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INTERTIDAL *ZIRFAEA CRISPATA* (L.) BURROWS AS INDICATORS OF FLUCTUATING LOW WATER LEVEL IN MINAS BASIN, NOVA SCOTIA

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Colonies of the great piddock *Zirfaea crispata*, rock-boring clam, have created numerous conical burrows in shale terraces at Cape Blomidon, Minas Basin, Nova Scotia. Carbon 14 dating indicates that valves can remain trapped in the rock cavities for at least 900 years. Higher on the shore to about 80 cm above the present populations of live *Zirfaea* are older burrows eroded nearly to their bases. Shell fragments from these cavities were too small to date, but could be near 1200 years old. Interpretation of this sequence of burrows indicates a rise and subsequent lowering of extreme low water level in Minas Basin. A slowing of the rate of rise in mean sea level in combination with an increase in megatidal amplitudes is proposed as a hypothesis to explain these observations.

Des colonies de *Zirfaea crispata*, une huitre freuse, ont creusé de nombreux trous coniques dans les terrasses de schiste argileux du Cap Blomidon, Bassin Minas, Nouvelle-Ecosse. La datation au C^{14} indique que les valves peuvant demeurer emprissonnées dans les cavités rocheuses pour au moins 900 ans. Des trous plus vieuz, érodés presque jusqùa leurs bases, sont localisés dans la partie plus élevée du rivage jusqu'a une hauter de 80 cm au-dessus des populations actuelles vivantes de *Zirfaea*. Les fragments de coquilles provenant de ces cavités sont trop petits pour être datés mais pourraient être agés de presque 1200 ans. L'interpretation de cette sequence de cavités indique qu'un élévation suivie d'une abaissement du niveau des eaux basses extrêmes s'est produite dans le Bassin Minas. Un ralentissement de la vitesse d'élévation du niveau moyen de la mer combiné avec une augmentation des amplitudes mégatidales constitute les fondements d'une hypothèse qui permettrait d'expliquer ces observations.

Introduction

The accumulated evidence for a progressive rise in mean sea level in eastern Canada over the past 6,000 years has been summarized by papers in Ogden and Harvey (1975) and by Amos (1978). These papers emphasize high water levels because the biological evidence for this boundary is readily evident as successive salt marsh horizons. Investigations at Fortress Louisburg, Nova Scotia (Grant 1975) demonstrated a rise in high tide levels of 0.8 m over the past 250 years accompanied by a nominal change in tidal range from 6.05 ft. to 6.00 ft. In the Bay of Fundy, there is clear evidence to indicate a gradual increase in daily tidal amplitude (range) over the last several thousand years (Grant 1970; Amos 1978). However, little is known of the relative position of low water levels over this same time period.

Amos (1978) proposed that if the development of the present large tides in the Bay of Fundy and Minas Basin was accompanied by a proportional rise in position of mean sea level then the result would be a relatively fixed level of low water during the last 6300 years or so. An unusual opportunity to test this hypothesis and to fix the position of low water over a period of perhaps the last 1200 years was pursued at Cape Blomidon, Minas Basin. The great piddock *Zirfaea crispata* (Linnaeus 1758), a rock-boring clam, is common at that site and as the sturdy valves remain entrapped in their rock chambers for hundreds of years, it seemed reasonable to attempt radio-carbon dating of the old burrows as a means of deciphering fluctuations in sea levels. Andersen (1971) was able to date *Zirfaea* valves from Danish clay deposits to 34,500 years B.P.

