A quantitative foraminiferal biozonation of the Late Jurassic and Early Cretaceous of the East Newfoundland Basin

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ABSTRACT: Last occurrence data on 113 Early Cretaceous–Late Jurassic foraminifers as observed from 13 hydrocarbon exploration wells in the East Newfoundland Basin were examined in an attempt to determine a regional stratigraphy. The majority of the wells differ from each other in the relative sequence of their events. The underlying stratigraphic signal within this data set was investigated with the aid of the quantitative biostratigraphic method RASC (RAnking and SCaling). Examination of RASC derived optimum and scaled optimum sequences facilitated the recognition of 11 RASC biozones of Cenomanian to Kimmeridgian age. Two correlation schemes are presented: the first is subjective appraisal of the RASC-derived zonation using a standard time scale; the second is an objectively derived scheme using the RASC results as input and a RASC timescale. The two schemes are essentially similar; the latter, however, is more objective and provides statistically derived measures of uncertainty (in meters) for each tie line.

INTRODUCTION

Paleontological data, particularly as obtained from exploration well cuttings, are often beset with an obscuring noise factor which makes difficult the subjective recognition and correlation of biozones. A large part of these vagaries is due to the incompleteness of the fossil record but is compounded by such geological effects as the presence of hiatuses, unconformities, disconformities, rapid vertical and horizontal facies changes, and faunal provincialism. Similarly, the non-geological effects of downhole contamination, observer bias, taxonomic misidentification and the frequency and quality of available samples (predominantly ditch cuttings) act together and obscure important stratigraphic information present within the data.

Biostratigraphers have, at the present time, a wide range of computer assisted quantitative and non-quantitative aids to help in the interpretation of such data. The philosophy, statistics, and desirability of quantitative treatment of some biostratigraphic data are documented in the literature and include multivariate analysis (Hazel 1977; Millendorf et al. 1978), biostratigraphic fidelity techniques, and methods involving the determination of most likely sequences using ranking and scaling methods (Shaw 1964; Hay 1972; Edwards and Beaver 1978; Gradstein and Agterberg 1982; Gradstein 1984). Although these methods exist, much resistance to their widespread use is evident (Raup 1981). This has been attributed (Brower 1981) to the complex nature of many of the methods, which assume concepts and philosophies that are alien to many. The methods most attractive to biostratigraphers seem to be those that borrow from the well-tried assumptions and concepts used routinely in biostratigraphy. Such a method (ranking and scaling or RASC) is described in Agterberg and Nel (1982a, 1982b), Gradstein and Agterberg (1982) and Heller et al. (1983). The purpose of this paper is to demonstrate further the usefulness and practicality of this method as a biostratigraphic tool when dealing with cuttings. The investigation concerns the complex Jurassic and Early Cretaceous foraminiferal record as recovered from cutting samples of several East Newfoundland Basin wells.

Geological background

Hydrocarbon exploratory drilling and seismic operations have, with an increasing precision, determined the presence of a thick Mesozoic and Cenozoic sedimentary wedge off the eastern continental margin of Canada. The sequences are preserved in a series of northeast and southwest trending basins and subbasins (text-fig. 1). The most prominent of these is the East Newfoundland Basin, and its southwest extension termed the Jeanne d'arc subbasin. The Hibernia oil field, which is classed as a major oil accumulation (McKenzie 1981) lies within the Jeanne d'arc subbasin.

The general basinal architecture and depositional styles of this whole region are well documented in the literature (Sherwin 1972; Amoco Canada Ltd. and Imperial Oil, 1973; Jansa and Wade 1975; Wade 1980; McWhade 1980; McKenzie 1981; and Benteau and Sheppard 1982), and reflect in part the rift history of the North Atlantic Ocean. Initial movements and separation of the European and North American plates began some time in the Triassic and resulted in several deformation features that included a series of northeast to southwest trending rift valleys. These basins were infilled with continental red beds and salt deposits. Active spreading began earlier in the Scotian Basin and southern Grand Banks (mid-Jurassic) than in the more northerly East Newfoundland Basin (Late Jurassic-Early Cretaceous) and resulted in a Jurassic transgression of marine carbonates, shales and sands over the initial continental deposits. Subsequent Early Cretaceous deposits are the expression of major progradational deltaic pulses and include marine and marginal marine sands and shales. The Avalon uplift around Middle Cretaceous times led to widespread erosion of Early Cretaceous and Jurassic sediments. Later Cretaceous deposits are of a deeper paleobathymetrical nature and are relatively flat-lying;

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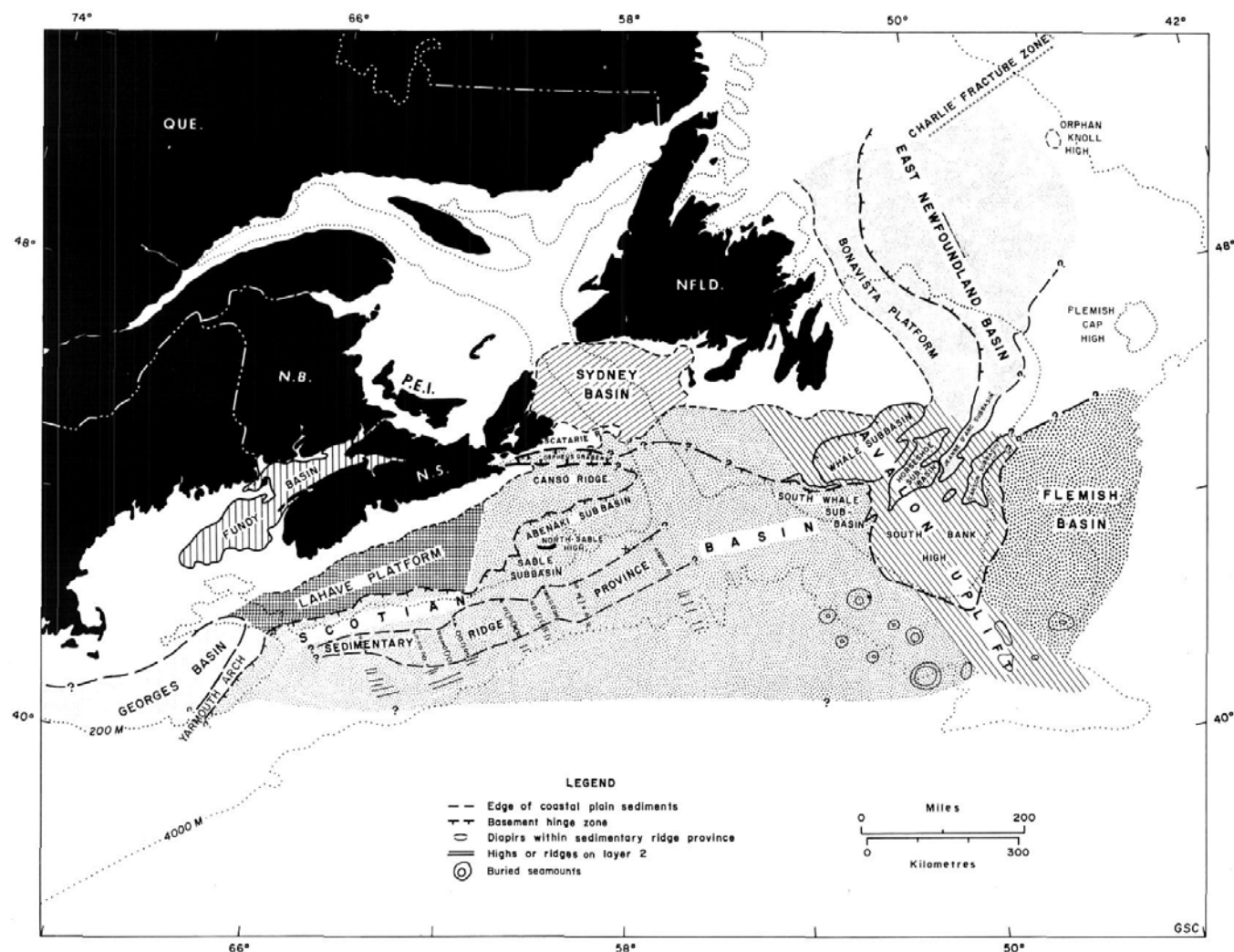
TEXT-FIGURE 1
Main tectonic features of the continental margin off eastern Canada (from Jansa and Wade 1975).

similarly flat-lying Cenozoic sediments record evidence of many transgressive and regressive episodes.

The Hibernia area itself is structurally complex and is in the form of a large roll-over anticline with a complex series of normal faults and a large basement-controlled hinge or listric fault. Salt diapirism toward the axis of the basin further complicates the structures. Although it is not the purpose of this paper to investigate the nature of the Hibernia and surrounding structures (interested readers should consult McWhade 1980; McKenzie 1981; Benteau and Sheppard 1982), it is important to consider the derived biozonation and correlations in terms of this history of subsidence and sedimentation of the area.

Previous biostratigraphic studies of wells off eastern Canada have been generally concerned with large-scale regional zonations (Upshaw et al. 1974; Gradstein et al. 1975; Ascoli 1976; Hart 1976; Barss et al. 1978; Jansa et al. 1980) of the preserved record. Other studies have concentrated on specific intervals (Jansa et al. 1980; Gradstein and Agterberg 1982; Doeven 1983) or specific wells (Williams et al. 1974; Jenkins

et al. 1974; Gradstein et al. 1975; Jansa et al. 1976). These works provide good regional frameworks for eastern Canada in general but become less practical for local correlations and applications to areas, such as the Hibernia wells of the East Newfoundland Basin. This study endeavors to establish, by quantitative means, a practical, locally applicable biozonation of the Early Cretaceous and Late Jurassic of some 13 Hibernia (and surrounding) wells providing a framework within which to place any new sections as they are drilled or become available. Such an approach, which is independent of zonal schemes developed for the Scotian Basin (some 900–1100 km to the southwest) or western Europe will provide a more strictly applicable scheme for this structurally complex area.

METHODS

A quick perusal of the correlation between Early Cretaceous and Jurassic foraminiferal events (largely, last occurrences in time; note that several of the events referred to are seismic) from the relevant sections of the East Newfoundland Basin

reveals a complex interweaving pattern showing considerably large inconsistencies of occurrence of the relative positions of many events. It is this complexity which renders the development of locally applicable zonal schemes difficult.

The RASC computer program was developed to "sift" objectively through all the stratigraphic information contained in the relative positions of the foraminiferal events. The program operates by recording the frequency that each event occurs above, below and simultaneous with each other event, and develops from this an optimum sequence of biostratigraphical events based on rank. This so derived "most likely sequence" is, in effect, an average of all the relative positions encountered in all the sections. Although useful in itself, the optimum sequence is simply a listing and gives no indication of the extent that the events group together. This aspect is addressed in the second part of the program. Through a calculation using the crossover frequency of pairs of events in the optimum sequence, the events can be scaled along an axis with the assumption that the greater the crossover frequency the closer together events are in terms of stratigraphic distance. In addition to this synthesis of the foraminiferal event data, the program also provides several methods (statistical and otherwise) of testing the normality of the individual well sections against the optimum sequence or standard.

The statistical assumptions and algorithms used in RASC are described in Agterberg and Nel (1982a, 1982b). The RASC program used in this study is a slightly updated version of the one released by the Geological Survey of Canada (Heller et al. 1983). The only features of this updated program pertinent to this study are the use of an option, ISCAT, which simply prints bivariate plots of individual well sequences versus the optimum standard sequence, and the choice of two CRIT values (see below). The plots are useful for quick appraisals of each well in terms of their normality, enabling the quick determination of anomalous events. The results discussed in this paper were produced on the Cyber 70 computer at the Bedford Institute of Oceanography, Dartmouth, Nova Scotia.

DATA AND RESULTS

The data investigated in this study consist of last occurrence information (tops or disappearance levels) on some 116 foraminiferal species recorded from 13 wells (text-fig. 2) situated in the East Newfoundland Basin. As this study is concerned only with the Lower Cretaceous and upper Jurassic intervals of these wells only the events encountered below the first downhole occurrence of *Rotalipora* sp. and or *Gavelinella cenomanica* (Brotzen) were considered. To facilitate matrix permutation, each foraminiferal event is assigned a unique dictionary or code number. The raw data, that is the individual sequence of events for each well studied are deposited at the Atlantic Geoscience Centre of the GSC and are published as an Open File by Gradstein et al. (1986). The table in Appendix 1 shows how the data for each well are arranged for input into the program. From left to right is the recorded sequence of coded fossil events; numbers linked with a hyphen indicate events occurring at the same level within a well. Actual code numbers for events occurring in the final scaled sequence are shown in text-figure 4.
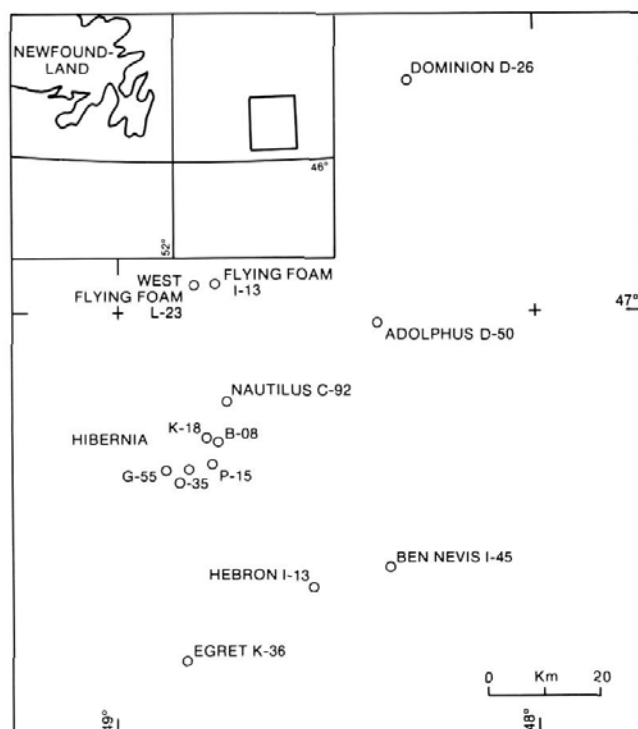
TEXT-FIGURE 2
East Newfoundland Basin well locations.

The initial ranking part of the program produces, through matrix permutations described in Agterberg and Nel (1982a), the optimum "average" sequence (text-fig. 3). However, in order to remove some of the obscuring noise at the outset, and to provide a minimum number of observations of relative order of events and pairs of events, certain program run conditions can be imposed. The conditions are termed K_c and M_c (or IOCR and CRIT in the program), and means that events are considered only if they occur in greater than K_c wells and each pair in the optimum sequence occurs in greater than M_c wells.

In order to determine which K_c, M_c conditions best summarize a particular data set, several runs are required. Other features of the program output aid the determination of optimum K_c, M_c values. Table 1 records the number of wells in which each event occurs, and tabulates the cumulative distribution of events. With $K_c = 4$ for example, some 54 events participate in the matrix permutations and contribute to the derivation of the optimum sequence. On the other hand, a K_c of 3 (table 1) would result in 66 events contributing to the optimum sequence. Examination of these tables and information produced during other runs (with varying thresholds) together with the range values of their optimum sequences (text-fig. 3) allow the determination of appropriate K_c and M_c values. Several runs of the present data set determined optimum K_c, M_c condition to be 4, 3. A few events, however, occurred in less than four wells but were deemed useful to the erection of a zonation in this area because they are well-documented markers from the Scotian Basin or adjacent European basins. In order to be included they are

APPENDIX 1
RASC INPUT FORMAT

HIBERNIA B-08

29	-24	-36	-76	-40	-111	-110	-35	113	-8	-42	-116	-79	-50
-115	7	-17	-135	-14	-44	13	10	-49	12	11	-48	149	64
-9	22	54	124	-137	125	162	131	138	65	139	85	88	-82

HIBERNIA G-55

76	-36	-32	164	40	-35	113	110	-117	-42	-15	-37	29	109
-118	33	-8	-135	116	-53	16	161	7	-17	9	-56		

Reading from left to right is the coded sequence of foraminiferal events for each well, event codes joined by a hyphen indicate simultaneous events.

