

Preservation potential of salt marsh foraminifera from the Fraser River delta, British Columbia

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ABSTRACT: Three biofacies were recognized in samples collected at a depth of 10cm along three transects from the marshes of the Fraser River delta, British Columbia. These biofacies, defined by comparison with those previously identified from surface marsh samples, correspond to three elevational zones: the High Marsh Zone, characterized by the *Jadammina macrescens* biofacies; the Lower High Marsh Zone, characterized by the *Ammonia beccarii* biofacies; and the Low Marsh Zone, characterized by the *Miliammina fusca* biofacies. A dramatic decrease in the abundance of *Ammonia beccarii* at 10cm depth suggests that the calcareous tests of this species are poorly preserved in the low pH subsurface sediments. As a result, the *Ammonia beccarii* biofacies will no longer be recognizable after extended burial. Although fewer biofacies can be resolved from paleommarshes of the Fraser delta than at the surface, it is still possible to differentiate between a High Marsh fauna (>+0.94m above mean sea level) and a Low Marsh fauna (<+0.94m above mean sea level).

INTRODUCTION

The Fraser River delta is located in the most seismically active region of Canada. Its position on the Cascadia Fault has led to increased concern over the effects that an earthquake would have on metropolitan Vancouver, built entirely on the delta plain. Coastal British Columbia has not, in modern times, experienced a major earthquake like those recorded in Alaska (1964) and Chile (1960). However, in recent years, mounting evidence of a potential megathrust earthquake in the region has focused increased attention on the seismic risk (Koppel 1989).

In the past, it has not been possible to assess seismic risk because of incomplete information on the depositional history of the region (Roberts et al. 1985). Recent studies on the foraminiferal distribution in marshes and within drill cores have improved interpretations of the physiography and depositional history of the delta (Patterson 1990; Patterson and Cameron 1991; Williams 1989). Marsh foraminifera, in particular, lend themselves to the paleoenvironmental assessment of delta sediments as their zones are useful in determining paleosea levels (Scott and Medioli 1978, 1980a, b).

This research is a continuation of a baseline study on the modern distribution and paleoecological importance of intertidal benthic foraminifera from the Fraser River delta (Patterson 1990). The objective of this investigation is to identify subsurface marsh foraminiferal biofacies at 10cm depth and to interpret them by comparison with foraminiferal biofacies identified at the surface. The information will provide an assessment of the preservation potential of marsh foraminiferal faunas down core. When applied to foraminiferal bearing sediments within the delta, results of the present study will provide data useful in evaluating tectonic movements and relative sea-level changes in the delta (Clague and Bobrowsky 1990). This information, in turn, may be invaluable in assessing potential seismic risk in the Fraser delta region.

Description of the Study Area

The Fraser River is the largest river emptying into the Pacific Ocean on the west coast of Canada. It drains an area of over 230,000km² and has formed a large delta protruding into the Strait of Georgia (text-fig. 1). The delta, with a perimeter of 48km on the Pacific Ocean, is influenced by saline conditions of the Strait of Georgia

and freshwater discharge and sediment load of the Fraser River (Hutchinson 1982).

The study area consists of the marshes on Sturgeon Bank and Roberts Bank, located on the active western delta-front of the Fraser River. The western delta-front extends south for 37km and faces the Strait of Georgia. The salt-marshes on both Sturgeon Bank and Roberts Bank lie near high tide level in a narrow, flat to hummocky, vegetated zone underlain by muddy sediments (Luternauer and Murray 1973).

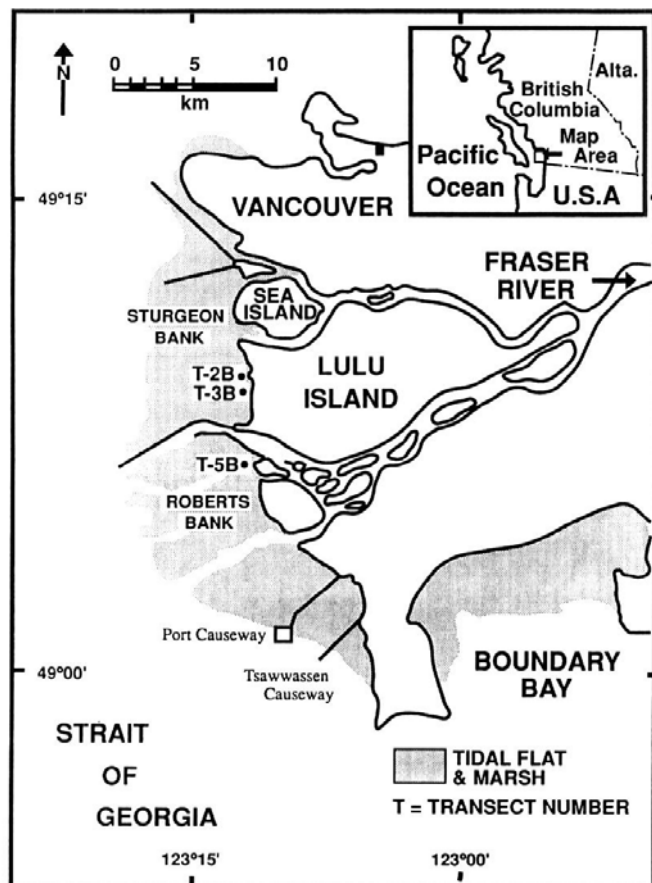
The marsh can be subdivided into three elevational zones based on a succession in the vegetational patterns (Hutchinson 1982). The low marsh is dominated by *Scirpus americanus* and *S. maritimus*. The middle marsh is dominated by *Carex lyngbyei*, *Triglochin maritimum*, and *S. maritimus*. The high marsh zone consists of a community of *Agrostis exarata*, *Potentilla pacifica*, *Distichlis spicata*, and *Typha latifolia* (Hutchinson 1982).

The Fraser River delta has been accreting at a rapid rate in the last few years. Local variation in accretion in the marsh is controlled by the distance to the sediment sources, elevation, man-made structures, vegetation and the feeding activities of waterfowl, such as Lesser snow geese (Hutchinson 1990). In high marsh areas, sedimentation rates are higher where *Typha latifolia* is common, while low rates of sedimentation occur where *Carex lyngbyei* is common. High rates of sedimentation also occur in mid-marsh where *Scirpus meridionus* is the most common plant species.

The delta has prograded an estimated 68 to 100m in the time required to deposit 10cm of marsh sediment. The marsh itself has prograded approximately 5m per year (Hutchinson 1990); however, progradation of the upper marsh may be affected by the compaction of the clays and peat in the marsh sediments.

Previous Work

Little previous work has been done to determine the distribution of foraminifera on the Fraser delta. Cockbain (1963) studied recent foraminiferal distributions in the Strait of Georgia, including a few samples from pro-delta deposits at depths ranging from 112 to 293m. Phleger (1967) described the foraminifera in 13 samples



TEXT-FIGURE 1
Locality map of Fraser delta showing the general positions of Transects 2, 3 and 5. Exact locations of samples used in this analysis are given in Table 1.

collected from the marshes of Sea Island and Smokey Tom Island in the delta.

More recently, Williams (1989) defined three elevational zones based on foraminiferal species from 24 samples on the tidal flats and delta foreslope off Lulu Island. In his examination of drill-core samples, Williams found low numbers of foraminiferal tests preserved in the subsurface sediments of the delta.

Patterson (1990) conducted a comprehensive study of the Fraser River delta's marshes and tidal flats, defining six foraminiferal biofacies associated with elevation, substrate and vegetation patterns. A complete list of the work done on marsh foraminiferal distributions of the west coast of North America is presented in Patterson (1990).