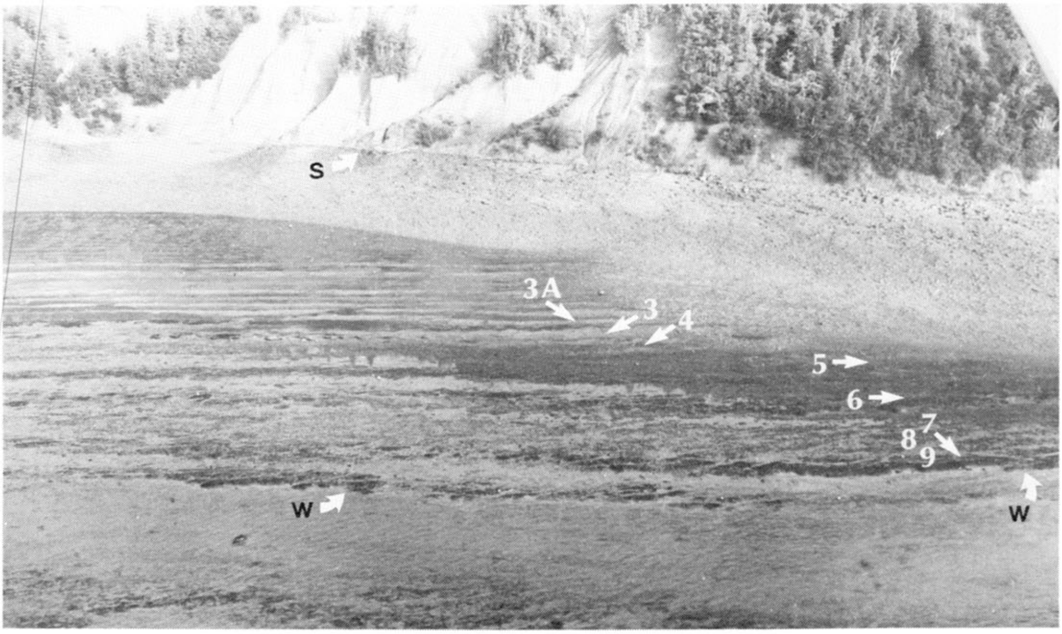

Fig 1. Aerial view, from altitude of 150m, of Cape Blomidon shale terraces, which to the right are buried beneath basalt rock slides. Tide is an extreme low water spring of 20 August 1978, and the vertical distance from water's edge (W) to strand line (S) is about 16 m. Elevations at survey station sites No. 3A to No. 9 are provided in Table II.

Study Area

At the cliff base of Cape Blomidon, Minas Basin, the lower intertidal zone is a series of terraces (Fig 1) which contain interbedded Triassic sandstones and shales (Crosby 1962). A detailed description of the study site has already been published (Bleakney, Robinson & Waugh 1980) and the transect line and station sites established then (1978) were also used for this study. The terraces on which the *Zirfaea* clams were found vary from 2 m to 20 m in width and the terrace faces from 25 cm to 45 cm in height. The terraces run approximately parallel to the shore and the lower terraces have been extensively burrowed by *Zirfaea.* (We know of one other similar area in the western Minas Basin, 0.6 km to the south at Lyon's Cove. Also, from hearsay accounts, there is the possibility that the area around Five Islands, along the north shore of the Minas Basin, has experienced similar *Zirfaea* activity). The horizontal distance that *Zirfaea* burrows occupy at Cape Blomidon is approximately 53 m in width. On the vertical scale, they reach 135 cm above extreme low water. When one traverses the terraces, it is immediately evident that the shallow depressions that constitute the uppermost burrows are but remnants of a once dense population of clams. There are now neither living *Zirfaea* nor deep burrows on these terraces, indicating that low water levels have receded relatively recently.

Materials and Methods

The Great Piddock is a large boring clam (shell length 5 to 7 cm, dry shell weight 12 to 20 g which, on the shores of the northwest Atlantic (personal com-

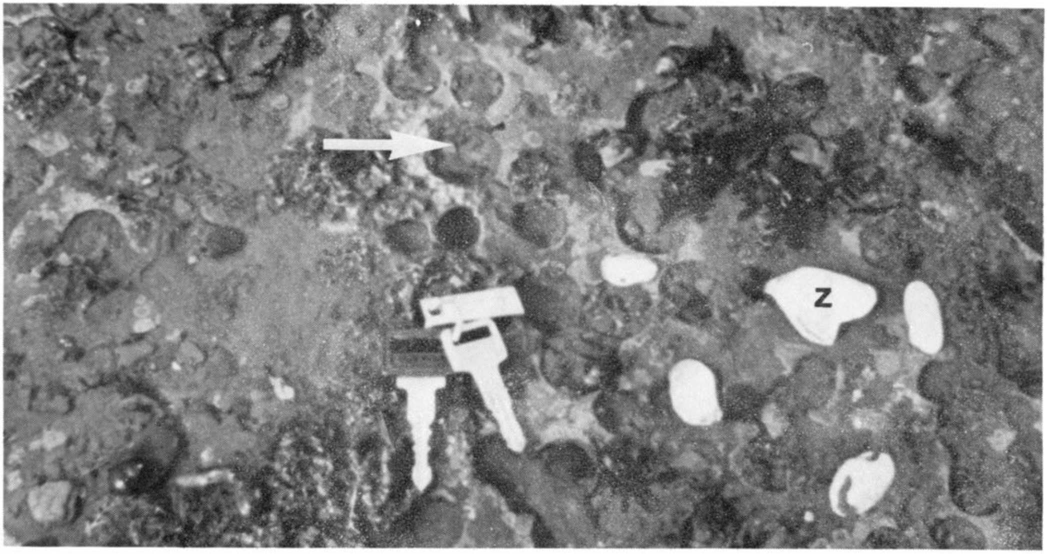

Fig 2. Burrows of *Zirfaea crispata* in Blomidon shale at station No. 7 and a portion of one valve at Z. The largest orifice at center of photo (arrow) is the basal chamber of a burrow exposed now after hundreds of years of erosion have removed about 18 cm of rock.