SEQUENCE POSITION	FOSSIL NUMBER	RANGE	FOSSIL NAME
1	24	0 — 3	ROTALIPORA CUSHMANI
2	3	0 — 4	ROTALIPORA GREENHORNENSIS
3	5	1 — 4	ROTALIPORA APPENINICA
4	76	3 — 5	GAVELINOPSIS CENOMANICA
5	40	4 — 6	GAVELINELLA AMMONOIDES
6	35	5 — 8	GAVELINELLA INTERMEDIA
7	32	5 — 8	HEDBERGELLA INFRACRETACEA
8	36	7 — 9	COARSE AGGLU SPP
9	111	8 — 11	DOROTHIA GRADATA
10	29	7 — 13	ROTALIPORA TICINENSIS
11	113	9 — 12	EPISTOMINA SPINULIFERA POLYPIOIDES
12	110	11 — 13	ARENOBULIMINA MACFADYENI
13	33	12 — 15	FALSOGAUDRYNELLA TEALBYENSIS
14	15	12 — 15	LENTICULINA GAULTINA
15	27	14 — 16	PLANOMALINA BUXTORFI
16	50	15 — 17	EPISTOMINA SPINULIFERA SPINULIFERA
17	115	16 — 18	TEXTULARIA BETTENSTAEDTI
18	8	17 — 19	EPISTOMINA CRETOSA
19	28	18 — 20	OSANGULARIA SCHLOENBACHI
20	37	19 — 21	GAUDRYINA DIVIDENS
21	118	20 — 22	GLOBIGERINELLOIDES FERREOLENSIS
22	51	21 — 25	SPIROPLECTINATA LATA
23	141	21 — 24	FALSOGAUDRYNELLA TRIANGULA
24	116	23 — 26	CONORBOIDES LAMPLUGHI
25	79	23 — 26	EPISTOMINA CARPENTERI
26	109	25 — 27	AMMOBACULITES SUBCRETACEOUS
27	42	26 — 28	GLOBOROTALITES APTIENSIS
28	135	27 — 29	LENTICULINA HEIERMANI
29	53	28 — 30	GAVELINELLA BARREMIANA
30	161	29 — 31	SEISMIC A
31	7	30 — 33	CHOFFATELLA DECIPIENS
32	17	30 — 33	TROCHOLINA INFRAGRANULATA
33	13	32 — 34	EPISTOMINA CARACOLLA
34	133	33 — 36	EVERTICYCLAMMINA VIRGULIANA RARE
35	12	33 — 36	EPISTOMINA HECHTI
36	14	35 — 37	LENTICULINA CREPIDULARIS
37	49	36 — 38	EPISTOMINA TENUICOSTATA
38	10	37 — 39	LENTICULINA NODOSA
39	11	38 — 40	EPISTOMINA ORNATA
40	64	39 — 41	NEOBULIMINA VARSOVIENSIS
41	47	40 — 42	LENTICULINA SAXONICA
42	48	41 — 43	CONORBOIDES HOFKERI
43	9	42 — 44	EVERTICYCLAMMINA VIRGULINIANA
44	54	43 — 45	MARGINULOPSIS SIGALI
45	137	44 — 46	PSEUDOCYCLAMMINA LITUUS
46	22	45 — 47	CONORBOIDES VALENDISENSIS
47	124	46 — 48	LENTICULINA GUTTATA
48	162	47 — 49	SEISMIC B
49	80	48 — 50	AMMOBACULITES COPROLITHIFORMIS
50	65	49 — 51	EPISTOMINA STELLICOSTATA
51	74	50 — 52	EOGUTTULINA LIASSICA
52	85	51 — 53	EPISTOMINA UHLIGHI
53	90	52 — 55	LENTICULINA QUENSTEDTI
54	82	52 — 55	EPISTOMINA MOSQUENSIS

TEXT-FIGURE 3
RASC optimum fossil sequence. Note that sequence includes seismic marker events.

3	0.0658	ROTALIPORA GREENHORNENSIS
5	0.0331	ROTALIPORA APPENINICA
24	0.3706	ROTALIPORA CUSHMANI
76	0.3957	GAVELINOPSIS CENOMANICA
40	0.3987	GAVELINELLA AMMONOIDES
32	0.0824	HEDBERGELLA INFRACRETACEA
35	0.4269	GAVELINELLA INTERMEDIA
36	0.0777	COARSE AGGLU SPP
29	0.0233	ROTALIPORA TICINENSIS
113	0.1173	EPISTOMINA SPINULIFERA POLYPIOIDES
111	0.0684	DOROTHIA GRADATA
38	0.0399	**GLOBIGERINELLOIDES GYROIDINAEFORMIS
110	0.2616	ARENOBULIMINA MACFADYENI
15	0.0432	LENTICULINA GAULTINA
33	0.1660	FALSOGAUDRYNELLA TEALBYENSIS
27	0.1936	PLANOMALINA BUXTORFI
115	0.0848	TEXTULARIA BETTENSTAEDTI
50	0.0314	EPISTOMINA SPINULIFERA SPINULIFERA
37	0.0623	GAUDRYINA DIVIDENS
8	0.0958	EPISTOMINA CRETOSA
118	0.0584	GLOBIGERINELLOIDES FERREOLENSIS
28	0.0834	OSANGULARIA SCHLOENBACHI
51	0.0392	SPIROPLECTINATA LATA
116	0.0720	CONORBOIDES LAMPLUGHI
79	0.0108	EPISTOMINA CARPENTERI
141	0.3059	FALSOGAUDRYNELLA TRIANGULA
42	0.0288	GLOBOROTALITES APTIENSIS
109	0.4182	AMMOBACULITES SUBCRETACEOUS
53	0.1655	GAVELINELLA BARREMIANA
16	0.0558	**ORBITOLINA SPP
161	0.0152	SEISMIC A
135	0.0972	LENTICULINA HEIRMANI
44	0.6422	**GLOBIGERINA HOTERIVICA
7	0.0611	CHOFFATELLA DECIPIENS
17	0.7694	TROCHOLINA INFRAGRANULATA
13	0.2457	EPISTOMINA CARACOLLA
46	0.1177	**GAVELINELLA SIGMOICOSTA
45	0.1529	**LENTICULINA EICHENBERGI
12	0.0023	EPISTOMINA HECHTI
133	0.3123	EVERTICYCLAMMINA VIRGULIANA RARE
14	0.0077	LENTICULINA CREPIDULARIS
10	0.0301	LENTICULINA NODOSA
49	0.4110	EPISTOMINA TENUICOSTATA
11	0.5534	EPISTOMINA ORNATA
64	0.0967	NEOBULIMINA VARSOVIENSIS
48	0.0132	CONORBOIDES HOFKERI
47	0.1344	LENTICULINA SAXONICA
9	0.2391	EVERTICYCLAMMINA VIRGULINIANA
137	0.0185	PSEUDOCYCLAMMINA LITUUS
54	0.5636	MARGINULOPSIS SIGALI
22	0.1885	CONORBOIDES VALENDISENSIS
124	0.1903	LENTICULINA GUTTATA
80	0.1982	AMMOBACULITES COPROLITHIFORMIS
162	0.7318	SEISMIC B
65	0.4098	EPISTOMINA STELLICOSTATA
81	0.8756	**ANCHISPIROCYCLINA LUSITANICA
85	0.0614	EPISTOMINA UHLIGHI
74	0.5655	EOGUTTULINA LIASSICA
92	0.5071	**TROCHOLINA TRANSVERSARII
82	0.0571	EPISTOMINA MOSQUENSIS
96	0.0390	**EPISTOMINA REGULARIS
84	0.0778	**ALVEOSEPTA JACCARDI
90		LENTICULINA QUENSTEDTI

TEXT-FIGURE 4
Dendrogram indicating RASC optimum sequence, weighted toward more common occurrence of pairs of events. Shaded portions of figure depict RASC biozones of age indicated. Asterisks indicate unique events.

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TABLE 1

Tabulation of event occurrences versus frequency of occurrence. Numbers in the left hand column refer to dictionary codes (see text) and in the right hand column to frequency of occurrence.

1	0	29	5	57	2	85	10	113	9	141	4
2	0	30	1	58	2	86	0	114	1	142	1
3	5	31	3	59	0	87	2	115	8	143	3
4	0	32	4	60	1	88	3	116	7	144	0
5	4	33	10	61	0	89	0	117	3	145	0
6	0	34	3	62	0	90	5	118	8	146	0
7	12	35	9	63	0	91	1	119	1	147	0
8	10	36	9	64	7	92	2	120	1	148	0
9	11	37	6	65	9	93	1	121	0	149	1
10	6	38	2	66	1	94	1	122	1	150	0
11	10	39	0	67	3	95	1	123	0	151	0
12	11	40	10	68	2	96	1	124	7	152	0
13	6	41	2	69	1	97	3	125	2	153	0
14	8	42	6	70	1	98	1	126	1	154	0
15	10	43	2	71	0	99	1	127	0	155	0
16	3	44	2	72	0	100	0	128	0	156	0
17	10	45	1	73	0	101	0	129	2	157	0
18	0	46	3	74	6	102	1	130	0	158	0
19	2	47	6	75	0	103	1	131	2	159	0
20	2	48	9	76	10	104	1	132	0	160	0
21	0	49	8	77	0	105	0	133	4	161	5
22	5	50	7	78	2	106	0	134	0	162	6
23	0	51	5	79	8	107	1	135	5	163	2
24	6	52	0	80	7	108	0	136	0	164	3
25	2	53	8	81	2	109	6	137	5	165	1
26	1	54	4	82	7	110	7	138	1	166	0
27	5	55	3	83	1	111	7	139	1	167	2
28	7	56	2	84	2	112	0	140	0	168	3
29	5	57	2	85	10	113	9	141	4		

NUMBER OF WELLS	1	2	3	4	5	6	7	8	9	10	11	12	13	14
NUMBER OF EVENTS	29	21	12	5	9	9	9	6	5	8	2	1	0	0
CUMULATIVE NUMBER	116	87	66	54	49	40	31	22	16	11	3	1	0	0

termed unique events, and are eventually positioned in the final scaled sequence on the basis of their position relative to more abundant events.

The optimum sequence

The optimum sequence determined with $K_c = 4$ and $M_c = 3$ is shown in text-figure 3 along with their relevant code numbers, sequence position and range value. These range values, which have no stratigraphic connotations, simply define the position limits of each event in that sequence; events can occur anywhere within these limits. A small range limit indicates that the program has been able to determine that events average position, whereas a larger range would suggest that the event is more uncertain in its position. Events at the top and bottom of the optimum sequence are liable to exhibit greater ranges due to the lack of events above and below with which to compare. An optimum sequence with many large range limits would be one criterion for running the program again with different K_c, M_c conditions. Large range limits may be the result of taxonomic inconsistency and/or facies controlled events. Similarly, they may reflect involvement in a cycle. Cycles occur when many events occur simultaneously, or with patchy and insufficient observations on relative order leading to conflicting situations in rank (Gradstein

and Agterberg 1982). These cycles are broken by the RASC program (Agterberg and Nel 1982b); involvement of an event in a destroyed cycle may produce a higher range value.

The optimum sequence produced with a 4/3 run (K_c/M_c) shows several high range values but many more low values, meaning that for the most part, a good optimum average sequence has been established. It is not possible to judge how events in the optimum sequence cluster in time (see scaling below) but reference to the literature, however, especially Moullade (1966), Magniez-Jannin (1975), Bartenstein (1977), Ascoli (1976), and Hart (1984) does provide a means of model verification. Large-scale discrepancies between the optimum sequence of foraminiferal events seen in this study and their reported disappearance levels in the Scotian and European basins, would be easy to recognize. In general, a close correspondence can be seen between the two and will be discussed later.

Comparison of individual well sections with the computed standard reveals important information on the stratigraphic normality of that section. The several methods of doing this are described after a consideration of the scaled optimum sequence, the latter providing a more complete summary of the consistency in order, the deviation and the distance in spacing of events in time (Gradstein 1984).

The scaled optimum sequence

Events in the optimum sequence are scaled in order to determine the extent that they cluster or group together in time (i.e. presence of "zones" in the optimum sequence). The scaling statistics are based upon the crossover frequency of events in the optimum sequence; that is, how often each event in the optimum sequence changes position with other events in different well sections. The synthesis of this information gives statistical values for "distance" between each event pair in the optimum sequence. These derived distance values are expressed graphically in dendrogram form. The statistical method as developed and rigorously tested in Agterberg and Nel (1982a, 1982b) and Hudson and Agterberg (1982) assumes that the position of each event along a relative time-scale has a normal (Gaussian) probability distribution with equal variance. Similarly distributed with unit variance are the event crossover frequencies. The greater the crossover frequencies the smaller the computed distances, and by implication, the more the involved events cluster in time. Text-figure 4 shows the scaled optimum sequence in dendrogram form from the 4/3 (K_c/M_c) run of this data set. In actual practice the RASC program produces several dendrograms each with a slightly different scaled optimum sequence. An initial dendrogram depicts unweighted interfossil distances and attaches no weight to the number of pairs of events used in the calculations of the distances. But because the stability of an estimate depends on the number of pairs of events used in the calculations, a weighting was devised which emphasizes distance as a function of the number of observations (Gradstein 1984). Calculations are repeated using these weightings. A feature of the statistical models used results in some interfossil distances being negative (an impossibility in nature). The events, therefore, are re-sorted on the basis of cumulative distance to obtain only positive interfossil distances, and this results in a slightly different scaled sequence as compared with the ranked sequence. Calculations are repeated until all distances are positive. Standard deviations for the distance values are also derived and are useful for any meaningful interpretations of the scaled output. The dendrogram shown in text-figure 4 includes unique events (marked with asterisks) and forms the basis for the biozonation to be described.

Stratigraphic normality

The extent of departure of the individual well sequence from the standard scaled, optimum sequence is a measure of abnormality in that section. These abnormalities or uncertainties in part obscure other useful stratigraphic information. It is thus important to be able to locate such spurious events and deal with them accordingly before developing a zonation. Several features of RASC facilitate this operation. The first method consists of a series of bivariate scattergrams which plot individual well sequences (horizontally) against the standard, scaled sequence. Events that appear to deviate from a straight line indicate that they occur higher or lower in the individual well (above and below the line, respectively) than in the standard. Misidentification and facies control notwithstanding, anomalously high event or events in the well could be a result of reworking, whereas lower events may be cavings. Several scattergrams are shown in text-figure 5 and

present good continuous sequences with many events corresponding to the standard. Used in conjunction with a method that gives penalty points each time an event is out of place, rapid insight may be gained into the abnormalities of each individual well and so into the obscuring noise within the data set. Rigorous re-examination of these identified abnormalities in terms of: the state of preservation of the observed event; the taxonomic certainty of the original identification; the abundance of the event (rare or common); and the co-occurrence of other misplaced events, enable these abnormalities to be either removed entirely from the data set, or reassigned to another level in the well. A more statistical basis for re-examining the reliability of certain events is provided by a series of normality tests for each well. These normality tests put statistical values on observed positions of events with single and double asterisks indicating 95% or 99% probability that the events are out of place (Appendix 2).

Several 4/3 (K_c/M_c) runs of RASC on the present data set permitted a rigorous appraisal (as described above) of the normality of each well. A good example is seen by comparing the two scattergrams of Hibernia K-18 (text-figs. 5, 6).

The earlier run (text-fig. 6) shows a greater degree of scatter and more anomalous events when compared to the standard. Foraminiferal events; 33 *Falsogaudrynella tealbyensis* (Bartenstein), 35 *Gavelinella intermedia* (Berthelin), 46 *Gavelinella sigmoicosta* (Ten Dam), 17 *Trocholina infragranulata* Noth and 11 *Epistomina ornata* (Roemer) were all subject to close re-examination. In each case adjustment in their respective levels was necessary, either because other specimens were found at a higher level or because the specimens showed evidence of reworking. In the latter run (text-fig. 5), the event sequence of Hibernia K-18 compares more favorably with the standard, thus some potentially obscuring noise has been removed, or at the least, reduced. Scrutiny of all the wells in such a manner has led to the final RASC run described in this paper and is the basis for the biozonation reviewed in the following section.

RASC biozonation

Application of RASC to the forminiferal data of Cenomanian and older sediments from the East Newfoundland Basin results in a scaled optimum sequence that displays 11 distinct clusters or groups (text-fig. 4). Some 63 species events contribute to the elevenfold subdivision, of which 11 occur in less than four wells and were introduced as unique events.

