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Origin of the northern Atlantic's Heinrich events*

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Abstract. As first noted by Heinrich, 1988, glacial age sediments in the eastern part of the northern Atlantic contain layers with unusually high ratios of ice-rafted lithic fragments to foraminifera shells. He estimated that these layers are spaced at intervals of roughly 10000 years. In this paper we present detailed information documenting the existence of the upper five of these layers in ODP core 609 from 50° N and 24° W. Their ages are respectively 15000 radiocarbon years, 20000 radiocarbon years, 27000 radiocarbon years, about 40000 years, and about 50000 years. We also note that the high lithic fragment to foram ratio is the result of a near absence of shells in these layers. Although we are not of one mind regarding the origin of these layers, we lean toward an explanation that the Heinrich layers are debris released during the melting of massive influxes of icebergs into the northern Atlantic. These sudden inputs may be the result of surges along the eastern margin of the Laurentide ice sheet.

In a paper published in Quaternary Research Heinrich (1988) reports prominent peaks in lithic fragment abundance spaced at roughly 10000 year intervals in a series of three cores from 47° N and 19° W in the Atlantic Ocean spanning a depth range from 3.9 to 4.3 km. As reproduced in Fig. 1, six such peaks are present in the cold interval constituting marine stages 2, 3 and 4. Heinrich concludes that these peaks represent ice-rafting events.

We puzzled over these results and decided to determine whether similar peaks were to be found in a core from ODP site 609 (50° N 24° W 3.9 km) 3° latitude to the north and 5° longitude to the west of Heinrich's locale (see Fig. 2). We sampled this core at 1 cm intervals over the time span from about 10000 years to about 60000 years. Both radiocarbon dating (see Table 1) and the depth separation between the stage 1-2 and stage 4-5 boundaries require an average sedimentation rate of about 6 cm/10^3 years for this interval. Thus, our samples are spaced at about 150 year intervals. We examined the greater than 150 μm fraction from each sample and found it to consist of a mixture of foraminifera shells and mineral fragments. The mineral fragments are dominated by angular quartz grains, free of any coatings. Also present are feldspar grains and a few dark minerals. We counted the total number of lithic fragments and the total number of whole foraminifera shells in splits of each sample. We also counted the number of *Neogloboquadrina pachyderma* (left coiling) shells in each split. For each sample more than 500 grains were counted. Based on sample weights, coarse fraction weights and split fraction, these counds could be converted to grains per gram of sediment (see Table 2 for listing).

As shown in Fig. 3, when expressed as lithic fragment percent a pattern similar to that obtained by Heinrich (1988) is found. Five such peaks are present in the section we studied. Radiocarbon dating places one at about 15000 years BP, one at about 20000 years BP and one at about 27000 years BP. By extrapolation we estimate the ages of the other two to be about 40000 years and about 50000 years. Although Heinrich (1988) did not obtain radiocarbon dates for his cores, interpolation between the positions of the 5-4 and 2-1 boundaries in his cores leads to a similar chronology. Note also that the peaks, heights and widths are similar at the two locales. The stage 5-4 boundary in ODP 609 is at a depth of about 450 cm. Hence the measurements we have made to date do not extend deep enough in the core to reach the oldest of the six Heinrich peaks. We plan to extend our measurements into marine isotope stage 6 (i.e., to about 140000 years).

When the absolute counts are considered one gets a somewhat different impression than the one given by Heinrich (1988). The peaks in lithic fragment percentage do not represent times of unusually high lithic fragment concentration. Rather, they represent times of exceptionally low foraminifera concentration. For peak

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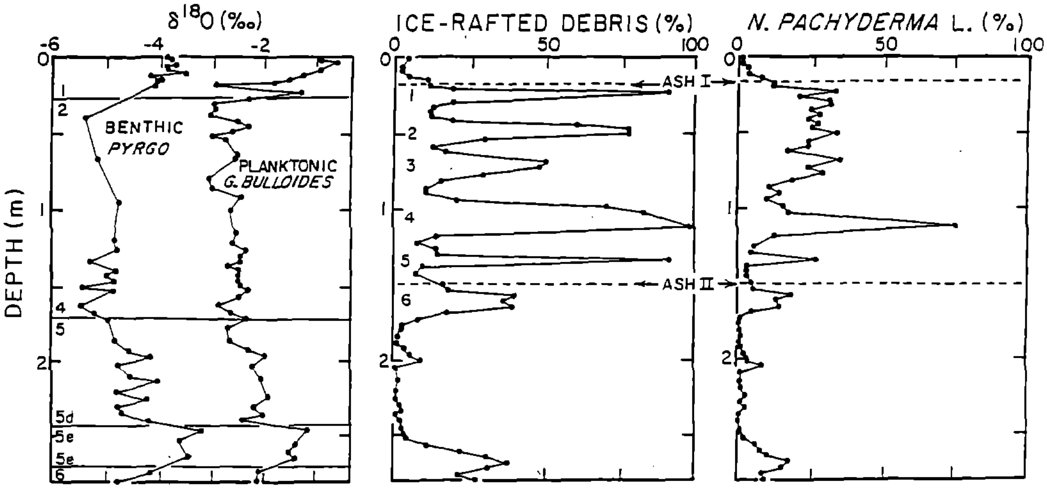

