on the AMS as a further check of our procedures.

We present $\Delta^{14}C$ results from CO_2 samples measured at WHOI and two other AMS laboratories as an external check on our accuracy. As further external checks, we analyzed the International Atomic Energy Association (IAEA) samples during the establishment of our laboratory and participated in the Third International Radiocarbon Intercalibration (TIRI) exercise.

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Methods for data screening, flagging, and error analysis at the National Ocean Sciences AMS Facility

R.J. Schneider, G.A. Jones, A.P. McNichol, K.F. von Reden, K.L. Elder, K. Huang and E.D. Kessel

All data collection, from sample submittal through processing into targets and AMS analysis is integrated within a large relational database (SYBASE). Over fifty tables are linked through key fields. Through structured queries, the information is analyzed and presented for a wide variety of applications. Benefits include enhanced quality control, more complete reports to users and more accurate transfer of data among the several laboratories on the network.

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Optimized data analysis for AMS radiocarbon dating

F.H. Séguin, R.J. Schneider, G.A. Jones and K.F. von Reden

Because the efficiencies of detection of ^{14}C and ^{12}C can and do vary with time during AMS data acquisition, it is desirable to have a data analysis technique which recognizes time variations and uses all available data to extract the maximum possible information content from a data set while providing meaningful statistical information about measurement errors. Toward this end, a new method of data reduction and error analysis is being developed for the determination of ^{14}C to ^{12}C ratios for radiocarbon dating from data sets taken at the National Ocean Sciences AMS Facility.

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Performance characteristics of the 3 MV Tandetron AMS system at the National Ocean Sciences AMS Facility

K.F. von Reden, R.J. Schneider, G.J. Cohen and G. A. Jones

Operational and machine performance parameters are discussed for the National Ocean Sciences AMS System. The system now routinely measures between 50 and 100 carbon samples per week in largely unattended mode using one of the two functional high-current ion sources. System development and procedures are described that enable us to reach and maintain the high precision level required for the measurement of deep sea water dissolved inorganic carbon samples.

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*ARTHUR, M.A., Dean, W.E., Neff, E.D., Hay, B.J., King, J.W. and Jones, G.A. (in press). Varve calibrated records of carbonate and organic carbon accumulation over the last 2000 years in the Black Sea. *Global Biogeochemical Cycles.*

BRENNER, M., Curtis, J.H., Hieguera-Gundy, A., Hodell, D.A., Jones, G.A., Binford, M.W. and Dorsey, K.T., 1993. Lake Miraguane, Haiti (Caribbean). In, Kelts, K. and Gierlowski, E. (eds.), *Global Geological Record of Lake Basins* (IGCP Project 219). Cambridge Univ. Press, Cambridge, 403-405.

COHEN, G.J., Hutton, D.L., von Reden, K.F., Osborne, E.A., McNichol, A.P. and Jones, G.A. (in press). Automated sample processing at the National Ocean Sciences AMS Facility. *Nuclear Instr. & Methods.*

COLMAN, S.M., Forester, R.M., Reynolds, R.L., Sweetkind, D.S., King, J.W., Gangemi, P., Jones, G.A., Keigwin, L.D. and Foster, D.S. (in press). Lake-level history of Lake Michigan for the past 12,000 years: the record from deep Lacustrine sediments. *Journal of Great Lakes Research.*

COLMAN, S.M., Kuptsov, V.M., Jones, G.A. and Carter, S.J. (in press). Radiocarbon dating of Lake Baikal sediments—A progress report. *Geologie I Geofizica.*

CURRIE, L.A., Klinedinst, D.B., McNichol, A.P., Schneider, R.J., von Reden, K.F., Jones, G.A., Klouda, G.A. and Verkouteren, R.M. (submitted). Comparative study of Fe-C Bead and Graphite Target Performance with the NOSAMS Facility Recombinator Ion Source. Part II: Small sample performance evaluation. *Nuclear Instr. & Methods.*

GAGNON, A.R. and Jones, G.A., 1993. AMS radiocarbon results obtained from graphite targets produced at the Woods Hole Oceanographic Institution between 1986 and 1991. *Radiocarbon*, 35:301-310.

*JIRIKOWIC, J.L. and Damon, P.E.(in press). The Medieval solar activity maximum. *Climatic Change.*

*JIRIKOWIC, J.L., Kalin, R. and Damon, P.E. (accepted). Tree- ring ^{14}C as a possible indicator of climate change. Climate Change in Isotopic Records. In: P.K. Swart, K.C. Lohmann, J. McKenzie, and S. Savin (eds.), Climate Change in Continental Isotopic Records, *Geophysical Monograph # 78*, Am. Geophys. Union

JONES, G.A. (accepted). Holocene climate and deep ocean circulation changes: Evidence from AMS radiocarbon dated Argentine Basin (SW Atlantic) sediment drifts. *Paleoceanography.*