In terms of their commonly reported stratigraphic ranges the taxa within each cluster (or RASC zone) show a progressively younger Kimmeridgian to Cenomanian age. That the statistical model based upon the crossover frequency of the optimum sequence events produces meaningful stratigraphic results is illustrated in text-figure 7 which plots for each species in the optimum sequence (vertical) the extinction point as seen in European basins (black circle) and North American basins (cross). Species that apparently become extinct simultaneously in Europe and North America are shown by a black circle only. The dashed lines indicate range of disappearance levels.
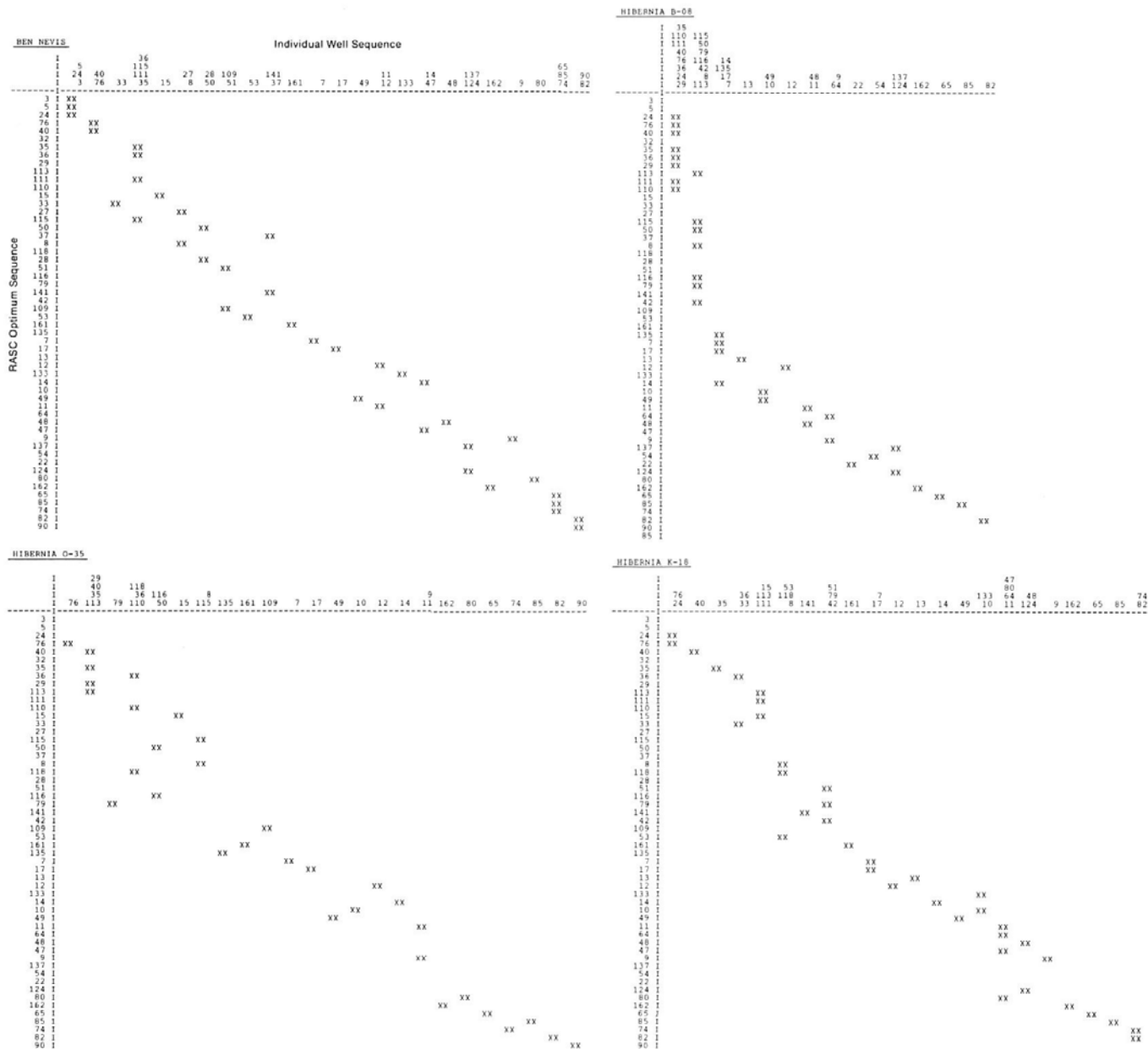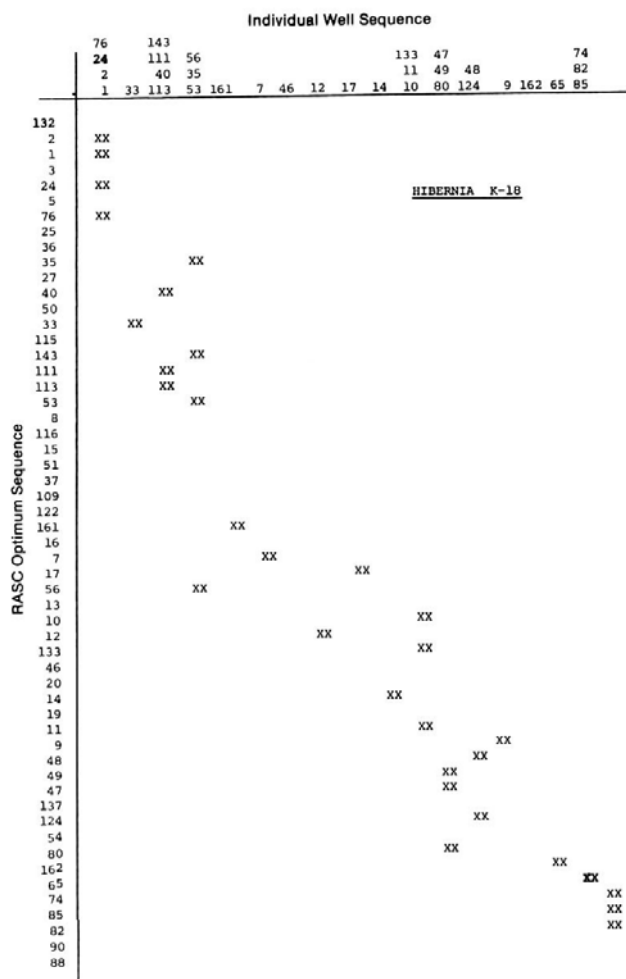
TEXT-FIGURE 5
Scattergram plots of well sequences (horizontal) versus RASC optimum sequence.

The specific composition of the RASC zones are shown in table 2 along with designated stage names.

The following discussion comments briefly upon each RASC zone, its component species age designations and reported European and eastern Canadian occurrences. The number in parentheses after each reference to a species (see below) represents the number of wells in which the species occurs. The plates and taxonomy section figure and reference some of the more important species of this zonal scheme.

RASC zone I: This zone is dominated by well-preserved planktonic taxa of distinctively Cenomanian character. The integrated microfossil biostratigraphy of the mid-Cretaceous

of Europe (Marks 1984) shows exits of *Rotalipora cushmani* (Morrow) (6) within the *Calyoceras naviculare* ammonite zone of the Upper Cenomanian (Porthault et al. 1966; van Hinte 1976). Similarly, Robaszynski and Caron (1977), Sigal (1977), and Wonders (1980) also show Total Range Zones of *Rotalipora cushmani* terminating in this Upper Cenomanian interval. The disappearance of *Rotalipora appeninica* (O. Renz) (4) is, according to Moullade (1974 Mediterranean), Pflaumann and Krasheninnikov (1978 eastern North Atlantic) and Gradstein (1984), somewhat earlier, being associated with the early mid-Cenomanian. The nature of the samples (ditch cuttings) does not allow detailed resolution of the Cenomanian of the East Newfoundland Basin. All that

Individual Well Sequence

```
   76   143
   24   111  56                           133  47                    74
    2    40  35                            11  49  48                 82
    1    33  113  53 161    7  46  12  17  14  10  80 124   9 162 65 85

132
  2    XX
  1    XX
  3
 24    XX                        HIBERNIA  K-18
  5
 76    XX
 25
 36
 35         XX
 27
 40      XX
 50
 33    XX
115
143         XX
111      XX
113      XX
 53         XX
  8
116
 15
 51
 37
109
122
161            XX
 16
  7              XX
 17                  XX
 56         XX
 13
 10                    XX
 12               XX
133                    XX
 46
 20
 14                XX
 19
 11                    XX
  9                        XX
 48                          XX
 49                  XX
 47                  XX
137
124                       XX
 54
 80                  XX
162
 65                          XX
 74                         XX
 85                              XX
 82                              XX
 90                              XX
 88
```

TEXT-FIGURE 6
Scattergram plot of Hibernia K-18 event sequences versus RASC optimum sequence. From an earlier run.

can be resolved with certainty is the fact that the planktonic taxa of this cluster of events, together with the presence of the benthonic species, *Gavelinella cenomanica* (10), *Gavelinella intermedia* (10), and *Gavelinella ammonoides* (Reuss) (10) (which are described from the European and North American Cenomanian; Hart 1976; Hart et al. 1981; Ascoli 1976; Bartenstein and Kovatcheva 1982) indicate a Cenomanian age for RASC zone I.

RASC zone II: This zone includes the planktonic taxa *Rotalipora ticinensis* (Gandolfi) (5) and *Globigerinelloides gyroidinaeformis* Moullade (2) which have both been described from the middle and upper Albian of Europe (Moullade 1966, 1974). More precisely, Marks (1984) showed the extinction of the former in Europe in the *Stoliczkaia dispar* ammonite zone of the Vraconian or upper Albian. Also notable is the benthonic taxon *Epistomina spinulifera polypioides* (Eichenberg) (9) described by Stranik et al. (1970) from the Tunisian mid-late Albian and by Price (1977b) from the middle to upper Albian of Europe. The presence of *Arenobulimina macfadyeni* Cushman (7) which exits in Europe in the end

Albian (Price 1977b) completes the upper Albian character of this zone.

RASC zone III: This zone also has an Albian character and has a richly diverse planktonic and benthic population. The planktonic taxon *Planomalina buxtorfi* (Gandolfi) (5), which exits within the Vraconian or upper Albian of Europe (Marks 1984), is a good indication of the latest Albian. It has been similarly described from the upper Albian of the Scotian Shelf (Ascoli 1976). Elsewhere, disappearance of *Planomalina buxtorfi* is apparently later than that for *Rotalipora ticinensis* (Marks 1984), although both exit in the same (*S. dispar*) ammonite zone. In this study their disappearances seem to be reversed; however, with reference to the dendrogram (text-fig. 4) it appears that the distinction (in terms of relative distance) between the two zones is not that great. Zones II and III therefore reveal an age similarity both indicative of a middle to upper Albian age. Also present in zone III is the planktonic form *Globigerinelloides ferreolensis* (Moullade) (8); this form has been described from the late Aptian (Moullade 1974 and Gradstein 1978). However, Pflaumann and Krasheninnikov (1978) have recorded it from the late Albian sediments in the eastern Atlantic. Off eastern Canada, Ascoli (1976) has observed it in Albian strata. Supplementary evidence for a mid-upper Albian age for zone III is provided by the benthic taxa present. *Gaudryina dividens* (Grabert) (6) has been described from the middle Albian of Tunisia (Stranik et al. 1970) and the early Albian of France (Sigal 1963). Similarly, Price (1977a) has described in his Albian zonation of northwestern Europe, exits of *Conorboides lamplughi* (Sherlock) (7) in the *Diploceras cristatum* ammonite subzone at the base of the upper Albian. Slightly younger in the *Hysteroceras orbignyi* ammonite zone of the upper Albian is the recorded exit of *Epistomina spinulifera spinulifera* (Reuss) (7) and *Epistomina carpenteri* (Reuss) (8). Crittenden (1983) has described the disappearance from Europe of *Osangularia schloenbachi* (Reuss) (5) in mid-to-late Albian times. Similarly Albian in nature are *Spiroplectinata lata* Grabert (5) and *Epistomina cretosa* Ten Dam (10) as observed by Ten Dam (1948), Kahn (1962), Magniez-Jannin (1975), Ascoli (1976), Bartenstein (1977) and Hart et al. (1981) from Europe and the Scotian Shelf.

Based mainly on the planktonic taxa present and from supplementary evidence provided by the benthics, RASC zones II and III are representative of middle to upper Albian sediments.

RASC zone IV: This zone includes typically Aptian foraminifers. The benthic taxa *Gavelinella barremiana* Bettenstaedt is present in many of the sections studied (8) and has previously described exits in the early (Bartenstein and Bettenstaedt 1962; Kahn 1962; Michael 1966), middle (Sigal 1963; Kovatcheva 1976; Bartenstein 1979; Hart et al. 1981) and late (Moullade 1974; Ascoli 1976) Aptian of Europe and eastern Canada. An orbitolinid species occurs and most closely resembles *Palorbitolina lenticularis* (Blumenbach) as described by Moullade (1974) from the mid-Aptian of the Mediterranean. Occurring less frequently is the planktonic taxon *Globigerina hoterivica* Subbotina. This form has previously been described by Ascoli (1976) and Bartenstein (1979) from the latest Barremian. However, Pflaumann and Krashen-

RASC ZONE	OXFORDIAN	KIMMERIDGIAN	TITHONIAN	BERRIASIAN	VALANGINIAN	HAUTERIVIAN	BARREMIAN	APTIAN	ALBIAN	CENOMANIAN	GEOLOGICAL TIME / SPECIES NAME
I										•	ROTALIPORA GREENHORNENSIS
										•	ROTALIPORA APPENINNICA
										•	ROTALIPORA CUSHMANI
										•	GAVELINOPSIS CENOMANICA
										•	GAVELINELLA AMMONOIDES
										•	HEDBERGELLA INFRACRETACEA
										•	GAVELINELLA INTERMEDIA
II									•		ROTALIPORA TICINENSIS
									•		EPISTOMINA SPINULIFERA POLYPIOIDES
									+	•	DOROTHIA GRADATA
									+		GLOBIGERINELLOIDES GYROIDINAEFORMIS
									•		ARENOBULIMINA MACFADYENI
									•		LENTICULINA GAULTINA
III									•		FALSOGAUDRYNELLA TEALBYENSIS
									•		PLANOMALINA BUXTORFI
								•	+		TEXTULARIA BETTENSTAEDTI
								+	+		EPISTOMINA SPINULIFERA SPINULIFERA
									+		GAUDRYINA DIVIDENS
									•		EPISTOMINA CRETOSA
								+			GLOBIGERINELLOIDES FERREOLENSIS
									+ —		OSANGULARIA SCHLOENBACHI
									+		SPIROPLECTINATA LATA
									•		CONORBOIDES LAMPLUGHI
									• +		EPISTOMINA CARPENTERI
									+		FALSOGAUDRYINELLA TRIANGULA
									•		GLOBOROTALITES APTIENSIS
									+		AMMOBACULITES SUBCRETACEOUS
IV								— • —			GAVELINELLA BARREMIANA
								+			ORBITOLINA SPP.
								•			LENTICULINA HEIERMANI
							+	— • —			GLOBIGERINA HOTERIVICA
V								•			CHOFFATELLA DECIPIENS
								•			TROCHOLINA INFRAGRANULATA
VI							— + • —				EPISTOMINA CARACOLLA
							+				GAVELINELLA SIGMICOSTA
						•	+				LENTICULINA EICHENBERGI
						— •					EPISTOMINA HECHTI
VII						•	+ — —		•		LENTICULINA CREPIDULARIS
						•					LENTICULINA NODOSA
						•					EPISTOMINA TENUICOSTATA
					— • —	—					EPISTOMINA ORNATA
VIII			— — — —	+		+	• —				NEOBULIMINA VARSOVIENSIS
						+					CONORBOIDES HOFKERI
						•					LENTICULINA SAXONICA
						•					EVERTICYCLAMMINA VIRGULIANA
						•					PSEUDOCYCLAMMINA LITUUS
						•					MARGINULOPSIS SIGALI
IX						•					CONORBOIDES VALENDISENSIS
					• —	—					LENTICULINA GUTTATA
				•							AMMOBACULITES COPROLITHIFORMIS
X			•								EPISTOMINA STELLICOSTATA
			• —								ANCHISPIROCYCLINA LUSITANICA
			• — —								EPISTOMINA UHLIGHI
			•								EOGUTTULINA LIASSICA
XI	•	•									EPISTOMINA MOSQUENSIS
		•									EPISTOMINA REGULARIS
	•										ALVEOSEPTA JACCARDI
		•									LENTICULINA QUENSTEDTI

TEXT-FIGURE 7

Correspondence of literature reported disappearance levels and RASC optimum sequence. Circles indicate data from European basins; crosses represent North American data. Circle only indicates simultaneous disappearance in both Europe and North America. Dashed line indicates range of disappearance level.

ninikov (1978) showed a range to mid-Aptian in the eastern Atlantic; similarly, Longoria (1974) recorded its exit at the base of the upper Aptian in his *Leupoldina cabri* Zone.

Seismic horizon A (which approximates the top of the Avalon sands; McKenzie 1981) occurs within this zone and was treated as a fossil event in the quantitative analysis and shows good consistent relative occurrence with low range values (text-fig. 3).

RASC zone V: This zone is of early Aptian age but comprises relatively few taxa. It is however one of the best, consistent

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TABLE 2
Species composition for RASC zones I–XI.

RASC ZONE	SPECIES COMPOSITION	AGE
I	ROTALIPORA GREENHORNENSIS ROTALIPORA APPENINNICA ROTALIPORA CUSHMANI GAVELINOPSIS CENOMANICA GAVELINELLA AMMONOIDES HEDBERGELLA INFRACRETACEA GAVELINELLA INTERMEDIA	CENOMANIAN
II	ROTALIPORA TICINENSIS EPISTOMINA SPINULIFERA POLYPIOIDES DOROTHIA GRADATA GLOBIGERINELLOIDES GYROIDINAEFORMIS ARENOBULIMINA MACFADYENI	LATE ALBIAN
III	LENTICULINA GAULTINA FALSOGAUDRYNELLA TEALBYENSIS PLANOMALINA BUXTORFI TEXTULARIA BETTENSTAEDTI EPISTOMINA SPINULIFERA SPINULIFERA GAUDRYINA DIVIDENS EPISTOMINA CRETOSA GLOBIGERINELLOIDES FERREOLENSIS OSANGULARIA SCHLOENBACHI SPIROPLECTINATA LATA CONORBOIDES LAMPLUGHI EPISTOMINA CARPENTERI	MIDDLE-LATE ALBIAN
IV	GLOBOROTALITES APTIENSIS AMMOBACULITES SUBCRETACEOUS GAVELINELLA BARREMIANA ORBITOLINA SPP. SEISMIC A LENTICULINA HEIERMANI GLOBIGERINA HOTERIVICA	APTIAN
V	CHOFFATELLA DECIPIENS TROCHOLINA INFRAGRANULATA	EARLY APTIAN
VI	EPISTOMINA CARACOLLA GAVELINELLA SIGMICOSTA LENTICULINA EICHENBERGI EPISTOMINA HECHTI EVERTICYCLAMMINA VIRGULIANA RARE	BARREMIAN
VII	LENTICULINA CREPIDULARIS LENTICULINA NODOSA EPISTOMINA TENUICOSTATA EPISTOMINA ORNATA	EARLY BARREMIAN LATE HAUTERIVIAN
VIII	NEOBULIMINA VARSOVIENSIS CONORBOIDES HOFKERI LENTICULINA SAXONICA EVERTICYCLAMMINA VIRGULIANA PSEUDOCYCLAMMINA LITUUS MARGINULOPSIS SIGALI	HAUTERIVIAN
IX	CONORBOIDES VALENDISENSIS LENTICULINA GUTTATA AMMOBACULITES COPROLITHIFORMIS	VALANGINIAN (BERRIASIAN)
X	EPISTOMINA STELLICOSTATA ANCHISPIROCYCLINA LUSITANICA EPISTOMINA UHLIGHI EOGUTTULINA LIASSICA	TITHONIAN
XI	TROCHOLINA TRANSVERSARII EPISTOMINA MOSQUENSIS EPISTOMINA REGULARIS ALVEOSEPTA JACCARDI LENTICULINA QUENSTEDTI	KIMMERIDGIAN

marker assemblages within this part of the East Newfoundland Basin. Its main component is the larger agglutinated form *Choffatella decipiens* Schlumberger (12) which has a described exit in Europe in the early Aptian (Kovatcheva 1976, Bulgaria; Colin et al. 1987, Celtic Sea). Sigal (1963) recorded its disappearance in France in the middle Aptian *deshayesi/clava* ammonite zones. Off eastern Canada, Ascoli (1976) recorded an early Aptian exit. Similarly, an early Aptian exit has been described for *Trocholina infragranulata* (10) in Trinidad, Europe and eastern Canada (Ascoli 1976;

Bartenstein 1978, 1979). This zone is assigned an early Aptian age although it is probable that the *Choffatella* marker may be facies dependent and thus may have disappeared from this area (late Barremian) before its recorded disappearance elsewhere (early Aptian). Testament to this is perhaps indicated by its close association with the top of the Avalon sands unit.