munications from Dr. Ruth D. Turner, Museum of Comparative Zoology, Harvard University, Mass.; Dr. John Evans, Memorial University, Newfoundland; and Dr. Derek Davis, Nova Scotia Museum of Science, Halifax) rarely lives above extreme low water. The fact that this species is exposed by extreme low-water tides in Minas Basin is not unexpected because local megatidal spring tides expose a wide margin of typically sublittoral fringe habitats on these gently sloping shores (Bleakney 1972). At Cape Blomidon such species as the deep sea scallop *(Placopectin magellanicus* (Gmelin), the ten-ridged whelk *(Neptunea decemcostata* (Say), the leafy bryozoan *(Flustra foliacea* (L)) and kelps *(Laminaria* spp.) become fully exposed during extreme low-water springs. On adjacent broad intertidal flats in Minas Basin, the stranding of fish is a common phenomenon during such tides (Bleakney & McAllister 1973).

At Cape Blomidon, *Zirfaea* have excavated vertical burrows in shale to depths of 22 cm (Fig 2). As the clams grow, they progressively deepen and widen their burrows creating inverted cone-shaped cavities with opening diameters of only 1 to 1.7 cm, potential depths of 20 to 22 cm, and basal maximum widths of 4.3 to 4.5 cm. After a life span of only 4 to 7 years (Allen 1969), they die and the paired valves are trapped in the shale chambers which soon become packed with detritus and silt. Removal of the valves will not occur until perhaps 8 to 16 cm of erosion has taken place, thereby enlarging the orifice enough to accommodate removal of the tightly fitting valves. Between September of 1978 and November of 1979, 124 burrows were measured (Table I) and many others were examined. The amount of erosion at each measured burrow (Table I) was estimated by best fitting each burrow's dimensions to a set of diagram outlines of lengthwise sections of burrows which were derived from detailed measurements of burrows housing living *Zirfaea* of various body sizes. Even the largest live *Zirfaea* did not have a burrow orifice greater than 1.7 cm. However, since many of the old burrows had orifice diameters in the order of 2.5 to 3.5 cm it was evident that a considerable amount of original rock substrate had been removed through natural erosion.

Table I Characteristics of 124 burrows examined, with data on *Zirfacea crispata* and their remains.

Station No. and Height Above Datum	Burrow Depth (cm)	Orifice Diam. (cm)	Estimated Rock Eroded (cm)	Presence of Valves (P) or clams (L)	Valve Weight (gm)	Valve date C^{14} Yrs.B.P.(1950)
3A (n=8)	2.0	2.5	8.0			
(+ 135 cm)	6.8	2.5	8.0	P	1.3	
	2.5	3.0	10.0			
	5.5	3.0	11.0			
	5.8	3.0	11.0			
	5.5	3.0	11.0			
	3.3	3.3	13.0			
	4.0	3.3	13.0			
3 (n=5)	5.2	3.2	12.5	P	3.7	
(+ 110 cm)	4.0	4.0	18.0			
	2.0	4.3	20.0	P	3.5	
	10.0	1.2	—	L		
	12.5	1.3	—	L		
4 (n=32)	12.5	1.8	1.0	P	11.5	380 ± 70
(+ 90 cm)	8.0	2.1	4.0	P	2.8	200 ± 95 processed as a single unit
	8.5	2.0	4.0	P	2.3	
	8.0	2.0	4.0	P	2.15	
	4.0	2.1	5.2			
	7.0	2.2	6.0	P	3.3	
	4.9	2.4	6.5			
	1.0	2.3	7.0			
	2.8	2.5	7.5			
	5.5	2.5	7.5	P	3.5	
	2.3	2.7	8.5			
	3.0	2.7	8.5			
	3.2	2.7	8.5			
	2.8	2.8	9.5			
	2.0	2.8	9.5			
	3.5	2.8	9.5			
	5.4	2.8	9.5			
	2.7	2.8	9.5			
	3.2	2.8	9.5			
	2.0	2.8	9.5			
	4.4	3.1	10.0	P	4.0	380 ± 125
	4.2	2.9	10.0	P	2.2	
	2.0	2.9	10.0			
	2.0	3.0	10.5			
	2.7	3.0	10.5			
	4.5	3.0	11.0	P		
	3.0	3.0	11.0			
	3.0	3.0	11.0			
	3.2	3.1	11.5			

