Journal of Danish Archaeology vol. 8, 1989, pp 7–12

Analyses of Shell Increment and Microgrowth Band Formation to Establish Seasonality of Mesolithic Shellfish Collection

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INTRODUCTION

The Mesolithic "Køkkenmødding" at Ertebølle, Denmark contains typical hard substrate vestiges from the culture such as flint tools, fractions of pottery, and left overs from meals based on hunting and fishing, e.g. bones from fish, birds and mammals. In particular, the kitchenmidden consists of shells of the following sea molluscs: *Ostrea edulis, Cardium* (*Cerastoderma*) *edule* and *C. lamarcki, Littorina littorea, Mytilus edulis,* and *Bittium reticulatum.*

No permanent housing has been excavated at the Ertebølle Settlement (Andersen and Johansen 1986) which may suggest that it was only used as summer residence. However, skeleton parts from seabirds that occur only during winter have been identified in the midden in quantities suggesting that extensive hunting took place also during that period (Enghoff, 1987). Sea food gathering can be maintained throughout the year except during periods with heavy icecover. In order to determine whether such seafood was collected in the warmer part of the year (as a supplementary gourmet diet?) or throughout the year (survival supplement in periods of starvation?) we wanted to determine seafood sampling dates using backdating techniques on the midden shells. The mussel shells from the midden were so disintegrated that only the region of the umbo and hinge was moderately well preserved, and the oyster shells, through superficially well preserved, could not even be aged by means of annual growth bands, and their shell matrix was much too loose for micro growth band identification. In contrast the *Cardium* shells were well preserved, annual growth marks could be identified (Orton, 1926), and measurements of shell length and the last shell increment could be obtained. Further, the shell matrix was sufficiently coherent in extensive parts for clear microgrowth lines to be found in a fair number of the shells.

Microgrowth lines are circadian growth lines formed in the shell matrix in periods where the cockle is active and the mantle lobes protrude between the shells. Such microgrowth lines have been used for studies of problems concerning use of a "biological clock", e.g. in paleaoecology, (Bourget 1980, Jones 1981, and Deith 1983). In habitats of regular tidal impact where the sediment is exposed to air at low tide, microgrowth band formation may reflect the tidal shifts as shown by Richardson *et al.* (1981); however, periodicity differs in *Cardium* from different environments (Bourget *et al.* 1991) and the finding of daily microgrowth band formation in *Cardium edule* by House and Farrow (1968) should still be considered. Many authors hypothesize that the narrow band which is formed in connection with shell closure

Fig. 1. The present coastline of the Limfjord with the Mesolithic locality, Ertebølle (E) and area of the modern samples, Aggersborg (A).

and which separates the wide bands, contains more organic material than the wide bands (Farrow 1971, Richardson *et al.* 1981 and Evans 1988). However Deith (1985) has presented convincing evidence that the narrow bands which dissolve slower in acid than the wide bands contain the same calcium compound as those, yet in a denser form.

Cardium edule is valued seafood as the latin name indicates, especialy in France, England and Ireland (remember Moly Malone's "cockles and mussels alive"?). Its close relative, *C. lamarcki* is not appreciated though commercial utilisation has been suggested (Iwell, 1979). However, when the two species co-occur they are not easily separated, and at the tidal flat of Andernos in Archachon Bay (France) where the two species were found in sympatry in 1987 and 1990 (Brock, in prep.) local people utilize both for consumption. The settlers at Ertebølle also consumed the two cockle species and we are confident that they would have distinguished between the two species if one had been considered without value. Having identified the habitat properties of the cockle sampling area (Brock et al. 1987) we used shells from samples of living *C. edule* and *C. lamarcki* collected at different times throughout a year from a habitat with similar properties. This recent material was used as reference for identification of collection dates of the midden cockles by means of backdating techniques. Two independent methods were used, correlation between the shell increments formed after the last annual growth mark (in mm) and sampling dates, and correlation between the sampling dates and the numbers of microgrowth lines formed after the last annual growth mark.