RASC zone VI: This zone is characterized by *Epistomina hechti* (Bartenstein, Bettenstaedt and Bolli) (11) which has recorded exits in the middle to late Barremian of Trinidad (Bartenstein 1977), North Germany (Bartenstein and Bettenstaedt 1962), the United Kingdom (Hart et al. 1981) and Bulgaria (Kovatcheva 1976). Off the Scotian Shelf this form disappears at the end of the Barremian (Ascoli 1976). *Epistomina caracolla* (Roemer) (6) shows a greater variation in reported exits which is possibly a function of associated taxonomic problems. Bartenstein (1979) and Kovatcheva (1976) extended its range into the early Aptian, whereas Bartenstein and Bettenstaedt (1962), Kahn (1962), and Hart et al. (1981) recorded exits in the early Barremian of North Germany and the United Kingdom. Ten Dam (1948) similarly showed a mid-Barremian exit whereas Ascoli (1976) has it ranging to the latest Barremian.

A less common taxon but an important Barremian indicator is *Gavelinella sigmoicosta* (3). Moullade (1966) has recorded exits of this species from the mid-lower Barremian *Moutoni* ammonite zone to the beginning of the upper Barremian. Mid-Barremian exits for this taxon have also been observed by Bartenstein and Bettenstaedt (1962 North Germany); Hart et al. (1981 United Kingdom) and Kovatcheva (1976 Bulgaria). Ascoli (1976) and Bartenstein (1979) extended the range of this form to the latest Barremian.

Another important Barremian marker present is *Lenticulina eichenbergi* Bartenstein and Brand (1). Sigal (1963) recorded the exit of this taxon in the mid-Barremian *deckmani* ammonite zone in France; similarly but in more detail, Moullade (1966) recorded its exit in the *Silesites seranonis* ammonite zone of the latest Barremian. Guillaume and Sigal (1965), Bartenstein (1979), and Hart et al. (1981 United Kingdom) all recorded a middle Barremian exit, whereas Kahn (1962 United Kingdom), Ascoli (1976 eastern Canada), and Sliter (1980 eastern Atlantic) all show a late Hauterivian/early Barremian exit.

RASC zone VII: This zone is assigned a late Hauterivian/Barremian age. The main species present is *Epistomina ornata* (Roemer) (10). Bartenstein (1979) gave it a world-wide range up to the mid-Aptian; Sigal (1963), however, recorded its exit in the *Strombecki* ammonite zone of the early Barremian. Other early Barremian exits are recorded by Kahn (1962 United Kingdom); Bartenstein and Bettenstaedt (1962 North Germany); Ascoli (1976 eastern Canada) and Kovatcheva (1976 Bulgaria). Hart et al. (1981) and Ten Dam (1948) restricted this form to the Hauterivian. *Epistomina tenuicostata* Bartenstein and Brand (8) is similarly restricted to the Hauterivian in Jansa et al. (1980) and Ascoli (1976). *Lenticulina crepidularis* (Roemer) (8) has been described in Bartenstein (1977) as having an early Aptian extinction in Europe but is restricted to the Hauterivian off eastern Canada by Jansa et al. (1980). Early to mid-Barremian exits, however,

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are recorded by Bartenstein and Bettenstaedt (1962), Ascoli (1976) and Hart et al. (1981). *Lenticulina nodosa* (Reuss) (6) has a wide range of recorded exits due in part at least to its taxonomic status. Bartenstein (1979) has recorded it and its subspecies world-wide from Upper Jurassic to Aptian strata. Aubert and Bartenstein (1976) documented it in uppermost Albian sediments, whereas Ascoli (1976) used it as an important Aptian zonal marker.

RASC zone VIII: Unlike zone VII, which has a late Hauterivian, early Barremian character, RASC zone VIII is decidedly Hauterivian in nature. *Lenticulina saxonica* Bartenstein and Brand (6) has described exits from the latest Valanginian to middle Hauterivian of the Scotian Shelf (Ascoli 1976). In Europe and Trinidad, however, its exit levels are restricted to Hauterivian deposits (Bartenstein and Bettenstaedt 1962; Bartenstein 1979). Sigal (1963) recorded its disappearance in the early Hauterivian (*Noricum* ammonite zone) of France. A similarly Hauterivian disappearance in French sections is noted in Guillaume and Sigal (1965). *Conorboides hofkeri* (Bartenstein and Brand) (9) ranges in the Tunisian Cretaceous to the mid-Valanginian (Stranik et al. 1970). In France, however, its peak range is at the end of the Hauterivian (Guillaume and Sigal 1965), although Bartenstein (1977) and Ascoli (1976) recorded a latest Valanginian exit in central-north Europe and eastern Canada, respectively. Bartenstein (1976), however, recorded this taxon from latest Barremian to early Aptian age deposits in Trinidad. The larger agglutinated foraminifer *Everticyclammina virguliana* (Koechlin) (11) occurs in most sections studied and has a relatively long range recorded in abundance from the Kimmeridgian (Barnard and Shipp 1981 — as *Ammobaculites cobbani*) to Aptian (Ascoli 1976). This large range is in part due to certain taxonomic aspects of the species. The species was originally described as *Buccicrenata italica* (Dieni and Massari 1965) from the Valanginian of Sardinia. Under the same name, Ascoli (1976) has used its extensive occurrence off eastern Canada as a Berriasian-Valanginian marker. Elsewhere, Jaffrezo (1980) has described it from the mid-Valanginian of Les Corbières, France. In the East Newfoundland Basin *Everticyclammina virguliana* is associated with a Hauterivian type fauna, although a separate *E. virguliana* event (a "rare" top, and so separated as a distinct event) is known from younger deposits (RASC zone VI; Barremian, text-fig. 4). It is most likely that this *E. virguliana* event is a distinct species although the paucity of specimens precludes its recognition as such. This zone also includes *Neobulimina varsoviensis* Bielecka and Pozaryski (7) a form previously described from older deposits (Bielecka and Pozaryski 1954). Off eastern Canada this form has previously been described in Jansa et al. (1980) from the Tithonian.

RASC zone IX: This zone includes a rather small group of benthic taxa of Valanginian character. *Conorboides valendisensis* (Bartenstein and Brand) (5) has a consistently described last occurrence in the late Valanginian of Europe (Kahn 1962; Bartenstein and Bettenstaedt 1962; Bartenstein 1979; Hart et al. 1981; Hart 1984) and eastern Canada (Ascoli 1976). *Lenticulina guttata* (Ten Dam) (7) has a slightly younger reported last occurrence. Bartenstein (1979) noted its disappearance world-wide from mid-Barremian deposits. Hart et al. (1981 United Kingdom) and Ascoli (1976 eastern

Canada), both restrict this species to the Hauterivian. On the other hand, Magniez-Jannin and Sigal (1983) had *Lenticulina guttata* ranging through the *Campylotoxa roubaudi* and *pertransiens* ammonite zones of the lower Valanginian of DSDP holes of the North Atlantic. Of markedly older character is the Kimmeridgian/Tithonian marker (Ascoli 1976) *Ammobaculites coprolithiformis* (Schwager) (7).

RASC zone X: Although loosely defined internally in terms of RASC distance values (text-fig. 4), this zone is distinct from that above, and represents the topmost zone of the Jurassic in the wells studied.

Good Tithonian markers are present within this zone. *Epistomina stellicostata* Bielecka and Pozaryski (9) and *Epistomina ulighi* Mjatliuk (10) both have described exits in latest Jurassic, Tithonian sediments and have been used off eastern Canada and New England as indicators of this interval (Ascoli 1976, 1984; Jansa et al. 1980). *Epistomina ulighi* has also been described from the Tithonian of the eastern North Atlantic (Sliter 1980). *Anchispirocyclina lusitanica* (Egger) (2) occurs more rarely than the previous two taxa common to this zone, and has a slightly younger exit in the latest Tithonian (or early Berriasian). Although rare off eastern Canada it has been used as a diagnostic Tithonian marker in Gradstein (1978a) and Ascoli (1976). The uppermost Tithonian nature of this taxon is further indicated in Europe, and is described in Ramalho (1969) and Rey (1972) from Portugal and Jaffrezo (1980) from France. In addition Maync (1938) has described it from the Cretaceous-Jurassic of Switzerland.

RASC zone XI: This zone comprises a well-defined group of taxa of markedly older character than zone X. Occurring quite infrequently in sections studied is the larger agglutinating foraminifera *Alveosepta jaccardi* (2). This taxon has been used as a zonal indicator (off eastern Canada) of Kimmeridgian/Oxfordian deposits (Ascoli 1976; Gradstein 1978a). It has also been described from the Kimmeridgian of Europe (Jaffrezo 1980) and Africa (Bismuth et al. 1967; Barbieri 1968; Mansour 1975). Also of distinctively Kimmeridgian nature are *Epistomina mosquensis* Uhlig (7) and *Lenticulina quenstedti* (Gumbel) (5). Ascoli (1976, 1984) and Jansa et al. (1980) have well documented *Epistomina mosquensis* as a Kimmeridgian indicator species.

The above synthesis shows that the sequence of RASC generated clusters (RASC zones) are internally characterized by species of progressively older age designation, highlighted in text-figure 7. The lack of any great deviaton from a straight line in this figure reflects the ability of this method to produce a stratigraphically meaningful sequence of events, with RASC zones I through XI showing progressively older characters from the Cenomanian to the Kimmeridgian. A Berriasian type fauna or zone is absent and is due in part to the non-marine or shallow-water nature of the environment at that time.

At this point, brief mention should be made of the nature of the zones discussed above. Each described biozone (text-fig. 4; table 2) is simply a group or cluster of fossil events that internally show a degree of inconsistency of relative disappearance levels from well to well. These groupings of incon-

sistencies or clusters resemble assemblage zones of conventional stratigraphic practice. As the top of one zone defines the base of the zone above, the RASC produced biozones also resemble interval zones of the North American Stratigraphic Code (Article 45, section 3, 1983). Industrial and other micropaleontologists, who for years have dealt with cutting type samples using an interval zone approach, should be attracted to the RASC quantitative biostratigraphic zonation, producing as it does, easily interpreted interval and assemblage type zones. Similarly attractive is the practicality of the RASC zonation compared to more conventional, subjective zonations constructed from similar data. This increased practicality is due to the use, only of events frequent enough to occur in the most likely sequence (i.e. in this study, only those events occurring in more than four wells), thus reducing dependence upon rare index fossils. Furthermore, RASC clusters allow a certain amount of substitution of absent zonal species with other species from the same cluster and facilitates designation of zones within a well. This substitutability, which has been practiced by industrial micropaleontologists for many years has thus been put on a statistical basis (P. Moore 1984, pers. commun.). The quality of stratigraphic information gained from the foraminiferal record of the Early Cretaceous and Late Jurassic is thus enhanced through application of RASC and facilitates correlation of the studied wells.

Stratigraphic correlation

For a foraminiferal event to participate in a final RASC zonation, it must be present in greater than a specified number of wells. In practice this facilitates a relatively easy correlation from well to well. The correlation chart in text-figure 8 was produced by carrying through each well the biozones defined and described earlier (text-fig. 4; table 2). The boundaries were placed with reference to the order of events of each individual sequence (precise depth to boundary limits are shown in text-fig. 9). Any event or events that clearly did not fit in or accompanied a group of events with which they were not associated in the scaled optimum sequence (text-fig. 4), were down-played or ignored.

Most of the sections studied show a good sequence of the RASC biozones described, in particular Ben Nevis, Hebron I-13 and Hibernia K-18. Several wells, however, are "missing" certain zones. Hibernia B-08 and Nautilus C-96 are missing RASC zone IV, which represents the Aptian; this is important in the light of the association of this zone with the Avalon sands oil reservoirs (i.e. the top Avalon sands occur in this zone in Hibernias G-55, O-35, K-18 and P-15). Both the wells, however, have a well-developed zone V which is believed to represent the early Aptian. The wells Hibernia G-55, O-35 and P-15, and Hebron I-13, are lacking RASC zone VI here designated Barremian in age.

As mentioned briefly in the Introduction, Early Cretaceous and Late Jurassic sedimentation involved the accumulation of thick sandstone and shale bodies in a deltaic setting. More specifically, there are three sandstone bodies that are of economic interest in this area, the tops of which are marked in text-figure 9. (All tops and picks are from Well History Reports of the Operating Companies or from information in

the Offshore Schedule of Wells, Canadian Oil and Gas Lands Administration [COGLA] 1983.)

The youngest sand unit of the Early Cretaceous is termed the Avalon sands and is thought to represent shoreline sand deposits (McKenzie 1981). The top of the Avalon sands, where present, seems to lie within RASC zone IV of mid-to-late Aptian age. As with RASC zone IV, the Avalon sands unit is not developed in Hibernia B-08. Above the Avalon sands lies the Avalon unconformity which seems to be associated with RASC zone III (lower Albian). Beneath these two markers and consistently associated with RASC zone V is the pre-Aptian unconformity. In fact RASC zone V has been assigned an early Aptian age on the basis of foraminifers.

A second sandstone body of deltaic and shoreline character (McKenzie 1981) is commonly found with RASC zone IX (or Valanginian-Berriasian). This is the main Hibernia sand and is characteristic of the Late Jurassic-Early Cretaceous transition zone. The Catalina member is often developed above the Hibernia sands and is in some places expressed as an arenaceous limestone, in others as sandstone. The seismic B marker, which was treated as an event in the derivation of the biozonation is taken from this member (text-fig. 4). This unit is associated throughout the area with RASC zone IX. Finally within RASC zone X is found the Verril Canyon unit.

Although the biozonation is quantitatively derived through application of RASC, the ensuing correlation of individual biozones as described above remains subjective, even though decisions for boundary placements are made with reference to the quantitative RASC output. RASC output, however, is ideally suited to further quantitative treatment that automatically and objectively correlates between sections. Such a method, CASC (correlation and scaling in time) has been described briefly in Agterberg and Gradstein (1983). It is not within the scope of the present paper to summarize fully the algorithms and mechanics of the CASC program. Similarly, the full discussion of its application to the RASC output from the Mesozoic of the East Newfoundland Basin is meant for later publication. It is possible, however, to review the concept of CASC and briefly present some aspects of its use on the data set from Hibernia and surrounding area. It has been seen that for each individual well, one is able to plot the derived RASC optimum sequence as a function of the event sequence (i.e. scattergrams of text-fig. 5) in that well. Similarly, from event depth information for each well, one is also able to plot the event sequence as a function of depth. From the above information it is possible to derive a third plot depicting the optimum sequence versus depth for each individual well. The end result is a series of optimum sequence versus depth plots for each well. Subsequent correlation from well to well is thus facilitated. Line fitting (cubic spline function) techniques allow an amount of smoothing of the data and ultimately provide a measure of reliability of particular correlation tie lines in the form of standard errors. By replacing the optimum sequence with the RASC distance values (from RASC scaled output, text-fig. 4) one can plot for each well the RASC distance versus event sequence. With a knowledge of the age in millions of years of some good marker events, one is able to substitute the RASC distance with an
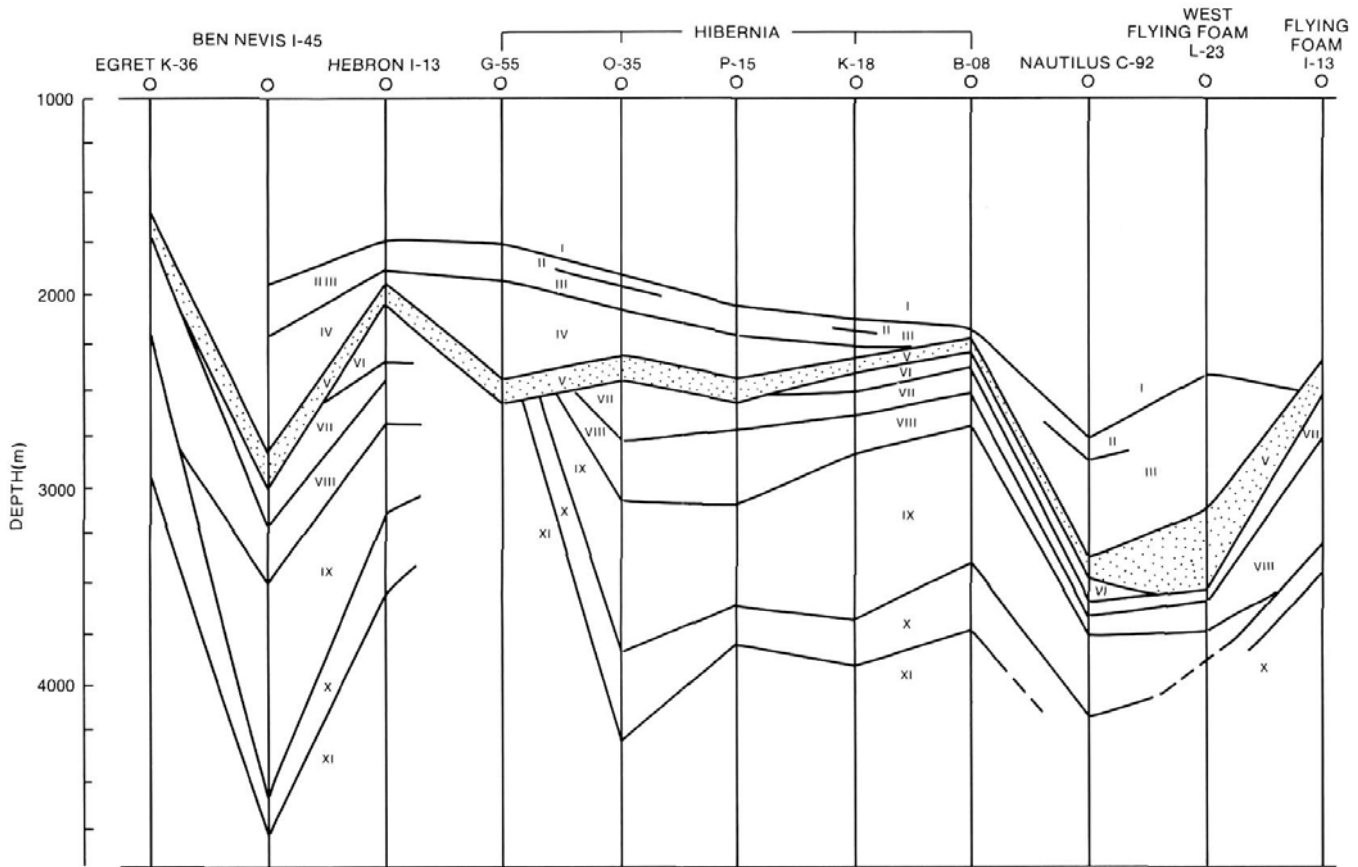
TEXT-FIGURE 8
Correlation of RASC biozones through the Hibernia and surrounding wells.
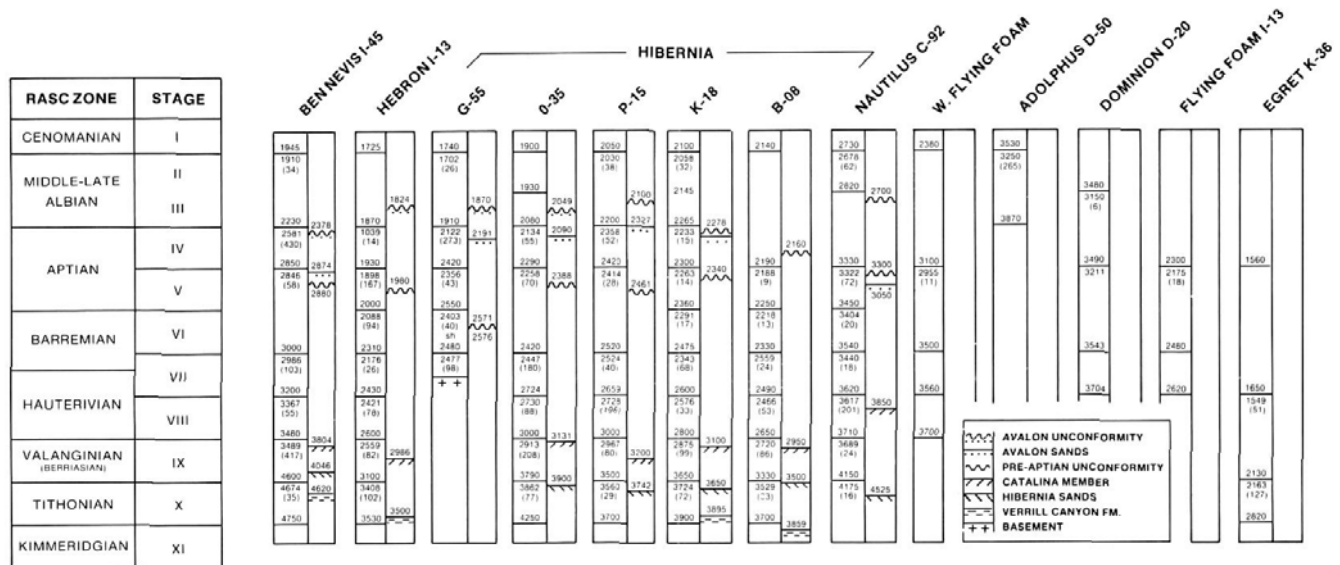
TEXT-FIGURE 9
Depth values of RASC biozones in each well. Numbers above each boundary are from a subjective interpretation of RASC results. Number underlying each boundary depicts the objective CASC produced value. Number in parentheses is standard error in meters of the CASC produced value.