	3.2	3.2	12.0			
	3.5	3.2	12.0			
	3.5	3.5	14.5			
5(n – 42) (+ 75 cm)	4.5	1.0	0.0			
	1.0	1.5	2.0			
	1.5	1.5	2.0			
	3.5	1.5	2.0			
	3.0	1.3	2.5			
	3.0	1.5	2.5			
	3.0	1.5	2.5			
	3.5	2.0	5.0			
	3.0	2.0	5.0			
	2.0	2.0	5.0			
	5.0	2.0	5.0			
	1.0	2.0	5.0			
	3.0	2.0	5.0			
	5.0	2.0	5.0			
	2.5	2.0	5.0			
	10.0	2.0	5.0	P	5.1	25 yrs max
	7.5	2.0	5.5	P	3.3	
	6.0	2.5	7.0			
	4.0	2.5	7.5			
	4.5	2.5	7.5			
	4.5	2.5	7.5			
	5.0	2.5	7.5			
	5.0	2.5	7.5	P	2.5	
	10.0	2.3	7.5	P	5.0	25 yrs max
	3.5	2.5	8.0			
	3.0	2.5	8.0			
	3.5	2.5	8.0			
	2.0	3.0	10.0			
	4.5	3.0	11.0			
	3.0	3.0	11.0			
	3.0	3.0	11.0			
	3.0	3.0	11.0			
	3.0	3.0	11.0			
	5.0	3.0	11.0			
	4.0	3.0	11.0			
	3.0	3.0	11.0			
	4.0	3.0	11.0			
	4.0	3.0	11.0			
	4.2	3.0	11.0	P		
	7.0	3.0	11.5	P	6.5	25 yrs max
	2.0	3.5	14.5			
	4.5	3.5	16.0			
6(n – 15) (+ 58 cm)	12.0	1.0	—	L		
	12.0	1.0	—	L		
	21.0	1.2	—	L		
	22.0	1.7	—	L		
	17.5	2.5	7.0			
	4.2	2.4	7.0			

	9.0	2.5	7.5			
	5.0	2.5	7.5			
	17.5	3.0	(5-10?)	P	5+	210 ± 95
	5.0	2.7	8.0			
	9.0	3.0	11.0	P	5	865 ± 100
	7.0	3.0	12.5			
	3.8	3.5	14.5			
	5.2	3.5	16.0	P	5.2	485 ± 105
	5.5	3.7	16.0			
6A (+ 41 cm)	7.5	3.0	11.0	P	3.8	
	7.0	3.5	14.0	P	2.0	
	21.0	1.7	—	L		
6B (+ 35 cm)	18.0	1.1	—	L		
7(n = 16) (+ 35 cm)	9.8	1.0	0.0			
	10.5	1.5	1.5			
	14.0	2.2	4.0	P	11.15	50 yrs max
	6.5	2.1	5.0			
	9.0	2.2	5.0			
	9.0	2.0	5.0	P	5.4	
	6.7	2.4	7.0			
	10.0	2.5	7.5			
	5.5	2.6	8.0	P	2.0	
	10.0	2.5	8.0	P	7.2	
	9.0	2.7	8.0	P	8.2	865 ± 75
	4.5	3.0	11.1			
	7.0	3.0	11.0	P	0.2	
	2.3	3.2	12.5			
	4.8	3.4	14.0			
	4.0	3.5	14.5			
8 (+ 25 cm)	6.0	3.2	11.0	P	9.0	25 yrs max
9 (+ 15 cm)	7.0	2.9	10.0	P	5.8	

Results and Discussion

Table II depicts the relative elevations of *Zirfaea* burrows from observed extreme low water level (based on observations during 9 extreme low-water spring tides) and the maximum densities that were noted at several elevations. Live *Zirfaea* were evident up to Station No. 6 (+58 cm) but in spite of flushing of numerous burrows (Bleakney, Robinson & Waugh 1980), none were observed above that level (with one exception) although old burrows pocketed the rock up to 135 cm above low water. That exception was in an outflow trough that drained waters from No. 3A terrace (+135 cm). On the continually watered slope of this terrace face were old burrows from which an estimated 12 to 20 cm of rock had been eroded (Table I, Station No. 3) but there were also several live *Zirfaea*, two of which were chiseled out of the shale. It is evident that *Zirfaea* veliger larvae are settling on the terraces but that above +60 cm they find few areas suitable for survival. This again indicates that extreme low water has receded, but the reported evidence in Nova Scotia indicates rising sea levels (Ogden & Harvey, 1975; Amos, 1978).