METHODS AND MATERIALS

Twenty-seven samples were taken along three transects in the marshes on Sturgeon Bank and Roberts Bank (text-fig. 1). Transects 2 and 3 were located in the marsh adjacent to Sturgeon Bank near the terminus of Blundell Road. Transect 5 was adjacent to the north end of Westham Island on Roberts Bank. The locations and vegetational characteristics of each sample are summarized in table 1.

Samples from a depth of 10cm were collected at the same time and from the same stations (table 1) as the set of surface samples

TABLE 1

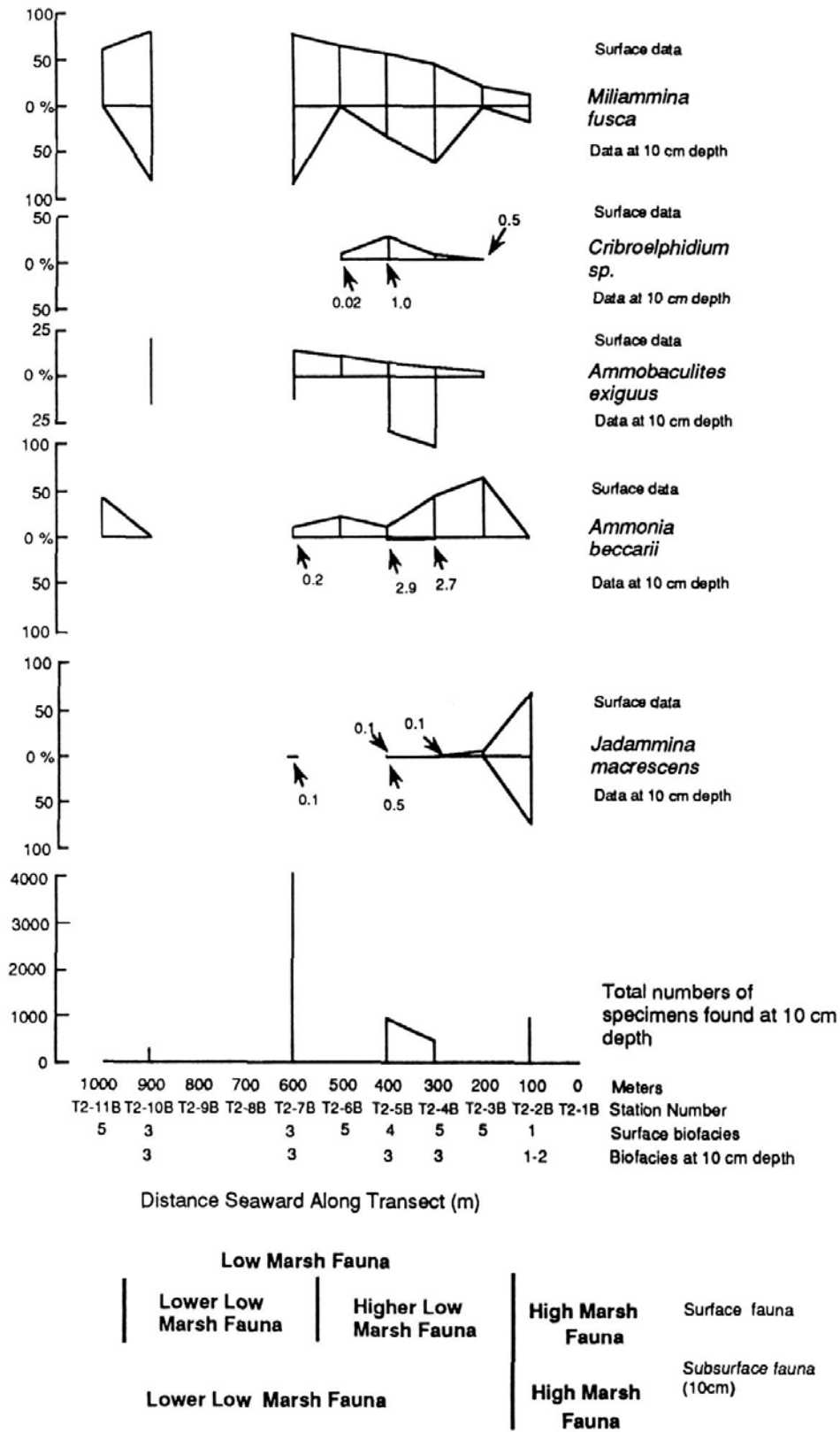
Latitude and longitude of sample stations in the marshes of Sturgeon Bank and Roberts Bank. Species names for the floral symbols listed with each station are as follows: AGAL (*Agrostis alba*); CALY (*Carex lyngbyei*); DISP (*Distichlis spicata*); JUBA (*Juncus balticus*); POPA (*Potentilla pacifica*); SCVA (*Scirpus validus*); SCAM (*Scirpus americanus*); SCMA (*Scirpus maritimus*); TRMA (*Triglochin maritimum*); TYLA (*Typha latifolia*); (*) signifies dominant floral species at each station.

Sample Number	Latitude	Longitude	Vegetation
T2-2	100m due west of 49° 09.35'	123° 11.70'	*SCAM;*TYLA
T2-4	300m due west		*SCMA;SCAM
T2-5	400m due west		*SCMA;SCAM
T2-7	600m due west		*SCMA;SCAM
T2-10	900m due west		*SCAM
T3-1	49° 12.60'	123° 12.60'	*SCAM
T3-2	100m due east		*SCAM
T3-3	200m due east		*SCMA;SCAM
T3-4	300m due east		*SCMA;SCAM
T3-5	400m due east		*SCMA;SCAM
T3-6	500m due east		*SCMA;SCAM
T3-7	600m due east		*SCMA;SCAM
T3-8	700m due east		*SCMA;SCAM
T3-9	800m due east		*CALY;*DISP; TRMA; POPA; AGAL
T3-10	900m due east		*CALY;*DISP; TRMA; *POPA; AGAL
T3-11	1000m due east		*CALY;*DISP; TRMA; *POPA; AGAL TYLA
T5-1	49° 06.35'		*TYLA
T5-2	100m west		*SCVA; CALY
T5-3	200m west		*SCVA; CALY
T5-4	300m west		*CALY;*JUBA; SCVA
T5-5	400m west		*CALY;*JUBA; SCVA
T5-6	500m west		*CALY;*JUBA; SCVA
T5-9	800m west		*JUBA
T5-10	900m west		*JUBA
T5-11	1000m west		*CALY;TRMA
T5-12	1100m west		*SCAM;*SCVA

described in Patterson (1990). Collection methods were similar to those described by Scott and Medioli (1980a). Using a small stainless steel tube, 10cm cores were collected. The bottom 1cm was sliced off to obtain subsurface samples and the top 1cm was removed to obtain surface samples. The diameter of the tube was 2.67cm, so each subsample was 10 cc. The foraminiferal makeup of the surface samples has already been described (Patterson 1990).