absolute age scale, thus, as in the first case one can derive for each well age versus depth plots enabling the correlation of isochrons. The results of this latter option are presented here in text-figure 10. Solid lines are representative of the author's subjective appraisal of the RASC output and are the same as for text-figure 8. Each line is marked with an appropriate age in millions of years (from the time scale of Kent and Gradstein 1985). The dashed lines are the CASC version of the correlation lines for each respective age. The purpose of text-figure 10 is to demonstrate two aspects of CASC: First, the CASC program is able to derive successfully a seemingly accurate, objective correlation from the quantitative output of the previously applied RASC; the closeness of the subjective and objective tie lines is testament to this. Second, and perhaps more important, CASC has produced a measure of reliability of each tie line (text-fig. 9 records the depth to zone boundaries for each well and includes the CASC derived values with associated error together with the subjectively derived depths), something that has previously remained rather vague in conventional, subjective correlation schemes. Thus the possibility arises of a completely integrated objective treatment of biostratigraphic data from the original observations and the derivation of a zonation, to the automated correlation of that zonation thus producing a zonal and correlation scheme that is both scientifically reproducible and inherently easier to communicate to nonspecialists.

Discussion

Suffice it to say, any zonation of a group of wells is ultimately, only a means to an end. That is, it is but an established framework within which one endeavors to understand all aspects of a region's geological history, particularly the thermal, tectonic and sedimentation histories. Paleobathymetry is an important consideration when evaluating sedimentation history. As mentioned previously, the Early Cretaceous and Late Jurassic deposits of the East Newfoundland Basin comprise thick sand and shale shallow-water sequences laid down in response to major progradational deltaic pulses. The environments of deposition range from littoral, sub-littoral brackish or lagoonal (0–10 m) to a maximum of outer neritic (100–200 m). Table 3 depicts the depth characteristics of each biozone.

In summary, the foraminiferal assemblages of RASC zones I, II, III, and IV indicate a relatively rich, diverse population of outer neritic depths. RASC zone V of the early Aptian is markedly shallow in character with *Choffatella decipiens* Schlumberger and *Trocholina infragranulata*, possibly inner to middle neritic (10–100 m). The zones VI–VIII (Barremian-Hauterivian) have typically neritic type calcareous and agglutinated faunas. However, some horizons appear devoid of open marine foraminifera, and examination of cored intervals indicate that the environments of deposition fluctuated quite markedly from neritic to littoral or restricted environments. The Kimmeridgian and Tithonian zones (IX and X) are typically of a deeper water character (i.e. 50–100 m).

It is important to remember, however, that the zonation and this brief environmental synthesis is based upon ditch-cutting samples, which are of limited use for paleoenvironmen-

tal study. These paleodepth considerations then, are but approximations from the data available. The very fact that the greater part of the studied section was under a deltaic type influence indicates that in reality, there would have been quite rapid (i.e. littoral/lagoonal to mid-neritic) changes in depth characters in a relatively short period of time. Examination of ditch-cuttings is unable to resolve these subtle changes in depth. On-going study of cored intervals, however, is revealing several interesting assemblages. Some of these appear to be quite restricted and entirely composed of a few agglutinating types; others are similarly agglutinating but show greater species diversity while more appear less restricted, being comprised of calcareous and agglutinating types. Typically, all these assemblages have been found to occur close together (within a meter) in some cores. Clearly, detailed work on cored intervals will eventually reveal a more resolved paleobathymetry. What is apparent is that the Late Jurassic and Early Cretaceous is represented by a thick (+ 2000 m) sequence of shallow water, mostly marine deposits.

It is relevant to consider the sections from the East Newfoundland Basin in terms of what they can reveal about the early rifting history of the North Atlantic. Cumulative plots of sediment accumulation related to depth of sea and time approximate the subsidence and depositional history. Text-figure 11 shows the observed subsidence rate for Hibernia O-35, and it is representative of similarly observed rates for the other wells in this study. It is apparent that early, rapid subsidence and sedimentation rates in the Late Jurassic and Early Cretaceous gave way toward the mid-Cretaceous to lesser rates. In the early Cenozoic, these rates increase rapidly.

That sediment loading alone was not responsible for the observed subsidence is indicated through a comparison of the thickness of the sedimentary pile and the known paleo-water depths (see earlier). The requirements of isostasy demand that the maximum thickness of sediments can only be 2.5 times the availability of water depth (Watts and Steckler 1981).

Much work has been done on the subsidence and tectonic history of Atlantic type passive continental margins. These investigations have quantitatively examined the various contributions that such factors as eustacy, compaction, paleobathymetry, and basement flexural strength make toward the observed subsidence (Watts and Ryan 1976; Steckler and Watts 1978; Keen 1979; Watts and Steckler 1981). The effect of these factors may be accounted for through backstripping methods, with a residual subsidence that has been termed the tectonic subsidence and that is most likely a response to thermal contraction of the basement as it cools following initial rifting (Watts and Steckler 1979, 1981).

It is not the purpose of this paper to examine in detail the basement history and tectonics of Canada's eastern continental margin. It is, however, possible to describe broadly the sedimentation history of this part of the East Newfoundland Basin in terms of the kinematic and tectonic evolution of the North Atlantic. Backstripping of some Hibernia subsidence curves shows (as typified by Hibernia O-35, text-fig. 11) that a significant proportion of the subsidence at this location on the margin is tectonic in origin and not entirely
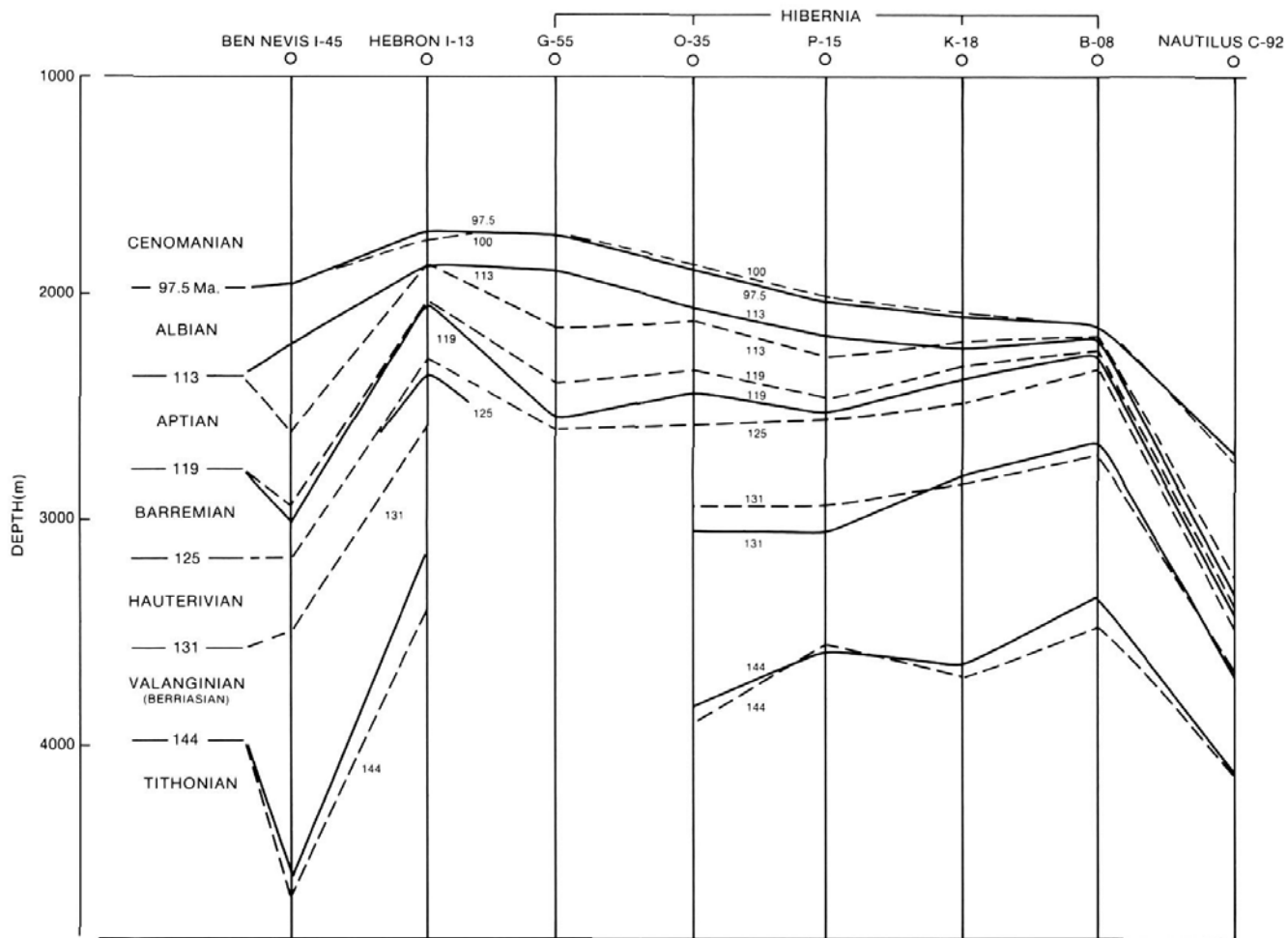
TEXT-FIGURE 10
Subjective (solid line) and objective (dashed) interpretations of RASC output.

due to sedimentary loading, and as such is an indication of the post rift thermal cooling of the basement. This lithosphere cooling rate had been shown to decay exponentially with time (Sleep 1971) and indicated that some similarity to the time

TABLE 3
Bathymetric character of RASC zones.

RASC zone	Bathymetry
I	Outer neritic 100–200 m
II	Outer neritic 100–200 m
III	Outer neritic 100–200 m
IV	Mid-neritic 100 m
V	Inner neritic 10–50 m
VI	Inner-mid neritic 10–100 m
VII	Inner-mid neritic 10–100 m
VIII	Inner-mid neritic 10–100 m
IX	Littoral to inner neritic 0–50
X	Mid-neritic 50–100 m
XI	Mid-neritic 50–100 m

constant of subsidence of mid-ocean ridges (50 Ma) should be expected (Montadert et al. 1979). Subsidence rates, however, are not the same at every point on a margin transect, and Montadert et al. (1979) have shown that for the East Newfoundland Basin's conjugate margin (i.e. Galicia Bank area) only the rates in the lower part of the margin (i.e. thinner continental crust) approximate that of the oceanic crust. Their point is illustrated in their figure 26 (Montadert et al. 1979) which shows the variation of subsidence rates across the North Biscay margin. Where continental crust is thinnest, subsidence rates approximate that of the oceanic crust. Shelfward the increasing thickness of the continental crust is concomitant with a decrease in subsidence rate. The conclusion from this is, "that post rifting subsidence without the influence of loading is essentially an isostatic adjustment to cooling of the lithosphere in which the continental crust has been previously thinned during the rifting process" (Montadert et al. 1979).

The wells considered in this study, however, all show similar subsidence rates due to their similar relative location on the western Atlantic margin. A comparison with the subsidence curve of Gabriel C-60 (text-fig. 12), which is situated lower
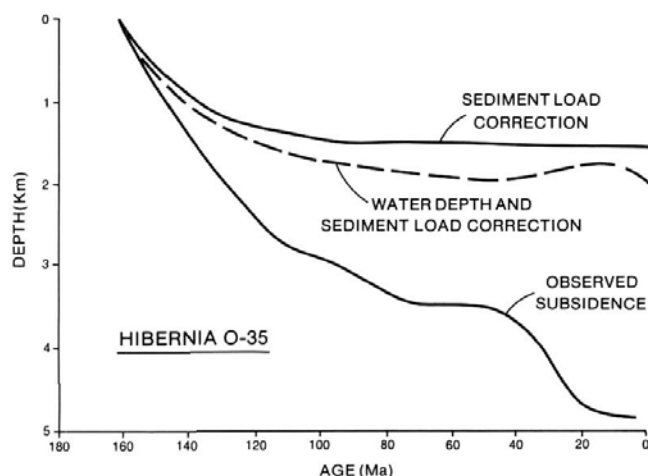
TEXT-FIGURE 11
Observed and tectonic subsidence curves for Hibernia O-35.
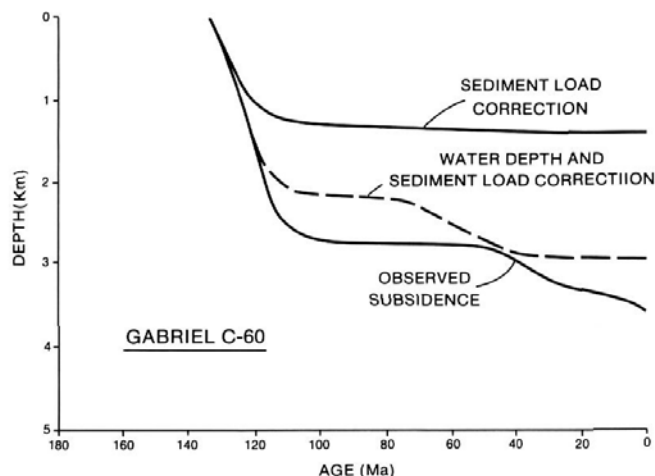
TEXT-FIGURE 12
Observed and tectonic subsidence curves for Gabriel C-60.

in the margin transect, shows that, like the margin transect described by Montadert et al. (1979), the eastern Canadian continental margin exhibits subsidence rates that approximate oceanic crust rates in lower parts of the margin (Gabriel C-60) with these rates decreasing shelfward (Hibernia O-35). More margin transects are required to fully document and understand this effect.

In summary, one can describe the broad history of the North Atlantic. Unfortunately, none of the studied wells penetrated basement and so the exact timing and nature of a proposed first tensional event in the Trias-Lias is rather obscure (Arthand and Matte 1975; Sibuet and Ryan 1979). Thick Trias-Lias evaporitic deposits are associated with rapid subsidence and are present in abundance in the Grand Banks and Scotian basins (and in other North Atlantic bordering basins), and provides supportive evidence for this early tensional phase (Sibuet and Ryan 1979). Subsequent to this early tensional phase, a period of rapid rifting and sedimentation occurred toward the Late Jurassic to Early Cretaceous. A large amount of this subsidence was basement controlled, reflected in the East Newfoundland Basin by the rotation of the main hinge line or listric faults.