Fig. 1. Records obtained by Heinrich, 1988 for oxygen isotopes (for the planktonic species, *G. bulloides* and for the benthic species, Pyrgo), the abundance of ice rafted debris and the abundance (in percent of total foraminifera) of *N. pachyderma* (*left*) in the northern Atlantic core Me 69-17 (latitude 47° N, longitude 19° W, depth 3.9 km). The *dashed lines* indicate the positions of ash horizons prominent throughout the northern Atlantic. The *solid lines* represent stage boundaries (i.e., 6–5e, 5e–5d, 54 and 2–1) clearly defined by the ^{18}O record. As can be seen, five peaks in ice rafted debris occur between ash II (~60000 years) and ash I (~10000 years) horizons, and one between the stage 4–5 boundary (~70000 years) and ash II

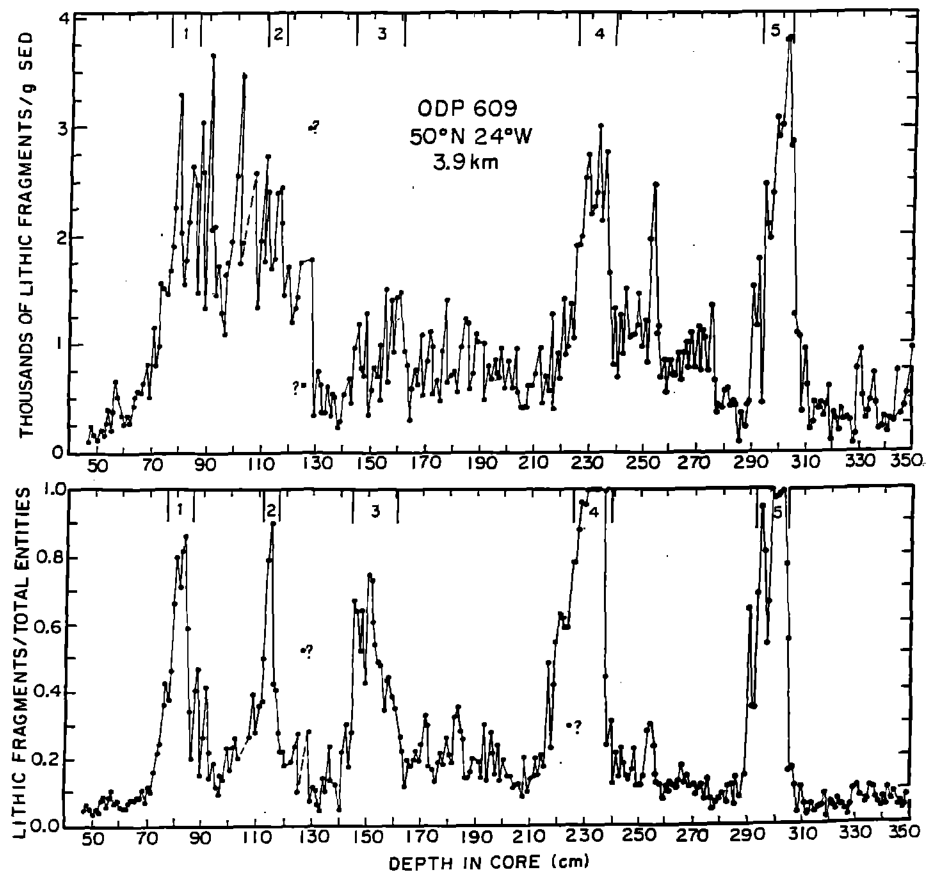

Fig. 2. Lithic fragment abundances: The *upper panel* gives the number of lithic fragments (> 150 μ) per gram of bulk sediment. The *lower panel* gives the ratio of lithic fragments to the sum of lithic fragments and foraminifera shells in the greater than 150 μm size fraction (i.e., the same format as the percent ice-rafted debris diagram reproduced from Heinrich 1988, Fig. 1)

number 4, five successive samples contained no forams at all (see Table 2). In the other Heinrich zones the abundance of foraminifera shells is more than an order of magnitude lower than that in the overlying and underlying sediment. So low in fact, that those forams present in the Heinrich zones could easily have been bioturbated into place from either the overlying or underlying sediment. So what needs to be explained is the unusually small concentration of foraminifera shells. Indeed, the youngest of these foraminifera free zones was recognized a decade ago by Ruddiman and McIntyre (1981) in a series of cores in the northeastern Atlantic. They refer to it as the foraminifera barren zone.