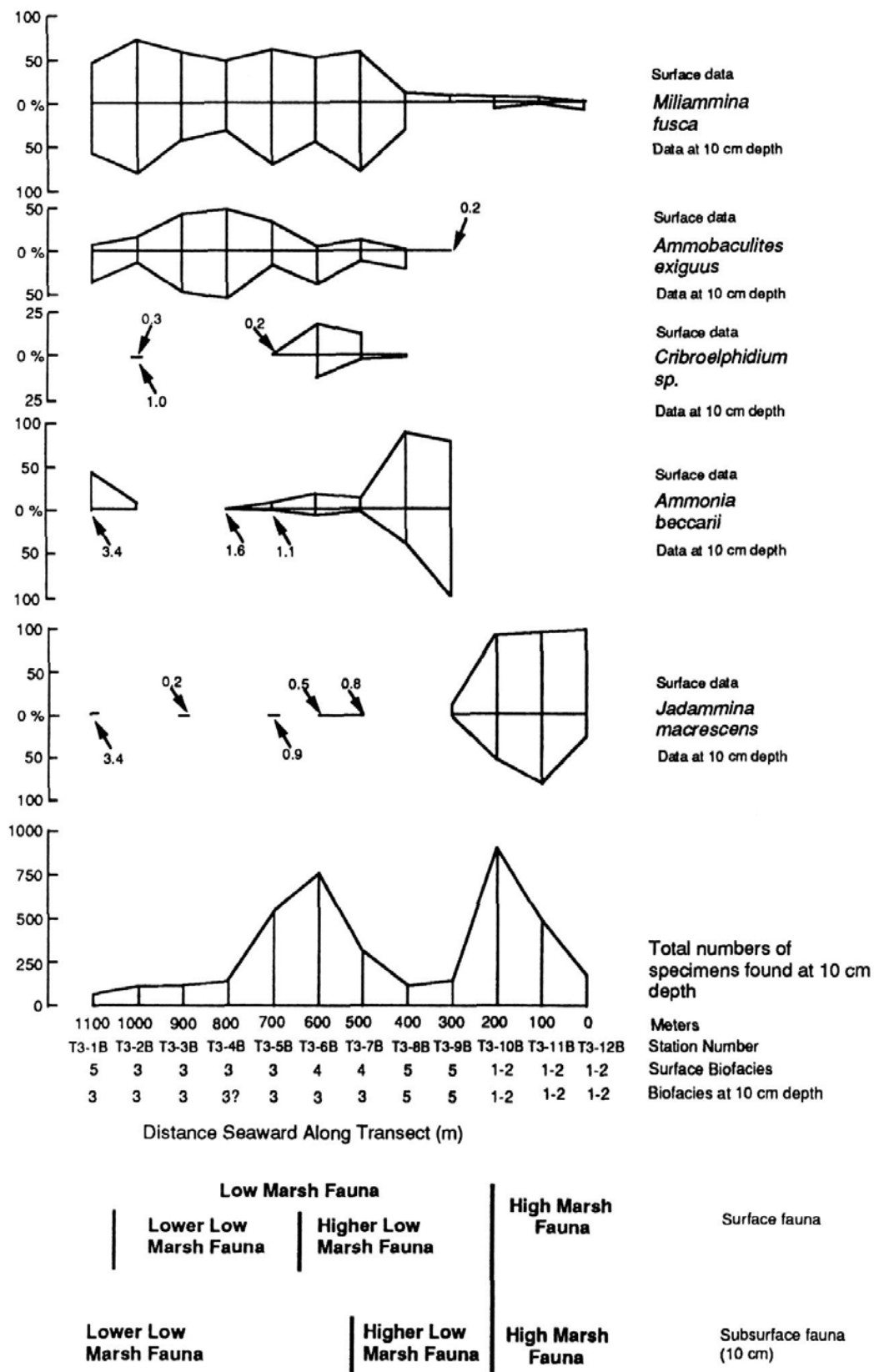
In the previous study (Patterson 1990), the approximate elevation of each sampling location was obtained from topographic maps of the tidal flats and marshes (Swan Wooster Engineering, Ltd. 1967). Salinity was not measured due to technical difficulties, and temperature was not measured because the marsh environment mirrors diurnal variations in the atmosphere, making these measurements meaningless (Scott and Medioli 1980a).

The subsurface samples were boiled with soda ash to cleanse the foraminiferal tests. Samples were then wet sieved using 0.5mm screens (35 Tyler equivalent) to remove the coarse organic matter and 0.063mm screens (230 Tyler equivalent) to retain the foraminifera. Samples immersed in water were examined under a binocular microscope. Water immersion facilitates the identification of specimens, as the abundant organic matter found in marsh samples will stick to the foraminiferal tests if the samples are dried. All subsurface samples contained foraminifera. The relative frequencies of each species and the fractional error of the results were



TEXT-FIGURE 2

Relative fractional abundance and total foraminiferal populations along Transect 2, collected in cores from the marsh flanking Sturgeon Bank on the Fraser River delta. The foraminiferal biofacies and zones are indicated for the surface and subsurface samples at each station.



TEXT-FIGURE 3
Relative fractional abundance and total foraminiferal populations along Transect 3, collected in cores from the marsh flanking Sturgeon Bank on the Fraser River delta. The foraminiferal biofacies and zones are indicated for the surface and subsurface samples at each station.

TABLE 2

Per cent occurrences of foraminiferal species in the subsurface from the Fraser River delta station. The "% uncertainty" was calculated for each species. The surface biofacies and the subsurface biofacies for each sample is also shown.

Sample	T2-2B	T2-4B	T2-5B	T2-7B	T2-10B	T3-1B	T3-2B	T3-3B	T3-4B	T3-5B	T3-6B	T3-7B	T3-8B	T3-9B	T3-10B	T3-11B	T3-12B	T5-1B	T5-2B	T5-3B	T5-4B	T5-5B	T5-6B	T5-8B	T5-10B	T5-11B	T5-12B	
Biofacies at 10 cm	1&2	3	3	3	3	3	3	3	3	3	3	3	3	3	5	5	1&2	1&2	1&2	1&2	1&2	5	5	5	3	3	3	
Surface Biofacies	1	5	4	3	3	5	3	3	3	3	4	4	5	5	2	1	1	1	1	5	5	?	5	5	5	5	5	
No. of Species	7	3	7	10	4	5	5	4	5	5	5	6	5	2	5	4	6	4	4	4	6	5	3	3	3	3	4	
Total Individuals	974	451	987	4092	236	59	102	106	132	545	751	294	111	140	895	476	176	1669	125	96	488	914	389	401	237	95	40	
<i>A. beccarii</i> %	-	2	2.4	0.2	-	1.7	-	-	0.8	0.7	6.4	2	40.5	98.6	-	-	-	-	0.8	13.5	29.6	98.2	95.9	0.5	10.5	-	-	
% Uncertainty ±	-	0.7	0.5	-	-	1.7	-	-	0.8	0.4	0.9	0.8	4.7	1	-	-	-	-	0.8	3.5	2.1	0.4	1	0.4	2	-	-	
<i>Criboelphidium</i> sp. %	-	-	0.7	0.02	-	-	1	-	-	12.9	2	0.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
% Uncertainty ±	-	-	0.3	-	-	-	1	-	-	1.2	0.8	0.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<i>J. macrescens</i> %	73.4	-	0.5	0.1	-	1.7	-	-	-	0.6	-	-	-	1.4	53.2	80.7	26.1	95.3	88.8	49	15.2	0.5	2.1	-	0.4	-	-	
% Uncertainty ±	1.4	-	0.2	-	-	1.7	-	-	-	0.3	-	-	-	1	1.7	1.8	3.3	0.5	2.8	5.1	1.6	0.2	0.7	-	0.4	-	-	
<i>M. fusca</i> %	17.5	61	34	82.6	79.7	57.6	82.4	43.4	32.8	71.6	43.5	78.8	31.5	-	6.9	0.8	8	4.3	-	12.5	51.8	0.2	-	98	84	94.7	87.5	
% Uncertainty ±	1.2	2.3	1.5	0.6	2.6	6.4	3.8	4.8	4.1	1.9	1.2	2.4	4.4	-	0.8	0.4	2	0.5	-	3.4	2.3	0.1	-	0.7	2.4	2.3	5.2	
<i>T. inflata</i> %	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	2.7	-	45.4	-	-	-	-	-	-	-	-	-	-	
% Uncertainty ±	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	0.5	-	3.8	-	-	-	-	-	-	-	-	-	-	
<i>A. exiguus</i> %	-	37	29.5	11.5	14	37.3	13.7	48.1	53.8	15.2	37	12.9	21.6	-	-	-	-	-	-	-	-	-	1.4	0.1	-	1.5	1.7	2.1
% Uncertainty ±	-	2.3	1.5	0.5	2.3	6.3	3.4	4.9	4.3	1.5	1.8	2	3.9	-	-	-	-	-	-	-	-	-	0.5	0.1	-	0.6	0.8	1.5
<i>A. salsum</i> %	0.3	-	22.3	3.4	1.7	-	2	4.7	6.8	3.1	0.1	2.7	5.4	-	-	-	-	-	-	-	-	-	0.8	-	-	-	-	
% Uncertainty ±	0.05	-	1.3	0.3	0.8	-	1.4	2.1	2.2	0.7	0.1	0.9	2.1	-	-	-	-	-	-	-	-	0.4	-	-	-	-	-	
<i>H. manilaensis</i> %	7	-	-	0.04	-	-	-	-	-	-	-	-	-	-	25.6	0.6	8	0.1	2.4	-	-	-	-	-	-	-	-	
% Uncertainty ±	0.8	-	-	-	-	-	-	-	-	-	-	-	-	-	1.5	0.4	2	0.1	1.4	-	-	-	-	-	-	-	-	
<i>P. limnetis</i> %	1.6	-	0.1	0.2	-	-	-	-	-	-	-	-	-	-	10.6	17.9	11.9	0.3	8	25	1.2	0.9	2.1	-	-	-	-	
% Uncertainty ±	0.4	-	0.1	-	-	-	-	-	-	-	-	-	-	-	1	1.8	2.4	0.1	2.4	4.4	0.5	0.3	0.7	-	-	-	-	
<i>Reophax</i> sp. %	0.1	-	11	1.8	4.7	1.7	-	3.8	6.1	8.8	-	1.7	-	-	-	-	-	-	-	-	-	-	-	-	3	3.2	5	
% Uncertainty ±	0.1	-	1	0.2	1.4	1.7	-	1.9	2.1	1.2	-	0.8	-	-	-	-	-	-	-	-	-	-	-	-	1.1	1.8	3.4	
<i>E. vitrea</i>	-	-	-	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<i>I. islandica</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.6	-	-	-	-	-	-	-	-	-	-	
<i>N. stella</i>	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<i>G. quinqueloba</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4	-	