CONCLUSIONS

The brief discussion above outlines some of the applications of derived biozonations. By way of conclusion it is perhaps pertinent to review several aspects of the quantitative methods used, in particular to highlight several advantages of using the methods on some data sets compared to conventional biostratigraphic approaches.

1. The method is objective, removing at the outset many errors ordinarily introduced through observer bias. As such, the method produces reproducible results and interpretations removing any elements of individuality of biozonations.

2. The method considers all the data available and facilitates the use and recognition of species of foraminifera which, although of limited use for global correlations may be of significance in developing local zonal schemes.

3. The normality or abnormality of each individual well section can be thoroughly evaluated, statistically or otherwise with reference to the optimum or average sequence.

4. RASC produces a practical zonation which can be easily correlated from well to well by virtue of the use in the zonation of only those events common enough to occur in a set number of wells. In addition, if an event, which is an important part of the zonation is found to be absent in one or two wells, then information on its position relative to other events (which are present), gained from all its other occurrences in other wells, aids in the interpretation of that well. In this way RASC produces a highly practical zonation which is independent of rare (but often good) index forms.

5. The quantitative RASC results are ideally suitable for input into automated, quantitative correlation methods. One such method, CASC, has been shown in this study to be capable of producing accurate, objective correlations that provide an independent measure of the confidence one can place in any particular tie line.

6. Standardization of data as evidenced in RASC facilitates access to the data and interpretations of nonspecialists and allows the worker greater insight into the body of his (or her) data—allowing, for example, recognition of unreliable (in terms of relative position, etc.) or troublesome events.

7. The method is able to synthesize large data sets, which, as a rule usually get bigger with time, and allow any new sections from an area to be fitted into the framework produced by RASC. This thus facilitates immediate recognition of stratigraphic abnormalities contained in new sections.

8. The mechanisms of the RASC program merely put on a statistical basis many of the concepts and philosophies that have been used for many years by biostratigraphers, and as such, prospective users of the program would require minimal conceptual orientation in order to maximize their interpretations from a particular data set.

The application of RASC and CASC to the foraminiferal event data of selected wells from the East Newfoundland

Basin has facilitated the production of the described zonal and correlation scheme.

TAXONOMY

Any biozonation, derived by whatever means; indeed any interpretation originating in paleontological data, can only be as good as the quality of taxonomy involved in specific determinations. The Early Cretaceous and Late Jurassic benthic foraminifera encountered in this study are for the most part well described and documented in the literature. Several groups and some individual species however, remain taxonomically complex. It is not the purpose of this paper to discuss fully these complexities. Greater taxonomic treatment is reserved for a later publication which intends to present a fully documented stratigraphic and taxonomic atlas of Early Cretaceous benthic foraminifera both from eastern Canada and from conjugate North Atlantic basins and sections.

For present purposes the taxonomy is limited to a few pertinent references which illustrate the author's species concept. Citations include source when they have not been previously mentioned in the text. Selected taxa are accompanied by a few remarks.

Ammobaculites coprolithiformis (Schwager)

SCHWAGER 1867, p. 645, pl. 3, fig. 3.—GORDON 1965, p. 833, text-figs. 2–3, 25–28.—SHIPP and MURRAY 1981, p. 132, pl. 6.3.1., figs. 1–2.

Confusion regarding this species is due to its wide range of variation, a feature compounded by the often broken nature of specimens. Gordon (1965) figures the types of variation as observed in the British Corallian beds. Similar variation in form is seen off eastern Canada with stout, squat specimens possessing a distinct coil of three to five chambers to curvilinear forms, almost Reophax-like in nature.

Arenobulimina macfadyeni Cushman
Plate 1, figure 3

CUSHMAN 1936, p. 26, pl. 4, fig. 6.—PRICE 1977b, p. 510, pl. 59, figs. 7–8.

Relatively few specimens of this taxon were observed, although it was found in most wells studied. It follows closely those forms illustrated in Price (1977b) being small, short, rounded and finely arenaceous. The extinction in Europe within the *cristatum* subzone indicates a valuable Albian marker (Price 1977b).

Ammobaculites subcretaceus Cushman and Alexander
Plate 1, figure 1

CUSHMAN and ALEXANDER 1936, p. 6, pl. 2, figs. 9–10.—BARTENSTEIN 1952, p. 313, pl. 1, fig. 8; pl. 2, fig. 1.

Choffatella decipiens Schlumberger
Plate 1, figure 9

SCHLUMBERGER 1905, p. 763.—ASCOLI 1976, p. 754, pl. 7, fig. 5.

This taxon is a thin, planispiral form and is consistently

present in many wells off eastern Canada, unless cut out by unconformities.

Conorboides hofkeri (Bartenstein and Brand)
Plate 2, figures 22, 23

BARTENSTEIN and BRAND 1951, p. 325, pl. 11, fig. 320.—DIENI and MASSARI 1966, p. 176, pl. 8, figs. 30–31.

Distinctive open umbilicus, and comma shaped umbilical apertures. Generally less convex spirally than *C. valendisensis* and with a more broadly hemispherical and inflated final series of chambers.

Conorboides lamplughi (Sherlock)
Plate 2, figures 16, 17

SHERLOCK 1914, p. 290.—HART 1984, p. 289, pl. 1, figs. 1–3.

Hart's (1984) specimens from the United Kingdom and Europe are similar to those in this study. It has a biplano-convex test, acute periphery and sometimes lobulate outline. The ventral surface exhibits a distinct umbonal boss, a feature which also serves to distinguish it from *Conorboides hofkeri* and *Conorboides valendisensis*.

Conorboides valendisensis (Bartenstein and Brand)
Plate 2, figures 20, 21

BARTENSTEIN and BRAND 1951, p. 326, pl. 11, figs. 321–322.—ASCOLI 1976, p. 746, pl. 3, fig. 2.—HART 1984, p. 292, pl. 1, figs. 4–6.

Plano-convex, with a relatively high trochospire.

Dorothia gradata (Berthelin)
Plate 1, figure 2

BARTENSTEIN and BETTENSTAEDT 1962, p. 296, pl. 39, fig. 11.—GRADSTEIN 1978a, p. 684, pl. 3, figs. 14–17.

Epistomina caracolla (Roemer)
Plate 3, figures 10, 11

ROEMER 1841, p. 97, pl. 15, fig. 22a–c.—ASCOLI 1976, p. 746, pl. 3, fig. 10.

Epistomina carpenteri (Reuss)
Plate 2, figures 11–13

REUSS 1862, p. 94, pl. 13, fig. 6.—ASCOLI 1976, p. 748, pl. 4, fig. 5.

Epistomina cretosa Ten Dam
Plate 3, figures 5–7

TEN DAM 1947, p. 29, pl. 26, fig. 6.—ASCOLI 1976, p. 748, pl. 4, fig. 3.—HART 1984, p. 292, pl. 2, figs. 12, 16.

Planar, sharply truncate bicarinate test.

Larger specimens are generally flat with more convex smaller specimens. Present specimens correspond closely to those in Ohm (1967), Magniez-Jannin (1975), Ascoli (1976) and Hart (1984) and have a distinctive angular, pentagonal circumference.

Epistomina hechti (Bartenstein, Bettenstaedt and Bolli)
Plate 3, figures 12, 13

BARTENSTEIN ET AL. 1957, p. 46, pl. 7, figs. 17a–c.—OHM 1967, p. 138, pl. 18, fig. 6.—ASCOLI 1976, p. 748, pl. 4, fig. 1.

Epistomina mosquensis Uhlig
Plate 3, figures 21, 22

UHLIG 1883, p. 766, pl. 7, figs. 1–3.—OHM 1967, p. 125, pl. 16, figs. 7–10; pl. 17, figs. 1–12.

Epistomina ornata (Roemer)
Plate 3, figures 8, 9

ROEMER 1841, p. 98, pl. 15, fig. 25.—OHM 1967, p. 135, pl. 18, figs. 1–2; pl. 20, fig. 7.—ASCOLI 1976, p. 746, pl. 3, figs. 8a–b.

Epistomina spinulifera polypioides (Eichenberg)
Plate 3, figures 3, 4

EICHENBERG 1933, p. 21, pl. 3, figs. 1a–c.—OHM 1967, p. 141, pl. 18, figs. 7–8; pl. 19, figs. 1, 9.—PRICE 1976, p. 647, pl. 2, figs. 3–4.

Epistomina spinulifera spinulifera (Reuss)
Plate 3, figures 1, 2

REUSS 1862, p. 93, pl. 13, figs. 3–5.—PRICE 1977b, p. 506, pl. 2, figs. 1, 2.—HART 1984, p. 292, pl. 1, figs. 10–11.

Variation in the morphology of this subspecies (which is sometimes due to preservation) often leads to confusion with *E. spinulifera polypioides*. It is distinguished from the latter by its lesser degree of ornamentation and thinner sutures. Similarly, the centrally excavate umbilical collar is less deep in subspecies *polypioides* than *spinulifera*. Both subspecies have some individuals which become less convex ventrally, and, as each possesses a distinct umbilical collar, some similarity to *E. cretosa* and *E. ornata* may be apparent. They differ from the latter by virtue of the near absence of, or weak nature of, their ventral keels and the flattened, or straight line inner margin of their dorsal chambers.

Epistomina stellicostata Bielecka and Pozaryski
Plate 3, figures 14, 15

BIELECKA and POZARYSKI 1954, p. 171, fig. 136.—ASCOLI 1976, p. 744, pl. 2, fig. 6.

Epistomina tenuicostata Bartenstein and Brand
Plate 3, figures 16–18

BARTENSTEIN and BRAND 1951, p. 327, pl. 12, fig. 325.—OHM 1967, p. 134, pl. 18, fig. 9.

Epistomina uhligi Mjatliuk
Plate 3, figures 19, 20

MJATLIUK 1953, pl. 2, figs. 5a–b.—OHM 1967, p. 128, pl. 18, fig. 4.—ASCOLI 1976, p. 746, pl. 3, fig. 1.

PLATE 1

All photographs are SEM unless otherwise indicated

1 *Ammobaculites subcretaceus* (Cushman and Alexander)
Hebron I-13, 1850 m, side view, × 50.

2 *Dorothia gradata* (Berthelin)
Ben Nevis I-45, 2140 m, side view, × 58.

3 *Arenobulimina macfadyeni* (Cushman)
Hibernia B-08, 2145 m, side view, × 60.

4 *Falsogaudryinella triangula* (Bartenstein)
Ben Nevis I-45, 2010 m, side view, × 68.

5 *Falsogaudryinella tealbyensis* (Bartenstein)
Ben Nevis I-45, 1960 m, side view, × 65.

6 *Gaudryina dividens* (Grabert)
Ben Nevis I-45, 1990 m, side view, × 51.

7 *Textularia bettenstaedti* (Bartenstein and Oertli)
West Flying Foam, 3080 m, side view, × 54.

8 *Everticyclammina virguliana* (Koechlin)
Hibernia B-08, 2525 m, side view, × 20.

9 *Choffatella decipiens* (Schlumberger)
Ben Nevis, I-45, 3100 m, side view, × 12.

10–11 *Spiroplectinata lata* (Grabert)
Ben Nevis I-45, 1990 m, side view. 10, × 66; 11, × 63.

12 *Lenticulina saxonica* (Bartenstein and Brand)
Hibernia B-08, 2640 m, side view, × 59.

13 *Lenticulina eichenbergi* (Bartenstein and Brand)
Dominion D-26, 10,750′, side view, × 34.

14 *Lenticulina guttata* (Ten Dam)
Hibernia P-15, 2550 m, side view, × 41.6.

15–16 *Trocholina infragranulata* (Noth)
Hibernia B-08, 2225 m. 15, umbilical view, × 75; 16, spiral view, × 80.

17 *Lenticulina nodosa* (Reuss)
Hibernia B-08, 2375 m, side view, × 63.

18–19 *Lenticulina gaultina* (Berthelin)
Hibernia G-55, 2175 m, side view. 18, × 43 (optical); 19, side view, × 85.

20 *Lenticulina crepidularis* (Roemer)
West Flying Foam, 3560 m, side view, × 71.

21 *Lenticulina sigali* (Bartenstein, Bettenstaedt and Bolli)
Dominion D-26, 3271 m, side view, × 77.

22 *Lenticulina quenstedti* (Gumbel)
Hibernia O-35, 4225 m, side view, × 82.

23 *Globigerinelloides gyroidinaeformis* (Moullade)
Dominion D-26, 10,450′, apertural view, × 94.
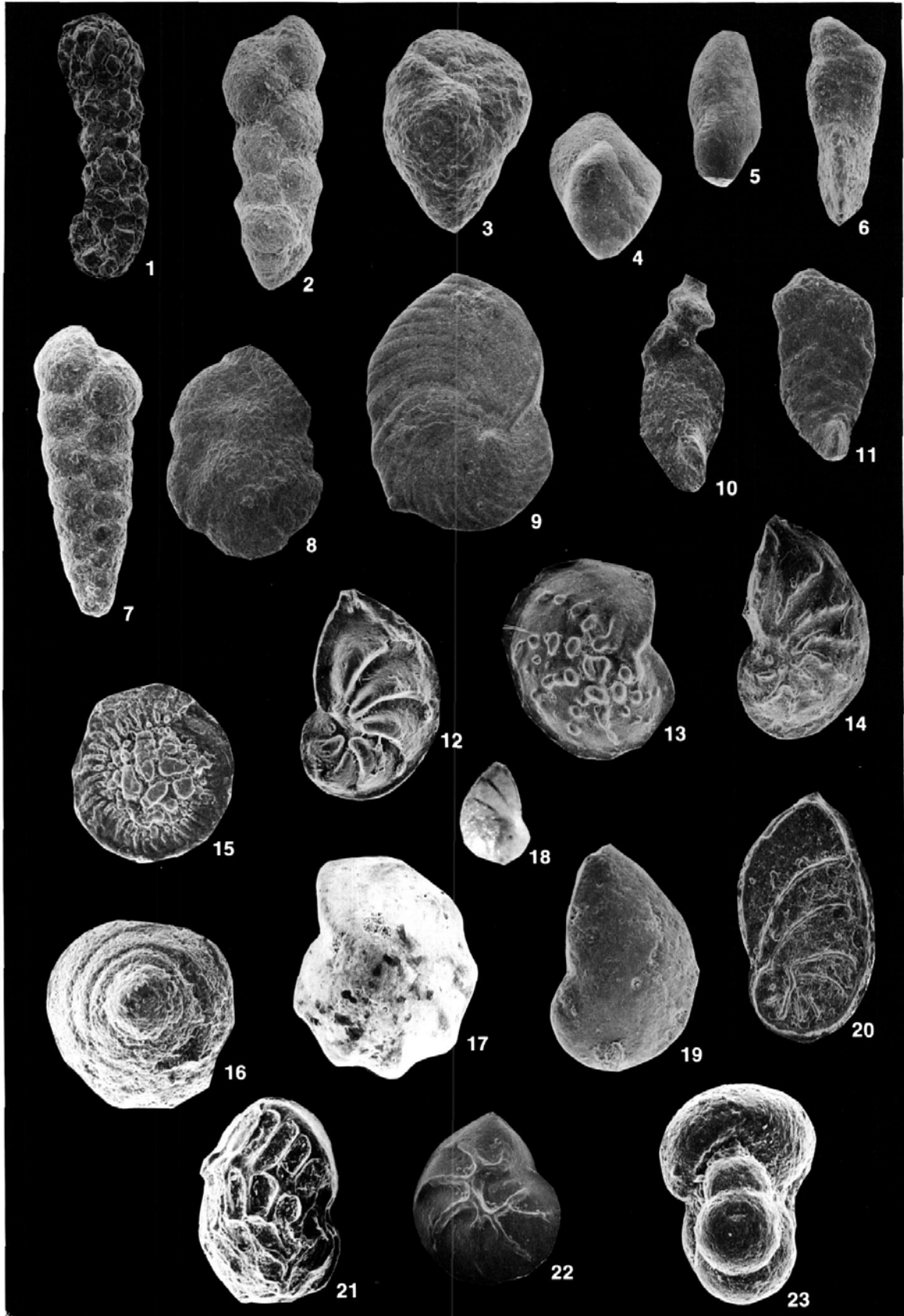
Specimens of this form are entirely smooth, with a distinct, biconvex test often with a large, glossy boss. Its smooth nature may lead to confusion with other "smooth" epistominids, such as *Epistomina caracolla*. Off eastern Canada *E. uhligi* is distinguished from *E. caracolla* by its often larger size. Also of use in its determination (although not necessarily a desirable method) is its distinct preservation which shows up as "glossy" brown. More work is necessary to achieve full understanding of this species.

Everticyclammina virguliana (Koechlin)
Plate 1, figure 8

KOECHLIN 1943, pl. 6, figs. 1–9.—ASCOLI 1976, p. 752, pl. 6, fig. 13.

This species is a larger agglutinated, slightly trochospiral foraminifer, found in many of the wells off eastern Canada. Ascoli (1976) has used this form extensively [he called it *Buccicrenata italica* (Dieni and Massari) as an Early Cretaceous indicator]. Similarly, Barnard and Shipp (1981) have illustrated specimens of Loeblich and Tappan's (1950) *Ammobaculites cobbani,* which are similar to specimens of *Everticyclammina virguliana* from eastern Canada (Gradstein, pers. commun.).

Falsogaudryinella tealbyensis (Bartenstein)
Plate 1, figure 5

BARTENSTEIN 1956, p. 513, pl. 3, fig. 63; 1981, p. 313, pl. 3, figs. 6–7.