Table 1. AMS radiocarbon ages (Broecker et al. 1990) on hand-picked foraminifera shells from DSDP Core 609 (49° 53′N, 24° 14′W, 3884 m)

Depth, cm	Species	Radiocarbon Age, years	Corrected Age[c], years
21–23	*G. bulloides*	5420 ± 80	5020
63–65	*G. inflata*	12380 ± 120	11880
79–81	*G. inflata*[a]	12740 ± 140	12340
90–91	*N. pachyderma*	16760 ± 150	16360
105–107	*N. pachyderma*	19340 ± 220	18940
112–113	*N. pachyderma*	21510 ± 220	21110
114–115	63–150 μ fraction[b]	37280 ± 490	—
115–116	*N. pachyderma*	21770 ± 220	21370
118–120	*N. pachyderma*	22780 ± 340	22380
139–141	*G. bulloides*	25660 ± 440	25260
153–155	*N. pachyderma*	29570 ± 660	25170
174–176	*G. bulloides*	31120 ± 730	30720

[a] As this sample was taken from one of the foraminifera barren zones, the shells dated could have been stirred downward from sediment deposited above the barren zone

[b] Bulk $CaCO_3$ from the second to youngest foraminifera barren zone (Heinrich # 2). The $CaCO_3$ in this sample is largely detrital limestone. The old age is consistent with this interpretation

[c] Corrected for an assumed 400 year age difference between surface watercarbon and atmospheric carbon

A possible explanation for the near absence of foraminifera shells in the Heinrich zones is that they were subsequently dissolved. One argument against this is that the forams found in these layers and immediately adjacent to them do not show evidence for partial dissolution. Of course one could counter this objection by calling on the downward bioturbation of foraminifera into the Heinrich zones after the dissolution event came to an end. Another argument against the dissolution explanation is that even if the ambient sedimentation rate is adopted, the events have durations less than the several thousand year long relaxation time for the $CO_3^=$ ion content of deep ocean water. This criticism might be overcome by calling on brief invasions into the North Atlantic of $CO_3^=$ deficient Antarctic water. However, during the Younger Dryas when such an invasion is documented to have taken place (Boyle and Keigwin 1987), no foram deficient zone was produced. Thus we tentatively reject $CaCO_3$ dissolution as the explanation for the Heinrich zones.

Another possible explanation for the Heinrich zones is that the production of foraminifera shells ceased (or at least was greatly reduced) in the surface waters overlying this area during these episodes. Such a reduction could be caused by meltwater. While the low foraminifera content of Heinrich zone sediment makes interpretations based on the ratio of *N. pachyderma* (left coiling) shells to total foraminifera shells suspect, we note that those foraminifera shells which are present in these zones are mainly of the species *N. pachyderma* (left coiling). Also the foraminifera rich sediments flanking the Heinrich zones have very high percentages of *N. pachyderma* (left coiling) foraminifera shells. This suggests that the Heinrich zones were produced during times of intense cold in the northeastern Atlantic. Hence we tentatively reject the melt water hypothesis.

Rather, we lean toward an explanation which suggests large-scale cover of the northeastern Atlantic by icebergs. This cover could be the result of either an intense cold period which allowed icebergs shed by the ice sheets surrounding the Atlantic to push far to the south or a surge of one of the ice sheets which flooded the Atlantic with icebergs. In either case, as the icebergs melted, the debris they contained was dumped onto the seafloor forming Heinrich layers. The low foraminifera concentration could either be accounted for by a dilution with the rapidly accumulating debris or by a reduction in plant productivity due to blockage of light by the floating ice. In order to determine which process is the more important, it would be necessary to establish the sedimentation rate for the Heinrich zones. As these zones constitute only a small portion of the total record, this proves a difficult task. Heinrich zones 1, 2, and 3 are respectively about 6, 3, and 11 cm wide. Adopting the average accumulation rate of 6 cm/10^3 y as an upper limit, the duration of these three events are respectively less than 1000, 500, and 1800 y. If the actual rates lie close to this upper limit, then a reduction in productivity caused by ice cover would have to be called on to account for the low concentration of foraminifera shells. On the other hand, if dilution is the primary cause for the low foraminifera shell concentrations, then sedimentation rates more than an order of magnitude higher (i.e., >60 cm/10^3 yrs.) would have to be called upon. In this case, the duration of events 1, 2, and 3 would have to be less than 50, 100, and 180 years respectively. Currently we have no means to distinguish between these two scenarios.