recorded (table 2) to determine the statistical significance of the foraminiferal associations (Patterson and Fishbein 1989).

Selected specimens were mounted on a plug, coated with gold and examined using a scanning electron microscope. Micrographs were taken with a Cambridge Instruments S-200 Scanning Electron Microscope using Polaroid (NP) type 53 film in the Electron Microbeam Laboratory at the Geological Survey of Canada.

RESULTS

Foraminiferal Distribution

The 27 subsurface samples from Transects 2, 3 and 5 (text-fig. 1), yield 14 species of benthic and planktic foraminifera. The planktic and some benthic species, such as *Islandiella islandica* (Nørvang) 1945 and *Epistominella vitrea* Parker 1953, are allochthonous. These species, common on the west coast continental shelf but not found living in marshes, were washed onto the delta during intense storms.

Patterson (1990) recognized five foraminiferal biofacies in surface samples from Transects 2, 3 and 5. Surface biofacies boundaries were defined by results of a Q-mode cluster analysis of the relative abundance of the five most numerous species: *Ammonia beccarii* (Linné) 1758; *Criboelphidium* sp. (identified as *Criboelphidium gunteri* Cole 1931, in Patterson 1990); *Jadammina macrescens* (Brady) 1870; *Miliammina fusca* (Brady) 1870; and *Trochammina inflata* (Montagu) 1808. A summary is presented in table 3.

In the first study, Biofacies 2 clustered very closely with Biofacies 1 (Patterson 1990). In a subsequent re-examination of the data using a newly developed "Error Weighted Maximum Likelihood" clustering method, Fishbein and Patterson (in press) concluded that there is no statistically recognizable difference between Biofacies 1 and 2. The interchange of some samples bearing Biofacies 1 and Biofacies 2 faunas between the surface and the subsurface is therefore not considered significant. Henceforth, in this study, the two are combined as Biofacies 1-2.

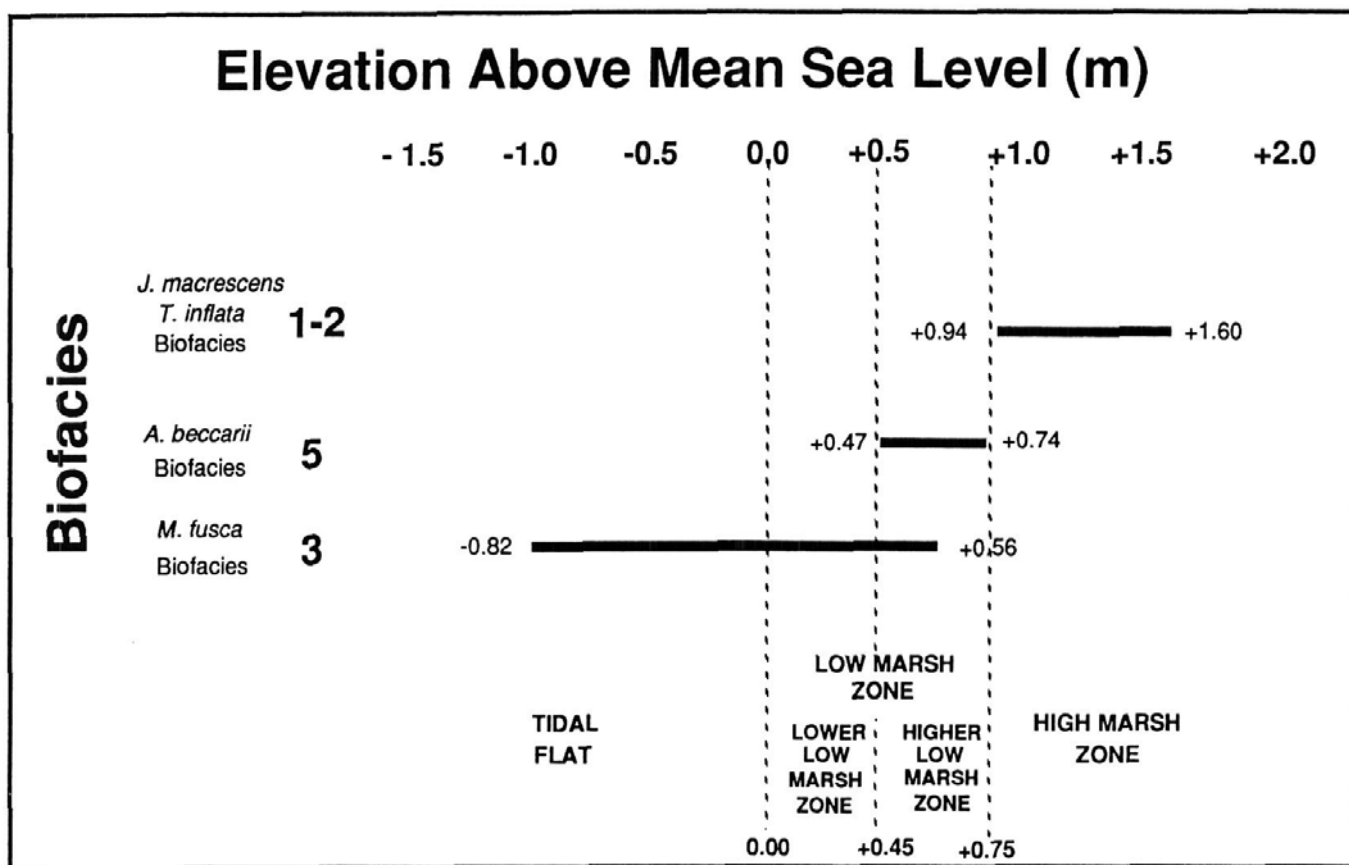
Subsurface biofacies were defined (table 2) by comparison with the ranges of observed percent occurrence of principle species that characterize each surface biofacies (table). Three biofacies occur in the samples at 10cm depth: 1-2, the *Jadammina macrescens-Trochammina inflata* biofacies; 3, the *Miliammina fusca* biofacies; and 5, the *Ammonia beccarii* biofacies. Biofacies 4, named for

Criboelphidium sp., does not occur at 10cm depth due to a dramatic decrease in the abundance of this species in the subsurface samples. This is especially apparent in Transects 2 and 3 (table 2; text-figs. 2, 3).