Gavelinella intermedia (Berthelin)
Plate 2, figures 9, 10

BERTHELIN 1880, p. 67, pl. 4, fig. 14.—MALAPRIS 1965, p. 138.—MICHAEL 1966, p. 432, pl. 50, figs. 4–13.—ASCOLI 1976, p. 748, pl. 4, fig. 9.

Although specimens of this taxon exhibit a wide variation, they are quite distinct from other gavelinellids, lacking the planispirality of *G. ammonoides*, the large, inflated final chambers of *G. sigmoicosta* and *G. barremiana* and the raised spiral ridgelike structure of *G. cenomanica*.

Gavelinella ammonoides (Reuss)
Plate 2, figures 5, 6

REUSS 1862, p. 214.—NEAGU 1965, pl. 9, fig. 50.—PRICE 1977b, pl. 60, figs. 12, 13.

Gavelinella barremiana Bettenstaedt
Plate 2, figures 7, 8

BETTENSTAEDT 1952, p. 275, pl. 2, figs. 26–29.—MALAPRIS-BIZOUARD 1976, p. 13, pl. 1, figs. 6–10.

Gavelinella cenomanica (Brotzen)
Plate 2, figure 4

BROTZEN 1942, p. 54, pl. 2, fig. 2.—PRICE 1977b, p. 516, pl. 60, figs. 5–6.

Gavelinella sigmoicosta (Ten Dam)
Plate 2, figures 1–3

TEN DAM 1948, p. 189, pl. 32, figs. 23–24.—MOULLADE 1966, p. 70, pl. 7, figs. 16–19.
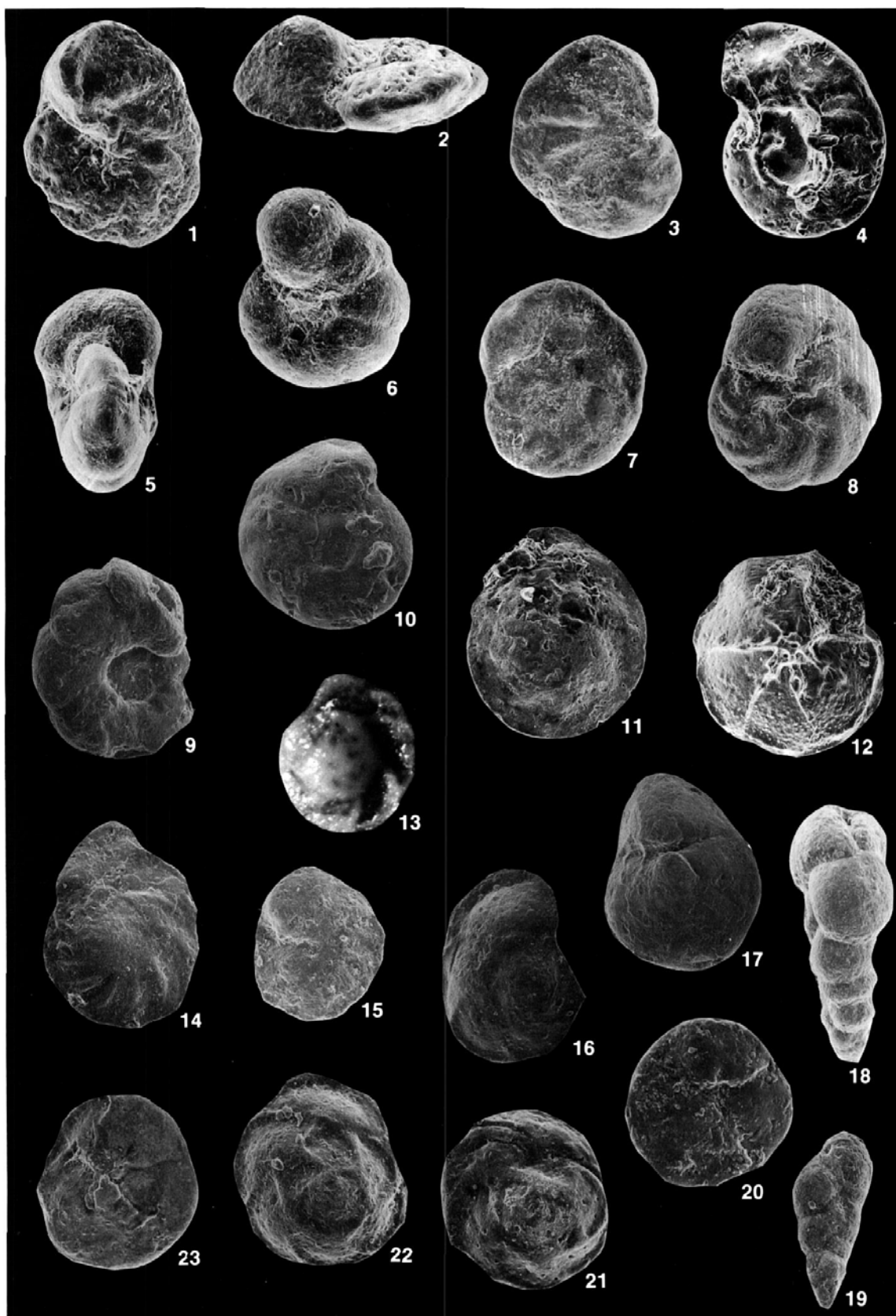
Gaudryina dividens Grabert
Plate 1, figure 6

GRABERT 1959, p. 9, pl. 1, figs. 3–5.—BARTENSTEIN 1959, pl. 1, figs. 56–57.—GRADSTEIN 1978b, p. 675, pl. 2, figs. 9–18.

Gradstein (1978b) discussed the plexus of *Gaudryina dividens* and *Spiroplectinata lata* from the Lower Cretaceous Blake Nose and Blake-Bahama samples (DSDP Leg 44). Specimens

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PLATE 2

1–3   *Gavelinella sigmoicosta* (Ten Dam)
Hibernia K-18, 2300 m. 1, ventral view, × 87.5; 2, side view, × 85.5; 3, dorsal view, × 60.

4   *Gavelinella cenomanica* (Brotzen)
Hibernia B-08, 2145 m, dorsal view, × 85.

5–6   *Gavelinella ammonoides* (Reuss)
Ben Nevis I-45, 1990 m. 5, side view, × 70; 6, umbilical view, × 63.

7–8   *Gavelinella barremiana* (Bettenstaedt)
Hibernia P-15, 2130 m. 7, dorsal view, × 100; 8, ventral view, × 80.5.

9–10   *Gavelinella intermedia* (Berthelin)
Hibernia B-08, 2145 m. 9, ventral view, × 85; 10, dorsal view, × 81.

11–13   *Epistomina carpenteri* (Reuss)
Hibernia K-18, 2260 m. 11, dorsal view, × 90; 12, ventral view, × 85; 13, dorsal view (optical), × 88.

14–15   *Osangularia schloenbachi* (Reuss)
Ben Nevis I-45, 1990. 14, dorsal view, × 84; 15, ventral view, × 80.

16–17   *Conorboides lamplughi* (Sherlock)
Hibernia, B-08, 2100 m. 16, spiral view, × 74; 17, umbilical view, × 65.

18–19   *Neobulimina varsoviensis* (Bielecka and Pozaryski)
Hibernia K-18, 2600 m, side view. 18, × 105; 19, × 75.

20–21   *Conorboides valendisensis* (Bartenstein and Brand)
Hibernia B-08, 3690 m. 20, umbilical view, × 98; 21, spiral view, × 81.

22–23   *Conorboides hofkeri* (Bartenstein and Brand)
Hibernia B-08, 3090 m. 22, spiral view, × 80.5; 23, umbilical view, × 81.

of *G. dividens* and *S. lata* recovered from the East Newfoundland Basin are similar. *Gaudryina dividens* has a relatively long triserial portion, often with a much smaller biserial or biserial-uniserial later portion. *Spiroplectinata lata*, however, possesses a much longer biserial portion, with strongly flattened chambers and a much reduced initial triserial section.

Globorotolites aptiensis Bettenstaedt

BARTENSTEIN, BETTENSTAEDT and BOLLI 1966, 59(1), p. 162, pl. 4, figs. 357–359.

Lenticulina crepidularis (Roemer)
Plate 1, figure 20

ROEMER 1841, p. 273, pl. 7, fig. 4.—ASCOLI 1976, p. 746, pl. 3, fig. 7.—HART ET AL. 1981, p. 272, pl. 7.20, figs. 11, 12.

Lenticulina eichenbergi Bartenstein and Brand
Plate 1, figure 13

BARTENSTEIN and BRAND 1951, p. 285, pl. 5, figs. 118–119.—MOULLADE 1966, pp. 50–51, pl. 4, figs. 4–8.—HART ET AL. 1981, p. 206, pl. 7.17, figs. 9–10.

Specimens of this species have curved, limbate, and ornamented sutures. Later sutures may lack this ornamentation. Although close to *L. guttata* Ten Dam, this species possesses a coarser and more irregularly disposed ornament.

Lenticulina gaultina (Berthelin)
Plate 1, figures 18, 19

BERTHELIN 1880, p. 49, pl. 3, figs. 15–19.—ASCOLI 1976, p. 748, pl. 4, fig. 7.

Lenticulina guttata (Ten Dam)
Plate 1, figure 14

TEN DAM 1946, p. 574, pl. 88, fig. 2.—ASCOLI 1976, p. 746, pl. 3, fig. 6.—HART ET AL. 1981, p. 206, pl. 1.17, figs. 11, 12.

A distinctive species with curved, limbate raised sutures ornamented with numerous, small guttiform pustules, often coalescing to form discontinuously marked sutures. Development of ornamentation and degree of coiling varies appreciably. A well-developed keel is distinctive.

Lenticulina heiermanni Bettenstaedt

BETTENSTAEDT 1952, p. 270, pl. 1, figs. 9–11.—NEAGU 1975, p. 59, pl. 47, figs. 1–4, 9–11.

Lenticulina nodosa (Reuss)
Plate 1, figure 17

AUBERT and BARTENSTEIN 1976, pp. 1–33, pl. 4, figs. 4–6; pl. 2, figs. 20–22.

Lenticulina quenstedti (Gumbel)
Plate 1, figure 14

GUMBEL 1862, p. 226, pl. 4, fig. 2.—ASCOLI 1976, p. 744, pl. 2, fig. 3.

Lenticulina saxonica Bartenstein and Brand
Plate 1, figure 12

BARTENSTEIN and BETTENSTAEDT 1962, p. 259, table 17, pl. 36, fig. 11.

Lenticulina sigali Bartenstein, Bettenstaedt and Bolli
Plate 1, figure 21

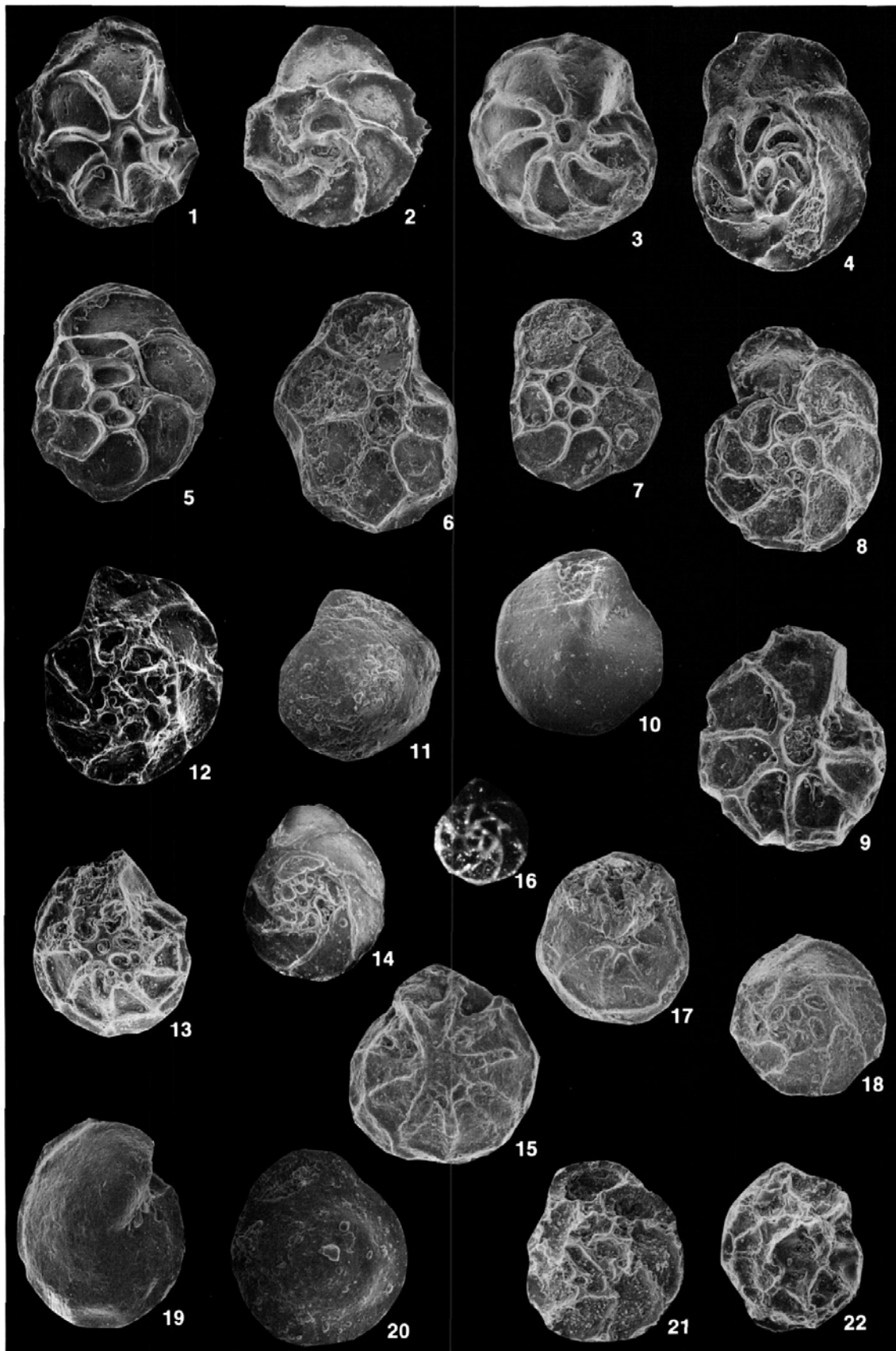BARTENSTEIN ET AL. 1957, p. 32, pl. 5, fig. 99; pl. 6, figs. 130–131.

Neobulimina varsoviensis Bielecka and Pozaryski
Plate 2, figures 18, 19

BIELECKA and POZARYSKI 1954, pl. 10, fig. 50.

PLATE 3

1–2   *Epistomina spinulifera spinulifera* (Reuss)
West Flying Foam, 2570 m. 1, ventral view, × 52; 2, dorsal view, × 50.

3–4   *Epistomina spinulifera polypioides* (Eichenberg)
West Flying Foam, 2810 m. 3, ventral view, × 37; 4, dorsal view, × 41.

5–7   *Epistomina cretosa* (Ten Dam)
Hibernia O-35, 2020 m. 5, dorsal view, × 49; 6, ventral view, × 45; 7, dorsal view, × 51.

8–9   *Epistomina ornata* (Roemer)
Hibernia O-35, 2465 m. 8, dorsal view, × 67; 9, ventral view, × 65.

10–11   *Epistomina caracolla* (Roemer)
Hibernia K-18, 2450 m. 10, ventral view, × 70.5; 11, dorsal view, × 73.

12–13   *Epistomina hechti* (Bartenstein, Bettenstaedt and Bolli)
Hibernia P-15, 2490 m. 12, dorsal view, × 93.7; 13, ventral view, × 71.

14–15   *Epistomina stellicostata* (Bielecka and Pozaryski)
Hibernia B-08, 3275 m. 14, dorsal view, × 61; 15, ventral view, × 73.

16–18   *Epistomina tenuicostata* (Bartenstein and Brand)
Hibernia B-08, 2435 m. 16, dorsal view (optical), × 82; 17, ventral view, × 56; 18, dorsal view, × 58.

19–20   *Epistomina uhligi* (Mjatliuk)
Hibernia B-08, 3660 m. 19, ventral view, × 65; 20, dorsal view, × 67.

21–22   *Epistomina mosquensis* (Uhlig)
Hebron I-13, 3550 m. 21, dorsal view, × 66; 22, ventral view, × 66.