We have one piece of evidence which allows us to reject any hypothesis which requires the same source of icebergs as that which supplied the quartz-rich lithic fragments suite to the ambient glacial age sediment. Heinrich layers 1, 2, 4, and 5 (but not 3) contain detrital limestone and dolomite not present in the sediment between the layers (Bond, in preparation). This suggests a different source for the icebergs which delivered the Heinrich layer material.

If, as we postulate, the Heinrich zones represent times of wide spread ice cover, then the climatic events which triggered this cover should be recorded elsewhere. To our knowledge this is the case for only the last of these events, i.e., that at about 15000 years ago. It corresponds to a time very close to termination Ia. If just before, it could correspond to the second peak of the two-fold glacial maximum (see Broecker and Denton 1989). If just after, it could correspond to the time of major deglaciation in the alps (Schlüchter 1988) and likely also in many other mountain ranges (Broecker and Denton 1989). No evidence for climatic changes corresponding to the earlier Heinrich events is known to us. For example, the Greenland ice core record (see Hammer et al. 1985), while showing numerous events spaced at intervals of a few thousand years has no pronounced features corresponding to Heinrich events. This absence would be nicely explained were the Hein-

Table 2. Summary of analysis made on the > 150 μm fraction of samples from ODP site 609. Where duplicate entries appear, they represent independent counts of the same sample. These levels were selected for recounts because the first result appeared anomalous based on those for adjacent samples. The samples from 47 cm to 150 cm were taken from core 1, section 1; those from 150 cm to 300 cm from core 1, section 2; and those from 300 cm to 350 cm from core 1, section 3

Depth (cm)	> 63 μm Fraction[a] (gm/gm)	No. Lithic Fragments per gram	No. Foram Shells per gram	Percent Lithic Fragments	Percent *N. pachyderma* (left coiling)
47–48	0.08	119	2468	4.6	8.1
48–49	0.09	241	3677	6.2	16.8
49–50	0.08	162	3062	5.0	19.1
50–51	0.10	124	3141	3.8	18.7
51–52	0.11	192	3444	5.3	19.7
52–53	0.14	177	3688	4.6	28.5
53–54	0.11	283	3505	7.5	34.0
54–55	0.15	397	4212	8.6	35.0
55–56	0.13	225	3932	5.4	39.3
56–57	0.16	380	4037	8.6	40.1
57–58	0.23	689	5987	10.3	45.6
58–59	0.24	556	7587	6.8	35.6
59–60	0.17	341	4194	7.5	36.1
60–61	0.15	268	4589	5.5	34.2
61–62	0.19	397	7074	5.3	28.9
62–63	0.18	276	4885	5.4	30.8
63–64	0.25	436	5979	6.8	45.4
64–65	0.24	520	6402	7.5	40.6
65–66	0.24	581	6919	7.8	34.6
66–67	0.21	564	5627	9.1	40.1
67–68	0.23	641	6449	9.0	34.7
68–69	0.28	829	6943	10.7	39.1
69–70	0.32	509	6473	7.3	50.6
70–71	0.30	1134	8742	11.5	45.3
71–72	0.22	826	7015	10.5	28.1
72–73	0.17	978	5264	15.7	27.6
73–74	0.24	1563	5667	21.6	19.1
74–75	0.26	1533	4838	24.1	23.4
75–76	0.25	1464	2631	35.8	24.4
76–77	0.28	1667	2292	42.1	45.5
77–78	0.27	1895	3211	37.1	36.9
78–79	0.32	2543	2976	46.1	42.9
79–80	0.35	3305	1659	66.6	41.9
80–81	0.27	2030	494	80.4	46.4
81–82	0.22	1553	627	71.2	27.6
82–83	0.24	1770	396	81.7	34.9
83–84	0.28	2257	346	86.7	50.0
84–85	0.43	2646	1844	58.9	80.8
85–86	0.48	2488	4756	34.4	88.7
86–87	0.46	1478	5925	20.0	86.9
87–88	0.49	3058	4377	41.1	84.8
88–89	0.54	2609	2953	46.9	77.8
89–90	0.52	1329	7315	15.4	80.7
90–91	0.61	3650	10100	26.6	82.9
91–92	0.44	2055	2891	41.6	78.6
92–93	0.41	2085	7426	21.9	93.1
93–94	0.52	1463	8944	14.1	13.5
94–95	0.58	1724	7586	18.5	92.7
—	0.58	4414	9397	32.0	90.8
95–96	0.53	1292	9771	11.7	90.6
96–97	0.48	1094	9688	10.2	87.7
97–98	0.35	1656	9375	15.0	84.7
98–99	0.50	1750	10786	14.0	81.5
99–100	0.36	1964	6536	23.1	68.9
100–101	0.28	2563	12813	16.7	99.1
—	0.28	2221	9032	19.7	97.2
101–102	0.27	3486	11429	23.4	99.1
—	0.27	4000	9000	30.8	96.8
102–103	0.21	1747	4899	26.3	98.2
103–104	0.26	1964	7893	19.9	97.6
107–108	0.22	2614	7114	26.9	98.6
108–109	0.23	1365	2127	39.1	93.3