Biofacies 1-2 occurs in surface and subsurface samples at stations T2-2, T3-10, T3-11, T3-12, T5-1 and T5-2 (table 2). Biofacies 1-2 is also present in sample T5-3B (Biofacies 5 occurs in the surface sample at T5-3A). In the surface samples, Biofacies 1-2 occurs in high marsh areas, where elevations range from +0.94 to +1.60m a.m.s.l. (text-fig. 4). Biofacies 1-2 is defined by the great abundance of the species *Jadammina macrescens*, ranging from 26.6 to 100.0% of the foraminiferal association, as well as 0.0 to 64.5% *Trochammina inflata* (table 3; text-fig. 2).

Biofacies 3 is dominated by the species *Miliammina fusca*, which comprises 34.0 to 99.5% of the foraminiferal specimens identified in the samples (table 3). This biofacies dominates the low marsh areas found along the seaward edge of the transects. Elevations of the subsurface samples range from -0.82 to +0.56m a.m.s.l. (text-fig. 4). These elevations include subsurface samples from all three transects: T2-4B to T2-10B, T3-1B to T3-7B and T5-9B to T5-12B. Surface samples from many of these stations are referable to other biofacies. Samples T2-4A, T3-6A and T3-7A are referable to Biofacies 5, while samples T2-5A, T3-1A and T5-9A to T5-12A are all referable to Biofacies 4. The remainder of the stations are all referable to Biofacies 3 in both the surface and the subsurface. This biofacies also contained significant numbers of *Ammotium salsum* (Cushman and Brönniman) 1948b and *Ammobaculites exiguus* Cushman and Brönniman 1948a. *Reophax nana* Rumbler 1911 also occurs in some samples (table 2).

Biofacies 4, characterized by moderate abundances of *Criboelphidium* sp., is not represented in any sample at 10cm depth, even though three surface samples, T2-5A, T3-6A and T3-7A, are referable to this biofacies. Elevations of these surface samples range from +0.47 to +0.55m a.m.s.l. (Patterson 1990), which is a slightly higher elevation than for Biofacies 3 in the surface samples. However, the foraminiferal associations of the subsurface samples from these same stations are referable to *Miliammina fusca* biofacies (3). Therefore, in the subsurface, the three samples are incorporated in the elevational range for Biofacies 3 (text-fig. 4). T2-5B also contains a significant number of *Reophax nana* (table 2).



TEXT-FIGURE 4

Ranges for elevation above mean sea level recorded for subsurface sampling localities for each biofacies from Sturgeon Bank and Roberts Bank. The vegetational zones are also indicated.

Biofacies 5 is characterized by relative abundances of *Ammonia beccarii* ranging between 14.6 and 98.5% (table 3). It is represented by samples found in the higher low marsh zone (text-fig. 4). Samples referable to Biofacies 5 (table 2; text-figs. 3, 5) occur in the subsurface only in Transect 3 of Sturgeon Bank (in both surface and subsurface sediments at stations T3-8 and T3-9), and in Transect 5 of Roberts Bank (in both surface and subsurface sediments at stations T5-4, T5-5 and T5-6). Although many surface samples collected from stations along Transect 2 are referable to Biofacies 5, no subsurface samples are referable to this biofacies (table 2; text-fig. 2).

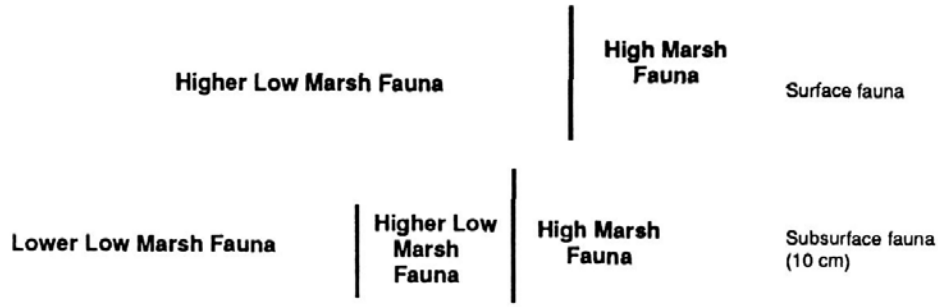
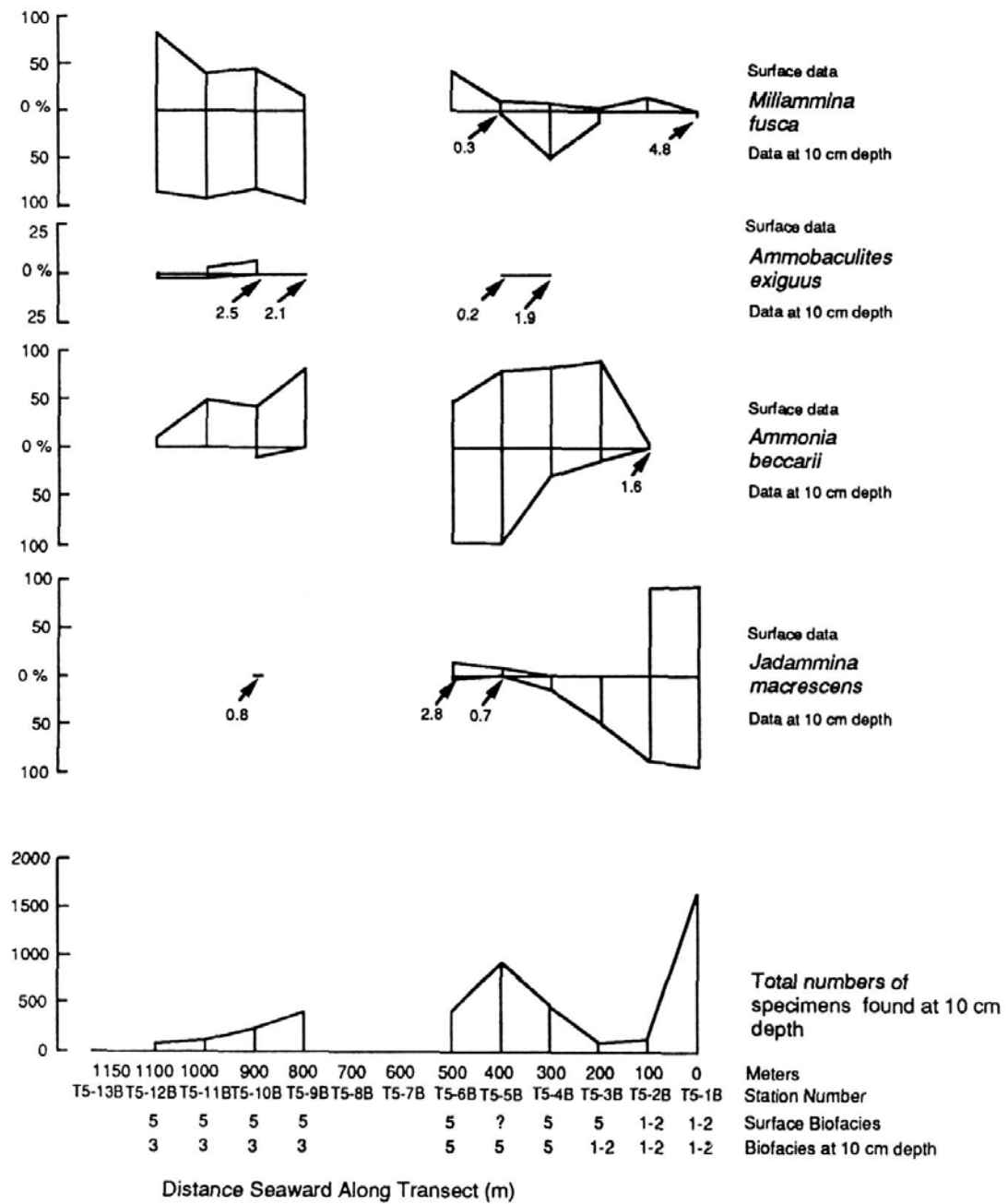
DISCUSSION