JONES, G. A. (in press). A new hypothesis for the Holocene appearance of coccolithophores in the Black Sea. *The Holocene.*

JONES, G.A. (accepted). Timing of the Holocene repopulation of the Atlantic Ocean by *G. menardii* and *G. tumida* and implications for surface watermass paleoceanography. *Deep-Sea Res.*

JONES, G.A. and Gagnon A.R. (in press). Radiocarbon chronology of Black Sea sediments. *Deep-Sea Res.*

JONES, G.A., Gagnon, A.R., Schneider, R.J., von Reden, K.F. and McNichol, A.P. (in press). High-precision AMS radiocarbon measurements of central Arctic Ocean seawaters. *Nuclear Instr. & Methods.*

JONES, G.A., McNichol, A.P., von Reden, K.F. and Schneider, R.J., 1993. The National Ocean Sciences Accelerator Mass Spectrometry Facility. *WOCE Notes*, V5. 5 pp.

KEIGWIN, L.D. and Jones, G.A. (in press). Western North Atlantic evidence for millennial-scale changes in ocean circulation and climate. *J. Geophys. Res.*

KLINEDINST, D.B., McNichol, A.P., Currie, L.A., Jones, G.A., Klouda, G.A., von Reden, K.F., Verkouteren, R.M. and Schneider, R.J. (submitted). Comparative study of AMS target performance using the NOSAMS recombinator ion source. Part I: Experimental design, sample preparation, and analysis protocol. *Nuclear Instr. & Methods.*

MCNICHOL, A.P., Jones, G.A., Hutton, D.L., Gagnon, A.R. and Key, R.M. (submitted). Rapid analysis of seawater samples at the National Ocean Sciences Accelerator Mass Spectrometry Facility, Woods Hole, MA. *Radiocarbon.*

MCNICHOL, A.P., Osborne, E.A., Gagnon, A.R., Fry, B. and Jones, G.A. (accepted). TIC, TOC, DIC, DOC, PIC, POC - Unique aspects in the preparation of oceanographic samples for ^{14}C- AMS. *Nuclear Instr. & Methods.*

*NADEAU, M-J., Litherland, A.E., Garwan, M.A. and Zhao, X-L. (submitted). Electric dissociation of negative ions-II. *Nuclear Instr. & Methods.*

OLDALE, R.N., Colman, S.M. and Jones, G.A., 1993. Radiocarbon ages from two submerged strandline features in the Western Gulf of Maine and a modified sea-level curve for the Northeastern Massachusetts coastal region. *Quat. Res.*, 40:38- 45.

OSBORNE, E.A., McNichol, A.P., Gagnon, A.R., Hutton, D.L. and Jones, G.A. (accepted). Internal and external checks in the NOSAMS Sample Preparation Laboratory for target quality and homogeneity. *Nuclear Instr. & Methods.*

SCHNEIDER, R.J.and Jones, G.A. 1992/1993. Accelerator Mass Spectrometry, tracing carbon in the marine environment. *Oceanus*, 35:93-95.

SCHNEIDER, R.J., Jones, G.A., McNichol, A.P., von Reden, K.F., Elder, K.L., Huang, K. and Kessel, E.D. (accepted). Methods for data screening, flagging, and error analysis at the National Ocean Sciences AMS Facility. *Nuclear Instr. & Methods.*

SÉGUIN, F. H., Schneider, R.J., Jones, G.A. and von Reden, K.F. (accepted). Optimized data analysis for AMS radiocarbon dating. *Nuclear Instr. & Methods.*

VON REDEN, K.F., Schneider, R.J., Cohen, G.J. and Jones, G.A. (accepted). Performance characteristics of the 3MV Tandetron AMS system at the National Ocean Sciences AMS Facility. *Nuclear Instr. & Methods.*

WEIDMAN, C.R. and Jones, G.A., 1993. A shell-derived time history of bomb-^{14}C on Georges Bank and its Labrador Sea implications. *J. Geophys. Res.*, 98:14577-14588.

WEIDMAN, C.R. and Jones, G.A. (in press). Development of the mollusc *Arctica islandica* as a paleoceanographic tool for reconstructing annual and seasonal records of $\Delta^{14}C$ and $\delta^{18}O$ in the mid-to high-latitude North Atlantic Ocean. In, Rozanski, K. (ed.), *Applications of Isotope Techniques in Studying Past and Current Environmental Changes in the Hydrosphere and the Atmosphere.* IAEA-SM-329/56/0, Vienna.

WEIDMAN, C.R. and Jones, G.A. (accepted). A new high-temporal resolution paleoceanographic tool for the northern North Atlantic: The mollusc *Arctica islandica*. *International Council for the Exploration of the Sea.*

WEIDMAN, C.R. and Jones, G.A. (accepted). The long-lived mollusc, *Arctica islandica*: A new paleoceanographic tool for the reconstruction of maximum bottom temperatures for the continental shelves of the northern North Atlantic Ocean. *J. Geophys. Res.*

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