Table 2. (continued)

Depth (cm)	> 63 μm Fraction[a] (gm/gm)	No. Lithic Fragments per gram	No. Foram Shells per gram	Percent Lithic Fragments	Percent *N. pachyderma* (left coiling)
109–110	0.15	2072	5362	27.9	100.0
110–111	0.30	1771	3129	36.1	87.9
—	0.30	2572	4343	37.2	94.6
111–112	0.27	2748	4657	37.1	95.7
112–113	0.28	2415	2454	49.6	96.8
113–114	0.22	1703	444	79.3	96.0
114–115	0.19	1796	190	90.4	96.8
115–116	0.31	2402	3317	42.0	93.8
116–117	0.35	2453	3587	40.6	90.7
117–118	0.33	2115	5497	27.8	95.8
118–119	0.30	1452	4939	22.7	96.5
119–120	0.32	1710	6073	22.0	93.6
120–121	0.20	1211	5503	18.0	96.1
122–123	0.33	1339	5750	18.9	87.6
123–124	0.41	1426	4575	23.8	90.7
124–125	0.32	1750	4727	27.0	88.5
125–126	0.31	670	5596	10.7	83.1
—	0.31	1383	5511	20.1	86.7
126.5–127.5	0.30	3000	2693	52.7	93.6
—	0.30	3960	3168	55.6	90.7
128–129	0.16	1797	4447	28.8	75.0
129–130	0.16	365	4615	7.3	69.2
130–131	0.27	754	5785	11.5	87.5
131–132	0.26	631	5117	11.0	75.7
132–133	0.18	328	4614	6.6	77.8
133–134	0.15	441	5751	7.1	50.8
—	0.15	331	6898	4.6	54.4
134–135	0.14	613	3697	14.2	73.1
135–136	0.12	351	2960	10.6	61.9
136–137	0.11	543	1752	23.7	69.5
137–138	0.15	507	3443	12.8	61.0
139–140	0.12	236	1713	12.1	51.7
140–141	0.13	291	5376	5.1	61.4
141–142	0.13	544	1917	22.1	77.6
142–143	0.11	673	1520	30.7	74.3
143–144	0.10	451	2145	17.4	63.8
144–145	0.11	983	2500	28.2	83.2
145–146	0.15	1178	580	67.0	96.0
146–147	0.19	768	425	64.4	95.3
147–148	0.10	708	624	53.2	92.2
148–149	0.09	1297	705	64.8	96.5
149–150	0.09	362	476	43.2	95.8
150–151	0.13	578	193	75.0	90.2
151–152	0.11	799	288	73.5	88.2
152–153	0.12	691	446	60.8	88.8
153–154	0.15	1000	831	54.6	93.4
154–155	0.16	492	515	48.9	86.2
155–156	0.19	1500	1613	48.2	93.0
156–157	0.17	637	1214	34.4	97.5
157–158	0.18	1430	1608	47.1	94.5
158–159	0.14	917	1122	45.0	94.0
159–160	0.22	1427	2282	38.5	90.5
160–161	0.18	1494	2782	34.9	90.1
161–162	0.15	859	1837	31.9	90.0
162–163	0.14	934	2563	26.7	87.9
163–164	0.13	792	2813	22.0	80.0
164–165	0.13	307	2292	11.8	71.3
165–166	0.13	602	2432	19.8	66.6
166–167	0.14	754	3568	17.5	46.8
167–168	0.15	625	2571	19.6	61.8
168–169	0.16	1077	3750	22.3	67.5
169–170	0.09	530	2148	19.8	58.3
170–171	0.14	861	2609	24.8	60.7
171–172	0.13	1121	2250	33.3	73.7
172–173	0.12	987	2304	30.0	51.0

Table 2. (continued)