Certain well-defined foraminiferal assemblages characterize specific elevations within the salt-marsh vertical range (Scott and Medioli 1978). The composition of the assemblage is also dependent on other facts including salinity. The effects of salinity variations are much more pronounced where there is considerable mixing with fresh water. Patterson (1990) divided the surface marsh zones of the Fraser delta into a High Marsh Zone and a Low Marsh Zone using benthic foraminiferal assemblages. The latter was subdivided into a Higher Low Marsh Zone and a Lower Low Marsh Zone. These zones are also represented in the subsurface biofacies, but any comparison between surface and subsurface samples must take the rate of delta progradation into consideration. However, over 900 to 1100m (the length of the transects) with a 100m sampling interval, the "progradation effect" has a negligible influ-

ence on the biofacies succession at each station in the marsh. Based on this evidence, the elevations observed for each sampling station from the surface samples are broadly applicable to the subsurface samples collected.

Based on an average rate of accretion of 18mm per year (from 1984-1988) in the marshes of the Fraser River delta, Hutchinson (1990) estimated that 10cm of marsh sediment, the depth at which samples from this study were collected, can accumulate in as little as 6-10 years. However, it could take as long as 20 to 50 years for 10cm to accumulate in areas of the marsh characterized by the slowest accretion rate (2mm per year). These rates of accretion give a reasonable estimate as to the probable age range of the sediments examined.

Agglutinated foraminifera are the most widespread marsh species due to their resistance to dissolution in the low pH conditions common to most marshes (Phleger 1966; Bradshaw 1968). They are the most common forms at 10cm depth and thus are preserved in the subsurface sediments in abundance (Goldstein 1988). Living specimens of *Ammobaculites exiguus* at depths of 5 and 10cm in Hommocks salt-marsh in New York (Steineck and Bergstein 1979) indicate in the proportion of *Reophax nana* in the subsurface on the Fraser delta may indicate its preference for an infaunal habitat. Unfortunately, samples examined for this study were not stained with the protoplasm indicator Rose Bengal, so the paleoecological



TEXT-FIGURE 5
 Relative fractional abundance and total foraminiferal populations along Transect 5, collected in cores from the marsh flanking Roberts Bank on the Fraser River delta. The foraminiferal biofacies and zones are indicated for the surface and subsurface samples at each station.

TABLE 3

Ranges of observed per cent occurrence of principle species within each biofacies from the surface data (Patterson 1990), which was used to infer the biofacies of the core samples.

SPECIES	BIOFACIES 1-2 J. macrescens and T. inflata Biofacies	BIOFACIES 3 M. fusca Biofacies	BIOFACIES 4 Cribroelphidium sp. Biofacies	BIOFACIES 5 A. beccarii Biofacies
A. beccarii	0.0 to 3.6%	0.0 to 12.5%	9.2 to 16.8%	14.6 to 98.5%
Cribroelphidium sp.	0.0 to 7.6%	0.0 to 0.5%	14.6 to 22.8%	0.0 to 3.7%
J. macrescens	26.6 to 100.0%	0.0 to 1.0%	0.0 to 0.85%	0.0 to 9.4%
M. fusca	0.0 to 15.4%	34.0 to 99.5%	52.8 to 61.1%	0.9 to 82.9%
T. inflata	0.0 to 64.5%	-	0.0 to 0.2%	0.0 to 13.8%

significance of the increase downcore of this species cannot be determined.

Biofacies 1-2, numerically dominated by *Jadammina macrescens* with *Trochammina inflata*, characterizes a High Marsh fauna (Patterson 1990). Although numbers have decreased slightly in the subsurface samples, these faunas are well represented at 10cm depth. However, many *Jadammina macrescens* tests are damaged and have begun to show some effects of breakdown at this depth.

Biofacies 3, predominated by *Miliammina fusca*, is the dominant Low Marsh assemblage in both surface and subsurface sediments. At 10cm depth, it is found up to +0.56m a.m.s.l., and corresponds to some sample stations referable to Biofacies 5 from the surface and all surface samples belonging to Biofacies 4, typified by moderate abundances of *Cribroelphidium* sp. (text-fig. 3). The tests of *Miliammina fusca*, although fragile, are mostly undamaged.

Most of the agglutinating species found in the surface biofacies of the Fraser River delta also occur at 10cm depth. The decrease in their numbers down core implies a poor preservation of foraminiferal tests, and perhaps less hospitable conditions than those of the surface for living foraminiferids (Steineck and Bergstein 1979).

Although calcareous foraminifera, such as *Ammonia beccarii* and *Cribroelphidium* sp., may be present in the surface assemblages of marshes, they are much less commonly preserved in the sediments (Parker and Athearn 1959; Murray 1971, 1973; Williams 1989). Scott and Medioli (1980a, b) reported that calcareous specimens make up a small proportion of assemblages in eastern Canadian marshes because the tests dissolved soon after death in the low pH marsh sediments. Calcareous specimens are rapidly destroyed after death, presumably due either to the ability of the living form to resist acidity or, more likely, to a postulated increase in acidity immediately below the sediment surface (Parker and Athearn 1959). During laboratory experiments examining the effects of lower pH on foraminiferal tests, Murray (1967) observed that calcareous tests first became opaque, then, in a matter of hours, were weakened and etched, even if complete dissolution did not occur.

The marked decrease in numbers of preserved calcareous tests indicates rapid dissolution in the subsurface marshes of the Fraser delta. As a result, the elevational range of Biofacies 5, characterized

by *Ammonia beccarii*, is reduced in the subsurface (text-fig. 4), although the remaining tests of *Ammonia beccarii* are well preserved. Commonly, the proportion of *Miliammina fusca* is much higher in subsurface samples at these locations compared to the surface assemblages, resulting in the samples being assigned to Biofacies 3. Williams (1989) also found fewer calcareous specimens in marsh cores and attributed the poor preservation in the low energy marsh area to percolation of acidic groundwater.

The rapid rate of dissolution of calcareous tests seen in modern marshes means that "ancient" marsh sediments in the sedimentary column from this area are not likely to contain calcareous species. Consequently, the number of biofacies will probably become reduced from five or six (Patterson 1990) at the surface to two at depth. In fact, Guilbault (pers. comm.) has recognized only two biofacies in core samples ranging from depths of 87cm to 487cm, from southern Vancouver and the Fraser delta region (unpublished data). These are the *Miliammina fusca* biofacies and the *Jadammina macrescens* biofacies. He found virtually no calcareous species in his samples.

At the surface, the marsh can be resolved into four elevational zones on the basis of benthic foraminiferal assemblages; the Higher High Marsh Zone, the Lower High Marsh Zone, the Higher Low Marsh Zone and the Lower Low Marsh Zone. The reduced preservation and consequent loss of biofacies at depth reduces resolution of paleomorph elevation to two zones: Biofacies 1-2 typifies the High Marsh Zone and Biofacies 3 indicates the Low Marsh Zone. Based on comparisons with surface foraminiferal distributions, the lower limit of the High Marsh Zone is +0.94m a.m.s.l., as evidenced by the presence of the *Jadammina macrescens* - *Trochammina inflata* biofacies. The *Miliammina fusca* biofacies characterizes elevations lower in the marsh. Therefore, despite the reduction of elevation-based biofacies down core, it is still possible to interpret fossil marshes from the region in terms of those present today.