APPENDIX 3

SPECIES NAME	CODE NUMBER	HIBERNIA					BEN NEVIS I-45	DOMINION D-26	HEBRON I-13	EGRET K-36	FLYING FOAM I-13	ADOLPHUS D-50	NAUTILUS C-92	WEST FLYING FOAM L-23
		K-18	O-35	B-08	P-15	G-55								
ROTALIPORA GREENHORNENSIS	3	0.0	0.0	0.0	1.5	0.0	1.0	0.0	2.0	0.0	0.0	.5	.5	0.0
ROTALIPORA APPENINICA	5	0.0	0.0	0.0	1.0	0.0	1.0	0.0	2.0	0.0	0.0	1.0	0.0	0.0
ROTALIPORA CUSHMANI	24	.5	0.0	3.5	0.0	0.0	1.0	0.0	2.0	0.0	0.0	1.5	.5	0.0
GAVELINOPSIS CENOMANICA	76	.5	0.0	3.5	.5	1.0	.5	0.0	2.0	0.0	0.0	0.0	1.5	0.0
GAVELINELLA AMMONOIDES	40	0.0	1.5	3.5	1.0	2.0	.5	.5	2.0	0.0	0.0	0.0	1.5	0.0
HEDBERGELLA INFRACRETACEA	32	0.0	0.0	0.0	0.0	2.0	0.0	1.0	2.5	0.0	0.0	2.0	0.0	0.0
GAVELINELLA INTERMEDIA	35	0.0	1.5	3.5	1.0	0.0	2.5	1.5	2.5	0.0	0.0	4.5	1.5	0.0
COARSE AGGLU SPP	36	.5	4.0	3.5	0.0	2.0	2.5	0.0	7.0	0.0	0.0	4.5	1.5	0.0
ROTALIPORA TICINENSIS	29	0.0	2.5	3.5	6.0	5.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0
EPISTOMINA SPINULIFERA POLYPIOIDES	13	2.0	2.5	5.0	2.0	1.0	0.0	0.0	7.0	0.0	0.0	0.0	3.0	0.0
DOROTHIA GRADATA	11	2.0	0.0	4.5	5.0	0.0	2.5	0.0	4.5	0.0	0.0	0.0	2.5	0.0
ARENOBULIMINA MACFADYENI	10	0.0	2.0	4.5	5.0	2.5	0.0	0.0	6.0	0.0	0.0	0.0	4.5	0.0
LENTICULINA GAULTINA	15	2.0	4.0	0.0	5.0	2.5	2.0	1.0	5.5	0.0	0.0	0.0	2.0	1.0
FALSOGAUDRYNELLA TEALBYENSIS	33	3.5	0.0	0.0	5.0	5.0	4.0	1.0	5.0	0.0	.5	4.0	2.0	0.0
PLANOMALINA BUXTORFI	27	0.0	0.0	0.0	5.0	0.0	1.5	0.0	5.0	0.0	0.0	4.0	2.0	0.0
TEXTULARIA BETTENSTADTI	15	0.0	4.5	3.0	5.0	0.0	3.5	1.0	0.0	0.0	0.0	0.0	6.0	1.0
EPISTOMINA SPINULIFERA SPINULIFERA	50	0.0	4.5	3.0	4.0	0.0	1.5	0.0	4.5	0.0	0.0	0.0	3.0	0.0
GAUDRYINA DIVIDENS	37	0.0	0.0	0.0	6.0	3.5	5.5	0.0	6.5	0.0	0.0	1.0	0.0	0.0
EPISTOMINA CRETOSA	8	1.0	3.5	3.0	3.0	4.0	2.5	0.0	7.0	0.0	0.0	0.0	2.0	1.0
GLOBIGERINELLOIDES FERREOLENIS	18	1.0	6.0	0.0	3.0	3.5	0.0	.5	7.0	0.0	0.0	0.0	2.0	0.0
OSANGULARIA SCHLOENBACHI	28	0.0	0.0	0.0	11.0	0.0	1.5	0.0	4.5	0.0	0.0	5.0	2.0	0.0
SPIROPLECTINATA LATA	51	3.0	0.0	0.0	1.0	0.0	1.5	0.0	12.5	0.0	0.0	0.0	2.0	0.0
CONORBOIDES LAMPLUGHI	16	0.0	4.5	3.0	8.0	3.5	0.0	0.0	3.5	0.0	0.0	0.0	0.0	1.0
EPISTOMINA CARPENTERI	79	3.0	8.0	3.0	1.5	0.0	0.0	0.0	4.5	0.0	0.0	0.0	2.0	1.5
FALSOGAUDRYNELLA TRIANGULA	41	3.0	0.0	0.0	0.0	0.0	2.5	1.5	14.5	0.0	0.0	0.0	0.0	0.0
GLOBOROTALITES APTIENSIS	42	2.0	0.0	3.0	0.0	6.5	0.0	1.5	1.0	0.0	0.0	0.0	0.0	0.0
AMMOBACULITES SUBCRETACEOUS	09	0.0	2.0	0.0	1.5	3.5	2.5	0.0	2.5	0.0	0.0	0.0	0.0	0.0
GAVELINELLA BARREMIANA	53	5.0	0.0	0.0	1.0	1.5	2.0	.5	2.0	0.0	0.0	0.0	0.0	2.0
SEISMIC A	61	0.0	2.0	0.0	3.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LENTICULINA HEIRMANI	35	0.0	2.0	1.5	0.0	4.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	.5
CHOFFATELLA DECIPIENS	7	.5	0.0	1.5	.5	.5	0.0	0.0	1.0	0.0	1.5	0.0	1.0	1.0
TROCHOLINA INFRAGRANULATA	17	.5	0.0	1.5	1.0	.5	0.0	0.0	0.0	0.0	1.5	0.0	1.0	1.0
EPISTOMINA CARACOLLA	13	1.0	0.0	1.0	1.5	0.0	0.0	.5	0.0	0.0	0.0	0.0	1.0	0.0
EPISTOMINA HECHTI	12	1.0	2.0	3.0	1.5	0.0	1.5	2.5	1.5	0.0	2.0	0.0	1.0	0.0
EVERTICYCLAMMINA VIRGULIANA RARE	33	2.5	0.0	0.0	0.0	0.0	2.0	0.0	1.0	0.0	1.5	0.0	0.0	0.0
LENTICULINA CREPIDULARIS	14	1.0	2.0	3.5	0.0	0.0	2.5	0.0	.5	0.0	2.0	0.0	2.0	.5
LENTICULINA NODOSA	10	1.5	3.0	1.5	0.0	0.0	0.0	5.5	0.0	0.0	2.0	0.0	2.0	0.0
EPISTOMINA TENUICOSTATA	49	2.0	3.0	1.5	1.5	0.0	3.0	0.0	1.5	0.0	1.0	0.0	0.0	2.0
EPISTOMINA ORNATA	11	1.5	.5	.5	2.5	0.0	2.5	2.5	0.0	0.0	3.0	0.0	1.0	1.5
NEOBULIMINA VARSOVIENSIS	64	1.5	0.0	1.5	0.0	0.0	0.0	0.0	2.5	0.0	3.5	0.0	1.0	1.0
CONORBOIDES HOFKERI	48	2.5	0.0	1.5	2.5	0.0	1.0	3.5	1.5	0.0	1.5	0.0	1.0	1.0
LENTICULINA SAXONICA	47	2.5	0.0	0.0	3.5	0.0	1.5	0.0	1.5	0.0	0.0	0.0	1.0	2.0
EVERTICYCLAMMINA VIRGULINIANA	9	2.0	.5	.5	2.5	0.0	3.0	3.0	5.0	0.0	1.5	0.0	0.0	0.0
PSEUDOCYCLAMMINA LITUUS	37	0.0	0.0	2.5	4.5	0.0	1.5	2.5	1.0	0.0	0.0	0.0	0.0	0.0
MARGINULOPSIS SIGALI	54	0.0	0.0	2.0	1.0	0.0	0.0	3.5	0.0	0.0	1.0	0.0	0.0	0.0
CONORBOIDES VALENDISENSIS	22	0.0	0.0	2.0	.5	0.0	0.0	.5	1.5	0.0	0.0	0.0	0.0	0.0
LENTICULINA GUTTATA	24	2.5	0.0	.5	2.0	0.0	1.5	0.0	2.5	0.0	0.0	0.0	0.0	0.0
AMMOBACULITES COPROLITHIFORMIS	80	4.5	1.0	0.0	2.0	0.0	1.0	0.0	.5	0.0	0.0	0.0	0.0	0.0
SEISMIC B	62	0.0	1.0	0.0	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
EPISTOMINA STELLICOSTATA	65	0.0	0.0	0.0	0.0	0.0	1.0	0.0	.5	0.0	.5	0.0	0.0	0.0
EPISTOMINA UHLIGHI	85	0.0	1.0	0.0	0.0	0.0	1.0	0.0	.5	1.0	1.0	0.0	0.0	0.0
EOGUTTULINA LIASSICA	74	.5	1.0	0.0	0.0	0.0	1.0	0.0	.5	1.0	1.0	0.0	0.0	0.0
EPISTOMINA MOSQUENSIS	82	.5	0.0	0.0	0.0	0.0	.5	0.0	.5	0.0	0.0	0.0	0.0	0.0
LENTICULINA QUENSTEDTI	90	0.0	0.0	0.0	0.0	0.0	.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Osangularia schloenbachi (Reuss)
Plate 2, figures 14, 15

REUSS 1862, p. 84, pl. 10, fig. 5.—CRITTENDEN 1983, p. 42, fig. 5.

Some specimens of *O. schloenbachi* show an umbilical or spiral boss. The presence of this boss and the larger inflated nature of the final chambers show some similarity to *Gavelinella intermedia, G. sigmoicosta* and *G. barremiana.* The nature of the aperture (distinct "V" or arcuate comma extending obliquely up the apertural face) and spiral/umbilical sutures enable determination of this *Osangularia* species.

Pseudocyclammina lituus (Yokohama)

YOKOHAMA 1890, p. 26, pl. 5, fig. 7.—JAFFREZO 1980, p. 396, pl. 26, fig. 2.

Spiroplectinata lata Grabert
Plate 1, figures 10, 11

GRABERT 1959, p. 16, pl. 1, fig. 9; pl. 2, figs. 31–35.—GRADSTEIN 1978b, p. 675, pl. 2, figs. 1–8.

See comments on *Gaudryina dividens.*

Textularia bettenstaedti (Bartenstein and Oertli)
Plate 1, figure 7

BARTENSTEIN and OERTLI 1977, p. 15, figs. 1–4.—BARTENSTEIN 1981, p. 310.

Trocholina infragranulata Noth
Plate 1, figures 15, 16

BARTENSTEIN, BETTENSTAEDT and KOVATCHEVA 1971, p. 148.—ASCOLI 1976, p. 754, pl. 7, fig. 4.

APPENDIX 4

NORMALITY TEST

HIBERNIA B-08

		CUM. DIST.	2ND ORDER DIFF.
ROTALIPORA TICINENSIS	29	1.8510	
ROTALIPORA CUSHMANI	24	.0989	3.4265 *
COARSE AGGLU SPP	36	1.7733	-2.9782 *
GAVELINOPSIS CENOMANICA	76	.4696	1.6995
GAVELINELLA AMMONOIDES	40	.8653	.7306
DOROTHIA GRADATA	111	1.9917	-1.0181
ARENOBULIMINA MACFADYENI	110	2.0999	-.8618
GAVELINELLA INTERMEDIA	35	1.3464	.5359
EPISTOMINA SPINULIFERA POLYPIOIDES	113	1.8743	1.2862
EPISTOMINA CRETOSA	8	2.9429	-.4032
GLOBOROTALITES APTIENSIS	42	3.6083	-1.0542
CONORBOIDES LAMPLUGHI	116	3.2196	.4608
EPISTOMINA CARPENTERI	79	3.2916	-.5145
EPISTOMINA SPINULIFERA SPINULIFERA	50	2.8491	.3577
TEXTULARIA BETTENSTADTI	115	2.7644	1.6062
CHOFFATELLA DECIPIENS	7	5.0313	-1.4603
TROCHOLINA INFRAGRANULATA	17	5.0924	-.8616
LENTICULINA HEIRMANI	135	4.2919	3.2014 *
LENTICULINA CREPIDULARIS	14	6.6928	-3.9775 **
EPISTOMINA CARACOLLA	13	5.8618	1.6697
LENTICULINA NODOSA	10	6.7006	-.0631
EPISTOMINA TENUICOSTATA	49	6.7307	-1.1281
EPISTOMINA HECHTI	12	6.3782	1.1159
EPISTOMINA ORNATA	11	7.1417	.6322
CONORBOIDES HOFKERI	48	7.7918	-1.4924
NEOBULIMINA VARSOVIENSIS	64	7.6951	1.0867
EVERTICYCLAMMINA VIRGULINIANA	9	7.9395	-.1687
CONORBOIDES VALENDISENSIS	22	8.7607	-1.3848
MARGINULOPSIS SIGALI	54	8.1971	.3157
LENTICULINA GUTTATA	124	8.9492	-.7771
PSEUDOCYCLAMMINA LITUUS	137	8.1786	1.1841
SEISMIC B	162	9.3376	-.4272
EPISTOMINA STELLICOSTATA	65	10.0695	.3533
EPISTOMINA UHLIGHI	85	11.1547	.0488
EPISTOMINA MOSQUENSIS	82	12.2887	

* -GREATER THAN 95% PROBABILITY THAT EVENT IS OUT OF POSITION
** -GREATER THAN 99% PROBABILITY THAT EVENT IS OUT OF POSITION

HIBERNIA P-15

		CUM. DIST.	2ND ORDER DIFF.
ROTALIPORA APPENINICA	5	.0658	
GAVELINOPSIS CENOMANICA	76	.4696	-.2830
ROTALIPORA GREENHORNENSIS	3	0.0000	.7445
GAVELINELLA AMMONOIDES	40	.8653	.2061
GAVELINELLA INTERMEDIA	35	1.3464	.0468
EPISTOMINA SPINULIFERA POLYPIOIDES	113	1.8743	.1044
OSANGULARIA SCHLOENBACHI	28	3.0969	-1.7488
PLANOMALINA BUXTORFI	27	2.5708	.3968
ROTALIPORA TICINENSIS	29	1.8510	1.2734
FALSOGAUDRYNELLA TEALBYENSIS	33	2.4047	-.9667
DOROTHIA GRADATA	111	1.9917	1.1857
TEXTULARIA BETTENSTADTI	115	2.7644	-1.4371
ARENOBULIMINA MACFADYENI	110	2.0999	1.7841
CONORBOIDES LAMPLUGHI	116	3.2196	-1.9777
LENTICULINA GAULTINA	15	2.3615	1.3771
GAUDRYINA DIVIDENS	37	2.8806	-1.1408
EPISTOMINA SPINULIFERA SPINULIFERA	50	2.8491	.8111
GLOBIGERINELLOIDES FERREOLENIS	118	3.0385	-.2850
EPISTOMINA CRETOSA	8	2.9429	-.2573
SPIROPLECTINATA LATA	51	3.1803	.8589
SEISMIC A	161	4.2767	-1.7359
AMMOBACULITES SUBCRETACEOUS	109	3.6371	.8844
EPISTOMINA CARPENTERI	79	3.2916	.5190
GAVELINELLA BARREMIANA	53	4.0553	.2122
CHOFFATELLA DECIPIENS	7	5.0313	.4449
EPISTOMINA CARACOLLA	13	5.8618	-2.1903
TROCHOLINA INFRAGRANULATA	17	5.0924	2.4077
EPISTOMINA TENUICOSTATA	49	6.7307	.0132
CONORBOIDES HOFKERI	48	7.7918	-2.4747
EPISTOMINA HECHTI	12	6.3782	2.2139 *
PSEUDOCYCLAMMINA LITUUS	137	8.1786	-3.4276 *
EPISTOMINA ORNATA	11	7.1417	2.4250
EVERTICYCLAMMINA VIRGULINIANA	9	7.9395	-1.1305
MARGINULOPSIS SIGALI	54	8.1971	-.6497
LENTICULINA SAXONICA	47	7.8050	1.9380
CONORBOIDES VALENDISENSIS	22	8.7607	-.9690
SEISMIC B	162	9.3376	-.7752
AMMOBACULITES COPROLITHIFORMIS	80	9.1394	-.0080
LENTICULINA GUTTATA	124	8.9492	1.3106
EPISTOMINA STELLICOSTATA	65	10.0695	-.0351
EPISTOMINA UHLIGHI	85	11.1547	.2228
LENTICULINA QUENSTEDTI	90	12.4626	

* -GREATER THAN 95% PROBABILITY THAT EVENT IS OUT OF POSITION
** -GREATER THAN 99% PROBABILITY THAT EVENT IS OUT OF POSITION

PLANKTONICS

Several important planktonic marker species were observed in the Cenomanian, Albian, and Aptian intervals of the wells. Most species in the Cenomanian are loosely referred to the genera *Rotalipora* in this study.

Rotalipora cushmani (Morrow)

MORROW 1934, p. 199, pl. 31, figs. 2–4.—WONDERS 1978, p. 135, pl. 4, figs. 1, 3, 4.

Rotalipora greenhornensis (Morrow)

MORROW 1934, p. 199, pl. 31, fig. 2.—WONDERS 1978, p. 133, pl. 3, figs. 1a–c, 2a–c.

Rotalipora appeninica (O. Renz)

O. RENZ 1936, p. 14, fig. 2.—WONDERS 1978, p. 130, pl. 1, figs. 5–6.

Rotalipora ticinensis (Gandolfi)

GANDOLFI 1942, p. 113, pl. 2, fig. 3; pl. 4, figs. 10, 11.—WONDERS 1978, p. 128, pl. 1, figs. 3–4.

Planomalina buxtorfi (Gandolfi)

GANDOLFI 1942, p. 103, pl. 3, fig. 7; pl. 5, figs. 3–6.—LONGORIA 1974, p. 92, pl. 8, fig. 16; pl. 25, fig. 10.

Hedbergella infracretacea (Glaessner)

GLAESSNER 1937, p. 28, text-fig. 1.—LONGORIA 1974, pp. 59–60, pl. 11, figs. 4–6; pl. 27, figs. 1–7.—PRICE 1977b, p. 519, pl. 61, figs. 7–9.

Globigerina hoterivica Subbotina

LONGORIA 1974, p. 49, pl. 11, figs. 9–11, 14–16.—PFLAUMANN and KRASHENINNIKOV 1978, p. 546 (not figured).

Globigerinelloides ferreolensis (Moullade)

MOULLADE 1961, p. 14, pl. 1, figs. 1–5.—LONGORIA 1974, p. 84, pl. 5, figs. 7–8; pl. 8, figs. 1–3, 8–15.—PFLAUMANN and KRASHENINNIKOV 1978, p. 548, pl. 3, figs. 1a–c.

Globigerinelloides gyroidinaeformis Moullade
Plate 1, figure 23

MOULLADE 1966, p. 128, pl. 9, figs. 16–22.—PLFAUMANN and KRASHENINNIKOV 1978, p. 548, pl. 1, figs. 13–15.

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