Depth (cm)	> 63 μm Fraction[a] (gm/gm)	No. Lithic Fragments per gram	No. Foram Shells per gram	Percent Lithic Fragments	Percent *N. pachyderma* (left coiling)
173–174	0.11	526	2447	17.7	47.3
174–175	0.13	655	3260	16.7	41.3
175–176	0.12	484	3160	13.3	36.6
176–177	0.14	935	3959	19.1	47.8
177–178	0.21	1415	5105	21.7	46.5
178–179	0.13	642	2781	18.8	51.5
179–180	0.12	748	1945	27.8	82.1
—	0.12	638	1904	25.1	84.1
—	0.12	1002	1718	36.8	81.7
180–181	0.12	742	2758	21.2	43.1
181–182	0.16	554	2316	19.3	49.1
182–183	0.15	778	1597	32.8	71.8
183–184	0.14	986	1838	34.9	67.0
184–185	0.16	1241	3211	27.9	62.8
185–186	0.18	1188	3438	25.7	56.4
186–187	0.16	574	3438	14.1	53.0
187–188	0.17	731	4477	14.0	48.1
188–189	0.16	1079	5614	16.1	49.1
189–190	0.17	1013	4125	19.7	50.9
191–192	0.15	1012	4310	19.0	41.9
192–193	0.11	490	2965	14.2	54.5
193–194	0.12	785	1792	30.5	55.1
194–195	0.14	667	4316	13.4	48.2
195–196	0.14	845	2442	25.7	70.2
196–197	0.11	737	2679	21.6	62.4
197–198	0.13	700	3873	15.3	53.7
198–199	0.14	979	3074	24.2	48.1
199–200	0.13	598	3848	13.5	53.6
200–201	0.14	831	3359	19.8	56.0
202–203	0.11	591	3296	15.2	38.6
203–204	0.16	976	5394	15.3	49.4
204–205	0.13	534	3962	11.9	39.1
205–206	0.10	423	3023	12.3	29.5
206–207	0.12	432	3045	12.4	18.9
207–208	0.10	610	2329	20.8	26.5
—	0.10	636	2698	19.1	23.2
208–209	0.15	395	4032	8.9	26.4
—	0.15	679	3643	15.7	21.1
209–210	0.15	611	5167	10.6	54.8
210–211	0.14	726	4381	14.2	47.5
211–212	0.12	606	3385	15.2	26.4
212–213	0.12	967	3878	20.0	19.8
213–214	0.09	427	2449	14.9	18.1
—	0.09	500	2824	15.0	21.9
214–215	0.10	748	2845	20.8	30.7
—	0.10	641	2340	21.5	27.8
215–216	0.12	444	2069	17.7	37.3
—	0.12	667	2972	18.3	31.3
216–217	0.14	1449	1228	54.1	67.0
—	0.14	1095	1443	43.1	65.4
217–218	0.25	397	1340	22.9	51.9
218–219	0.10	892	1203	42.6	66.3
219–220	0.09	686	563	54.9	76.4
220–221	0.17	1301	767	62.9	90.6
221–222	0.11	889	539	62.3	88.9
222–223	0.14	967	663	59.3	90.8
223–224	0.16	1324	907	59.4	76.2
224–225	0.14	1032	2487	29.3	46.2
—	0.14	1484	2048	42.0	40.8
225–226	0.20	1911	522	78.6	59.8
226–227	0.20	1911	516	78.7	87.0
227–228	0.21	1993	259	88.5	90.4
228–229	0.22	2550	100	96.2	85.0
229–230	0.23	2754	118	95.9	84.8
230–231	0.23	2216	0	100.0	—

Table 2. (continued)