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FAUNAL LIST

Order Foraminiferida Eichwald 1830

Ammobaculites exiguus Cushman and Brönniman

Plate 1, figure 1

Ammobaculites exiguus CUSHMAN and BRÖNNIMAN 1948a, p. 38, pl. 7, figs. 7, 8.

Ammonia beccarii (Linné)

Plate 2, figures 7-9

Nautilus beccarii LINNÉ 1758, p. 710, pl. 1, figs. 1c-a.

Ammotium salsum (Cushman and Brönniman)

Plate 1, figure 2

Ammobaculites salsus CUSHMAN and BRÖNNIMANN 1948b, p. 16, pl. 3, figs. 7-9.

Criboelphidium sp.

Plate 2, figures 5, 6

Criboelphidium gunteri (Cole) PATTERSON 1990, pl. 2, figs. 1, 2, (not *Elphidium gunteri* Cole 1931).

Elphidium gunteri (Cole) KNUDSEN in Feyling-Hanssen, Jørgensen, Knudsen and Anderson (eds.) 1971, p. 277, pl. 12, figs. 9, 10; pl. 21, figs. 4-7, (not *Elphidium gunteri* Cole 1931).

Remarks: In recent literature this species has frequently been referred to *Elphidium gunteri* Cole, which it superficially resembles. However, the present species differs from *E. gunteri* in the number of chambers in the final volution, having 10 not 14, and in the presence of raised supplementary multiple areal apertures (generally six) found on the apertural face. In addition, *E. gunteri* is described from shallow marine environments of the Pliocene of Florida, a significantly different environment from a salt marsh.

Epistominella vitrea Parker

Epistominella vitrea PARKER in Parker, Phleger and Peirson 1953, p. 9, pl. 4, figs. 34-36, 40, 41.

Globigerina quinqueloba Natland

Globigerina quinqueloba NATLAND 1938, p. 149, pl. 6, figs. 7a-c.

Haplophragmoides manilaensis Andersen

Plate 1, figure 9

Haplophragmoides manilaensis ANDERSEN 1953, p. 22, pl. 4, figs. 8a, b.

Islandiella islandica (Nørvang)

Cassidulina islandica NØRVANG 1945, p. 41, tf. 7, 8d-f.

Jadammina macrescens (Brady)

Plate 2, figure 4

Trochammina inflata (Montagu) var. *macrescens* H. B. BRADY, in G. S. Brady and Robertson 1870, p. 290, pl. 11, figs. 5a-c.

Jadammina polystoma BARTENSTEIN AND BRAND 1938, p. 381, 382, tfs. 1, 2.

Miliammina fusca (Brady)

Plate 1, figures 3, 4

Quinqueloculina fusca H. B. BRADY, in G. S. Brady and Robertson 1870, p. 47, pl. 11, figs. 2, 3.

Nonionella stella Cushman and Moyer

Nonionella miocenica Cushman var. *stella* CUSHMAN and MOYER 1930, p. 56, pl. 7, fig. 17.

Pseudothurammina limnetis (Scott and Medioli)

Plate 1, figures 5, 6

Thurammina (?) *limnetis* SCOTT and MEDIOLI 1980a, p. 43, 44, pl. 1, figs. 1-3.

Pseudothurammina limnetis SCOTT and MEDIOLI 1981, p. 126, 127.

Reophax nana Rhumbler

Plate 1, figures 7, 8

Reophax nana RHUMBLER 1911, p. 182, pl. 8, figs. 6-12.

Trochammina inflata (Montagu)

Plate 2, figures 1, 2

Nautilus inflatus MONTAGU 1808, p. 81, pl. 18, fig. 3.

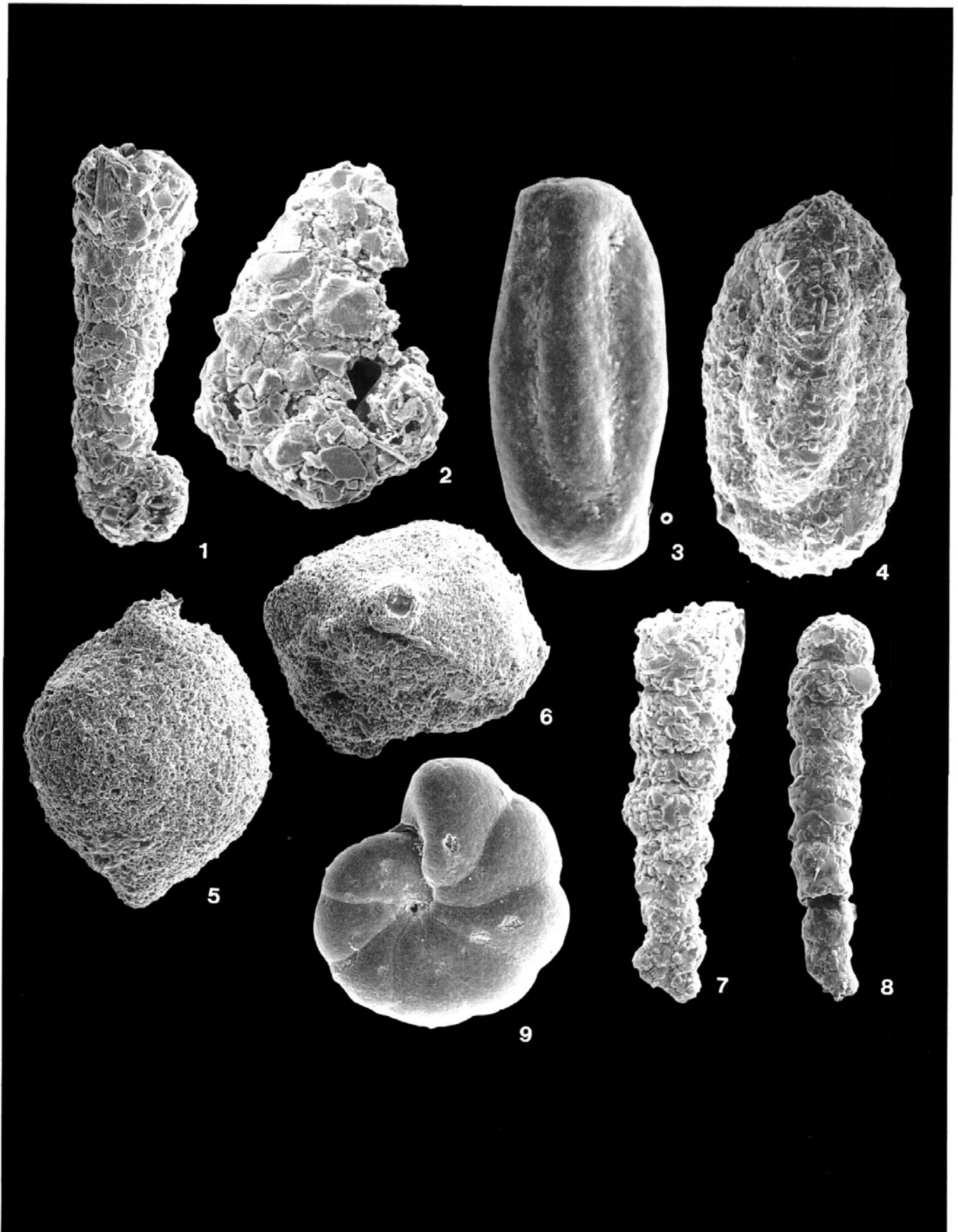
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Plate 1