Table II. Distribution of *Zirfaea crispata* and vertical distances between collecting stations relative to estimated low water, based on observation of 9 extreme low-water spring tides.

Tidal Height cm	Station No.	Vert. Diff. cm	Max. Density m^2	Comments
140				
	3A		6	**oldest identifiable burrows
130				
120		25		
110	3		(5 only)	isolated group of live *Zirfaea* in out-flow off above terrace.
100				
		20		
90	4		26	no live *Zirfaea*.
80		16		
	5		158	no live *Zirfaea*.
70				
		16		
60	6		22	**present upper limit of the live *Zirfaea* population.
50		17		
	6A			
40		6		
	6B, 7		75	
30		10		
	8			
20		10		
	9			
10				
		15		
0	estimated extreme low water			

The older upper terraces of *Zirfaea*-perforated rock are subject to intertidal wave and ice erosion. Attrition rates of the essentially subtidal stations No. 7 to No. 9 must be less than at those terraces exposed intertidally. The burrows at these lowest levels are of every depth and dimension and would indicate a continuous utilization of the terraces by *Zirfaea* for a thousand or more years. Carbon 14 dating of the entrapped *Zirfaea* valves should have provided some answers to the ages of these burrows and thus the rate at which the shore erosion is taking place in a vertical plane. Unfortunately, the C^{14} results do not encourage interpretation with any confidence (Table I). There seems no consistent correlation of age with burrow depth, or amount of erosion, or weight of valves, or height above mean low water. Additionally, because the Dalhousie University Carbon Dating Laboratory required at least 5 g of shell per sample, those smaller samples from the highest levels could not be dated. Perhaps even the 5 g samples used were too small or too contaminated. (Hopefully, the methodology or the machine itself was at fault.) All we can conclude is that some *Zirfaea* valves weighing over 5 g have remained entrapped in burrows for nearly 900 years, and that the older, thinner valves weighing only 2 and 3 gms might represent another 300 years. That the valves become reduced is not surprising as there are at least 88 species of metazoan animals that will take up residence in vacated, detritus-filled, *Zirfaea* burrows, and their activities must contribute to physical and chemical attrition (Bleakney, Robinson & Waugh 1980).

Of particular interest is supporting evidence for fluctuating low water levels from an area 11.5 km south of Cape Blomidon on the intertidal flats of Evangeline Beach. An extensive bed of oysters *(Crassostrea virginica)* which were growing under subtidal or extreme low water conditions about 3800 years B.P., are now 1.5-2.0 m above extreme low water (Bleakney & Davis, 1983). It follows that even though the upper limit of *Zirfaea* would have been even more restricted 3800 years ago because of then lesser tidal amplitudes, this species should nevertheless have ranged at least as high as the oysters, which would be nearly 2 m higher than present extreme low-water level at Blomidon. That would be about 60 cm above the 140 cm limit of the oldest evident burrows at Blomidon today. What was the eventual upper limit of low water in Minas Basin before it began to recede? How recently did that reversal take place? The answer to both questions (provided the problems with C^{14} dating can be identified and overcome) may lie beneath that talus slope of basalt rocks evident in Figure 1 where the shale terraces and *Zirfaea* burrows have been buried and protected from erosion.

Conclusions

Amos (1978) calculated rising sea-level curves for Minas Basin from a series of dated, high-water marsh horizons and from extrapolated mean sea levels. He lacked information for complementary low-water positions. He concluded that the progressive inundation in Minas Basin was a function of an increase in tidal range (50%) and a rise in apparent mean sea level (50%), and consequently low water levels remained static.

Biological evidence presented here indicates receding low-water levels. This can be accommodated within Amos's general thesis by assuming the rate of rise of mean sea level has recently slowed. This, in combination with ever-increasing tidal amplitudes, would have generated progressively lower tidal levels in recent times. Thus, whereas sea level rise in most areas assumes high water, mean sea level and low water are rising in conjunction with one another, the accelerated evolution of megatidal amplitudes in Minas Basin has actually exceeded mean sea level rise and has thereby depressed low-water limits to below that of the *Zirfaea* of 400 yrs B.P., 900 yrs B.P. and even below the 3800 yrs B.P. oyster bed.

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