Depth (cm)	> 63 μm Fraction[a] (gm/gm)	No. Lithic Fragments per gram	No. Foram Shells per gram	Percent Lithic Fragments	Percent *N. pachyderma* (left coiling)
231-232	0.22	2264	0	100.0	—
232-233	0.22	2337	0	100.0	—
233-234	0.19	3018	0	100.0	—
234-235	0.23	2146	0	100.0	—
236-237	0.26	2772	28	99.0	100.0
237-238	0.20	1641	2087	44.0	62.2
—	0.20	1636	1995	45.1	62.7
238-239	0.14	676	2235	23.2	34.0
—	0.14	890	2676	25.0	32.7
239-240	0.22	1399	3064	31.4	65.6
—	0.22	1234	2780	30.7	66.5
240-241	0.21	692	4713	12.8	64.3
241-242	0.22	1256	4615	21.4	60.0
242-243	0.20	900	5311	14.5	62.3
243-244	0.20	1512	5081	22.9	56.5
244-245	0.22	1050	4555	18.7	65.2
245-246	0.26	1366	6169	18.1	87.4
—	0.26	831	6577	11.2	69.4
246-247	0.21	1103	7000	13.6	49.8
247-248	0.19	1171	5761	16.9	51.9
248-249	0.16	1475	4808	23.5	35.0
250-251	0.15	989	7543	11.6	39.2
251-252	0.24	1189	8733	12.0	65.7
252-253	0.17	844	4918	14.6	57.2
253-254	0.25	1974	5079	28.0	45.6
254-255	0.29	2484	5926	29.5	47.4
255-256	0.18	1091	3565	23.4	41.0
256-257	0.17	1150	6688	14.7	28.2
257-258	0.16	690	4820	12.5	40.5
258-259	0.15	833	6097	12.2	28.7
259-260	0.18	569	6831	7.7	21.0
260-261	0.18	859	6533	11.6	24.5
261-262	0.17	726	6562	10.0	21.3
262-263	0.16	701	4670	13.1	26.5
263-264	0.19	921	6368	12.6	32.2
264-265	0.18	645	5190	11.1	34.2
265-266	0.20	889	5878	13.1	34.0
266-267	0.15	1009	4818	17.3	36.0
267-268	0.15	771	5385	12.5	28.8
268-269	0.18	1111	6633	14.3	31.7
269-270	0.17	776	5800	11.8	27.7
270-271	0.19	1153	8531	11.9	27.6
271-272	0.17	750	7290	9.3	33.9
272-273	0.18	1124	8888	11.2	33.5
273-274	0.18	1062	7926	11.8	31.8
274-275	0.18	747	8662	7.9	31.5
275-276	0.23	1358	8761	13.4	27.4
276-277	0.15	643	8000	7.4	22.0
277-278	0.19	353	6941	4.8	16.7
278-279	0.14	417	6472	6.1	11.8
279-280	0.14	403	5992	6.3	19.4
280-281	0.16	546	5859	8.5	13.8
281-282	0.15	571	5786	9.0	18.3
282-283	0.15	416	6247	6.2	13.0
283-284	0.12	475	3848	11.0	19.7
284-285	0.10	437	3376	11.5	20.5
285-286	0.07	109	1732	5.9	12.6
286-287	0.08	361	2067	14.9	20.1
287-288	0.07	230	2503	8.4	22.1
288-289	0.09	432	2408	15.2	25.2
289-290	0.11	445	2445	15.4	31.5
290-291	0.17	1517	812	65.1	72.7
291-292	0.16	1137	2094	35.2	26.8
292-293	0.08	1783	3319	34.9	16.3
293-294	0.16	2476	1123	68.8	44.8

Table 2. (continued)

Depth (cm)	>63 μm Fraction[a] (gm/gm)	No. Lithic Fragments per gram	No. Foram Shells per gram	Percent Lithic Fragments	Percent *N. pachyderma* (left coiling)
294–295	0.21	2470	130	95.0	60.7
295–296	0.16	2105	475	81.6	89.3
296–297	0.16	1956	1652	54.2	50.7
297–298	0.22	2385	1202	66.5	58.8
298–299	0.24	3085	25	99.2	84.0
299–300	0.28	2903	76	97.5	66.7
300–301	0.23	3023	65	97.8	58.8
301–302	0.26	3847	43	98.9	10.0
302–303	0.26	3858	26	99.3	50.0
303–304	0.22	2813	822	77.6	14.2
304–305	0.24	2871	2311	55.4	47.2
305–306	0.18	1278	6656	16.1	46.3
306–307	0.19	1082	5437	16.6	36.2
307–308	0.17	1055	7921	11.6	35.6
308–309	0.15	377	7484	4.8	25.6
309–310	0.18	951	7343	11.5	37.4
310–311	0.17	602	8594	6.5	32.3
311–312	0.12	190	6810	2.7	23.5
312–313	0.10	259	6238	4.0	24.7
313–314	0.13	457	6410	6.7	28.7
314–315	0.17	382	8800	4.2	24.2
315–316	0.15	451	7833	5.4	26.8
316–317	0.13	318	5418	5.6	19.0
317–318	0.14	443	7080	5.9	24.7
318–319	0.14	598	6464	8.5	24.2
319–320	0.13	99	5198	1.9	14.6
320–321	0.12	364	5415	6.3	20.3
321–322	0.12	281	5468	4.9	23.6
322–323	0.13	194	4765	3.9	27.0
323–324	0.23	380	4804	7.3	19.7
324–325	0.13	295	5128	5.4	18.3
325–326	0.12	298	5077	5.6	21.7
326–327	0.16	280	6080	4.4	16.0
327–328	0.08	82	3569	2.2	13.2
328–329	0.08	162	2859	5.4	20.3
329–330	0.19	762	6839	10.0	28.6
330–331	0.17	944	7232	11.6	32.5
331–332	0.12	509	5455	8.5	19.3
333–334	0.11	299	5103	5.9	24.7
334–335	0.12	374	4473	7.7	21.3
335–336	0.11	470	4183	10.1	32.7
336–337	0.19	721	6686	9.7	33.2
337–338	0.15	461	5578	7.6	29.0
338–339	0.09	182	2617	6.5	37.0
339–340	0.09	207	3852	5.1	34.4
340–341	0.11	335	3919	7.9	28.0
341–342	0.08	161	2530	6.0	32.5
342–343	0.08	287	2692	9.6	29.6
343–344	0.09	268	3375	7.4	37.6
344–345	0.14	746	7224	9.4	44.0
345–346	0.13	344	5740	5.7	32.1
346–347	0.13	366	5381	6.4	42.4
347–348	0.12	400	7740	4.9	59.6
348–349	0.17	529	10132	5.0	67.7
349–350	0.17	966	11103	8.0	42.4