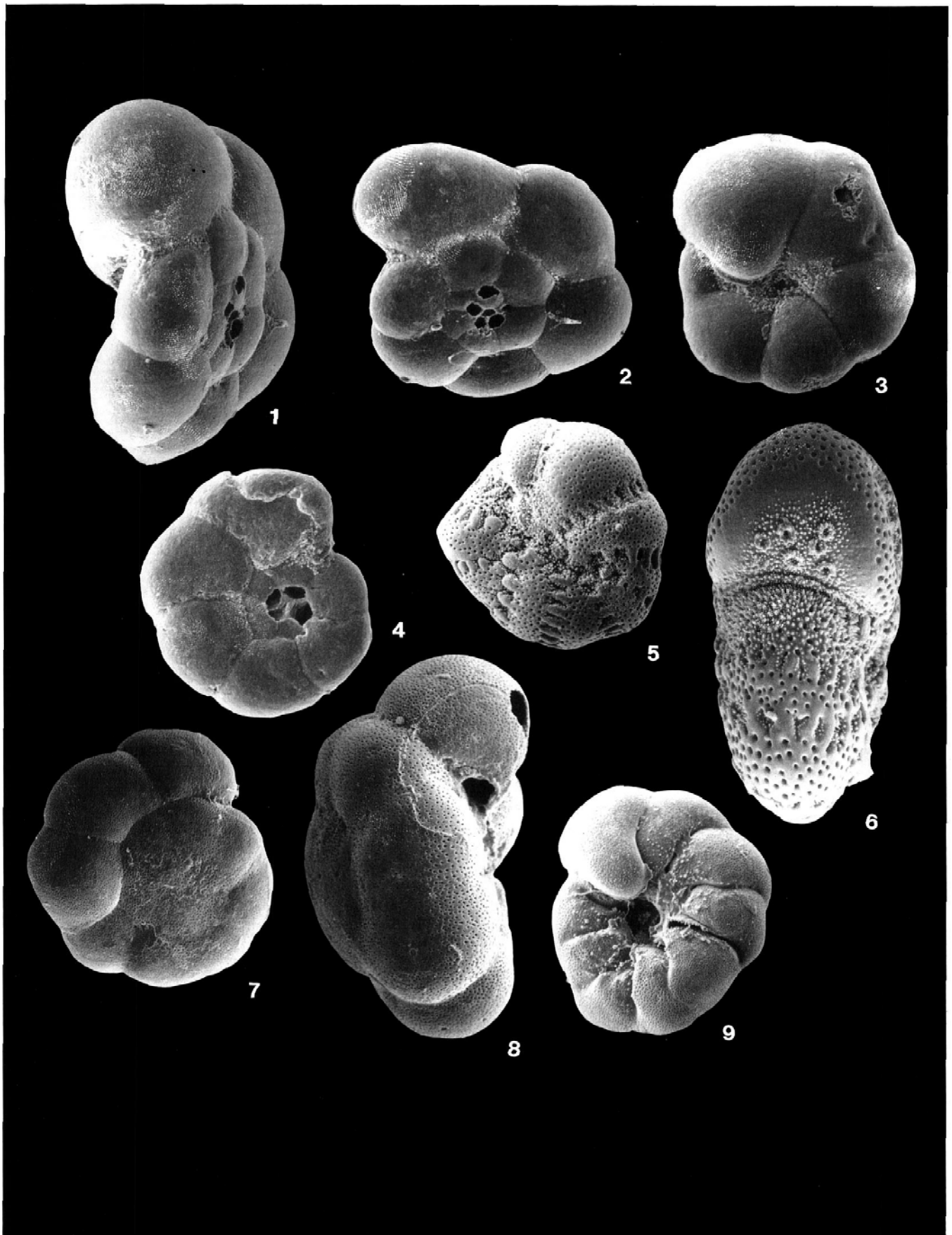
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|---|--|
| <p>1 <i>Ammobaculites exiguus</i> Cushman and Brönniman. Side view of hypotype (GSC 98551) from Station T2-5B, ×137.</p> <p>2 <i>Ammotium salsum</i> (Cushman and Brönniman). Side view of hypotype (GSC 98442) from Station T3-4B, ×251.</p> <p>3, 4 <i>Miliammina fusca</i> (Brady). 3, Side view (3 chambered side) of hypotype (GSC 98553) from Station T2-7B, ×275. 4, Side view (4 chambered side) of hypotype (GSC 98554) from Station T5-10B, ×211.</p> | <p>5, 6 <i>Pseudothurammmina limnetis</i> (Scott and Medioli). 5, Hypotype with two apertures (GSC 98555) from Station T3-10B, ×95.1. 6, Hypotype showing two of the three apertures (GSC 98556) from Station T3-10B, ×90.9.</p> <p>7, 8 <i>Reophax nana</i> Rhumbler. 7, Side view of specimen (GSC 98557) from Station T2-7B, ×186. 8, Side view of slightly damaged specimen (GSC 98558) from Station T5-10B, ×125.</p> <p>9 <i>Haplophragmoides manilaensis</i> Andersen. Side view of hypotype (GSC 98559) from Station T3-12B, ×115.</p> |
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Manuscript accepted April 27, 1992

PLATE 2

- 1-3 *Trochammina inflata* (Montagu). 1, Apertural view of slightly damaged hypotype (GSC 98560) from Station T3-12B, $\times 115$. 2, Dorsal view of slightly damaged hypotype (same specimen as above) (GSC 98560) from Station T3-12B, $\times 82.9$. 3, Ventral view of hypotype (GSC 98561) from Station T3-12B, $\times 137$.
- 4 *Jadammina macrescens* (Brady). Dorsal view of hypotype (GSC 98562) from Station T3-12B, $\times 115$.
- 5, 6 *Criboelphidium* sp. 5, Dorsal view of specimen (GSC 98563) from Station T3-6B, $\times 112$. 6, Apertural view of specimen; note the raised sub-areal apertures (GSC 98564) from Station T2-5B, $\times 211$.
- 7-9 *Ammonia beccarii* (Linné). 7, Dorsal view of hypotype (GSC 98565) from Station T3-6B, $\times 88.9$. 8, Apertural view of slightly damaged hypotype (GSC 98566) from Station T3-6B, $\times 125$. 9, Ventral view of hypotype (GSC 98567) from Station T3-6B, $\times 83.7$.



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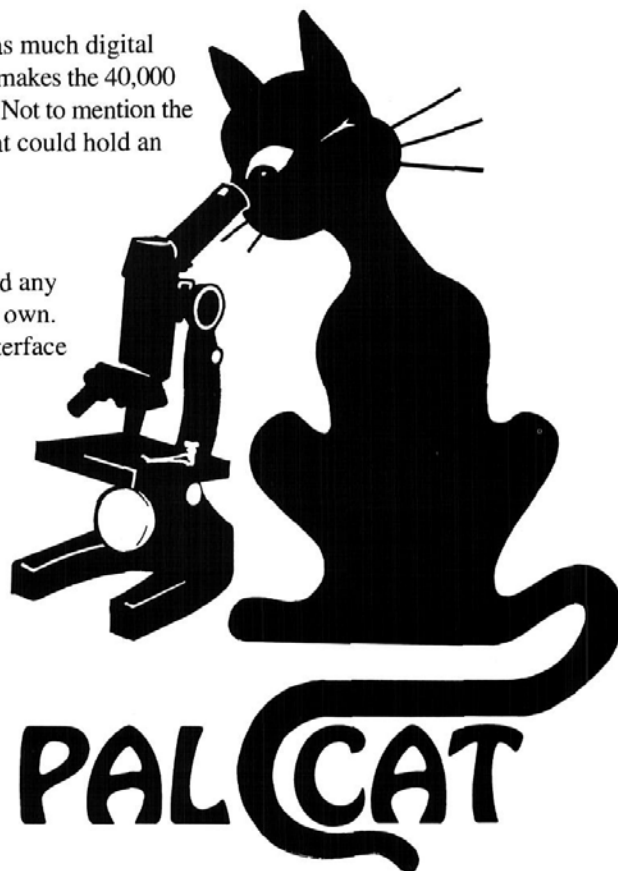
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