[a] The primary separation is made by passing the wet core material through a 63 μm sieve. The dry coarse fraction is passed through a 150 μm sieve and a split of this material counted

rich events the product of surges of the Laurentian ice sheet. Were this the case, no associated climate signal is to be expected.

In summary, when we initiated our study of ODP 609, it was with the purpose of finding evidence for the Dansgaard/Oeschger events which punctuate the Greenland ice core record. While evidence for these high frequency events does appear in the color record (Broecker et al. 1990) and in the *N. pachyderma* record (Fig. 3), the dominant features in marine stages 2, 3,

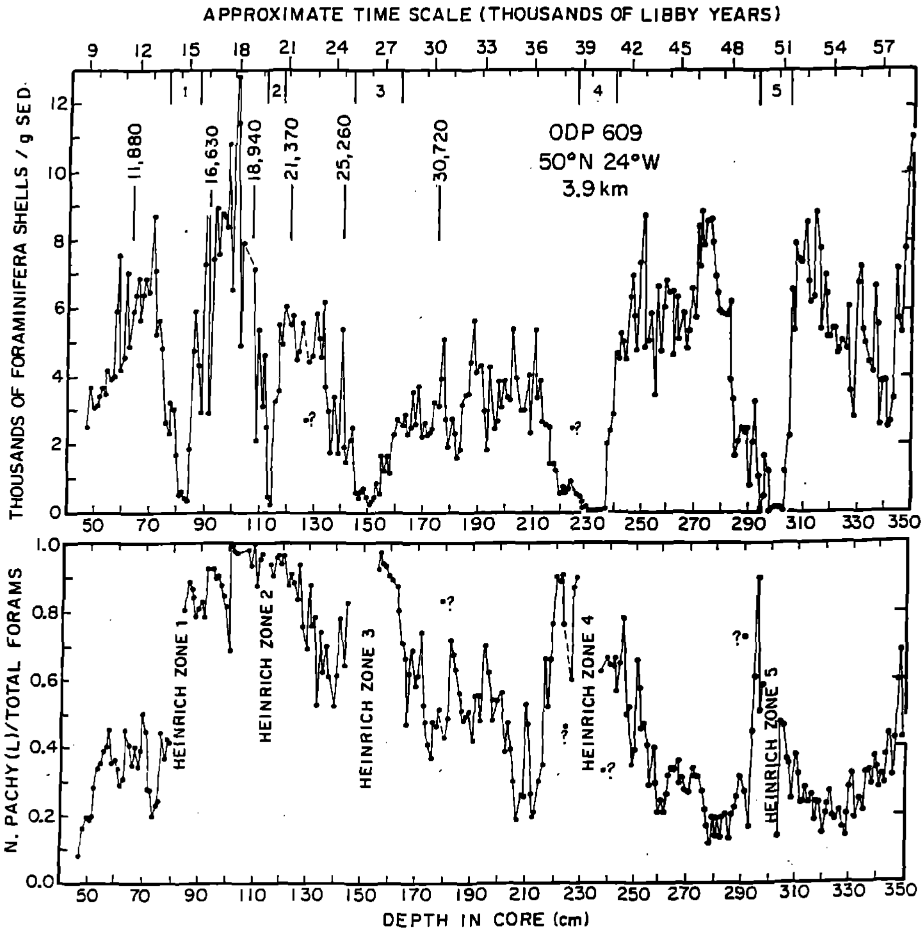

Fig. 3. Foraminifera abundances: the *upper panel* gives the number of whole foraminifera shells (> 150 μ) per gram of bulk sediment. The *lower panel* gives the ratio of *N. pachyderma* (left coiling) shells to the total foraminifera shells (i.e., the same format as the percent *N. pachyderma* 1. diagram reproduced from Heinrich 1988 in Fig. 1)

and 4 in the ODP 609 record are the lower frequency Heinrich events. Thus, yet another element must be added to an already complex history of the northern Atlantic basin.

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