MATERIAL AND METHODS

Shells of the two *Cardium* species were sorted out from a midden core (30x30x160 cm) that had been subsampled horizontally by means of archaeological criteria and dated by means of C-14 technique to 5270–5540 BP (Andersen & Johansen, 1986). The separation of the two species was based on shell edge identification (Brock 1978), and an identification of the *C. edule* ecotype which co-occur with *C. lamarcki* was based on cluster analysis (see Brock et al. 1987). The classified midden shells (sympatric *Cardium edule* and *C. lamarcki*) were used for the determinations of the cockle sampling periods at the settlement (see Table 1).

Archaeological strata	Layer	*C. edule*	*C. lamarcki*
Shells	5	1	1
	6	3	4
	7	1	2
	8	0	2
	9	21	26
	10	62	18
	11	44	19
Transition between shells and fireplace	12	37	12
Fireplace	13	60	9
Shells below fireplace	14	26	0
Fishbones and shells	15	40	4
Shells	16	1	0
	17	5	0
Black layer, rust coloured shells, firepl.	18	3	0
Rustcoloured shells	19	3	0
Shells	20	1	0
Large shells	21	1	0
Black/rusty shells	22	11	0
Grey layer	23	1	0

Table 1. The occurrence of *Cardium lamarcki* and the sympatric *C. edule* ecotype (numbers of whole shells) in the different layers of the N-core from the Mesolithic shell midden at Ertebølle.

The recent material for growth comparison was sampled alive in 1978 at the following dates, Feb. 2, Mar. 15 and 30, Apr. 18 and 27, May 17, Jun. 12 and 20, Jul. 17, Aug. 1 and 11, Sep. 8 and 22, Oct. 10, and Nov. 1. from a population which consists of both *Cardium* species at the Limfjord locality, Aggersborg (See Fig. 1).

Comparisons of species specific annual growth rates using the van Bertalanffy growth parameters, e^{-K} and L_∞ showed that growth of the sympatric mesolithic cockles equaled those of the Aggersborg samples (Brock et al. 1987). Growth increment (y = the difference between the actual shell length and the length of the shell at the previous annual growth mark) was measured to the nearest 0.1 mm using a caliper.

Microgrowth bands in the crystalline matrix of the shells (Bourget 1980) were counted on acetate peels of radial shell sections using a modification of Clarcks method (Clarck 1980). Shells were cut in halves along the ribs, the section area was polished and eventually grinded with silicon carbide (1000 grit), then etched in 1N HCl for 30 sec., rinsed in water, dried, and set on acetate film with acetone. After 5 min. the shell was removed and the imprint on the peel ready for microscopy.

RESULTS

For both species and for each of the three year classes examined (e.g. 2+: third growth period) the relation between sampling time (x) and corresponding shell increment (y) was estimated assuming linearity of growth (Table 2). Using the equations from Table 2, dates of death were obtained for the well preserved midden material (Fig. 2). Fig. 3 shows that shell increments of 82% of the midden material correspond to collection in the period May 15 to October 15. In 10% of the material no increment could be measured after the last annual growth mark indicating sampling prior to May 15, and on the last 8% of the shells, growth increments suggested sampling after October 15 but before formation of the annual growth mark.

Species	age	N	Relation between shell increment in mm (y), and time in days (x)
Cardium edule	2+	34	$y = (0.03 \pm 0.004)x + (1.40 \pm 0.29)$
Cardium edule	3+	48	$y = (0.03 \pm 0.002)x + (0.98 \pm 0.22)$
Cardium edule	4+	17	$y = (0.02 \pm 0.004)x + (0.42 \pm 0.51)$
Cardium lamarcki	2+	62	$y = (0.024 \pm 0.003)x + (1.75 \pm 0.28)$
Cardium lamarcki	3+	64	$y = (0.01 \pm 0.003)x + (1.60 \pm 0.30)$
Cardium lamarcki	4+	11	$y = (0.008 \pm 0.004)x + (1.26 \pm 0.38)$

Table 2. Relation between sampling time in days counted from May 15 (x) and corresponding shell increment in mm (y) assuming linearity from June 5 to October 15. The equations are based on modern sympatric *C. edule* and *C. lamarcki* sampled alive at two to three weeks intervals from February to November 1978 at the Limfjord locality, Aggersborg (e.g. 2+: cockles in their third growth season).

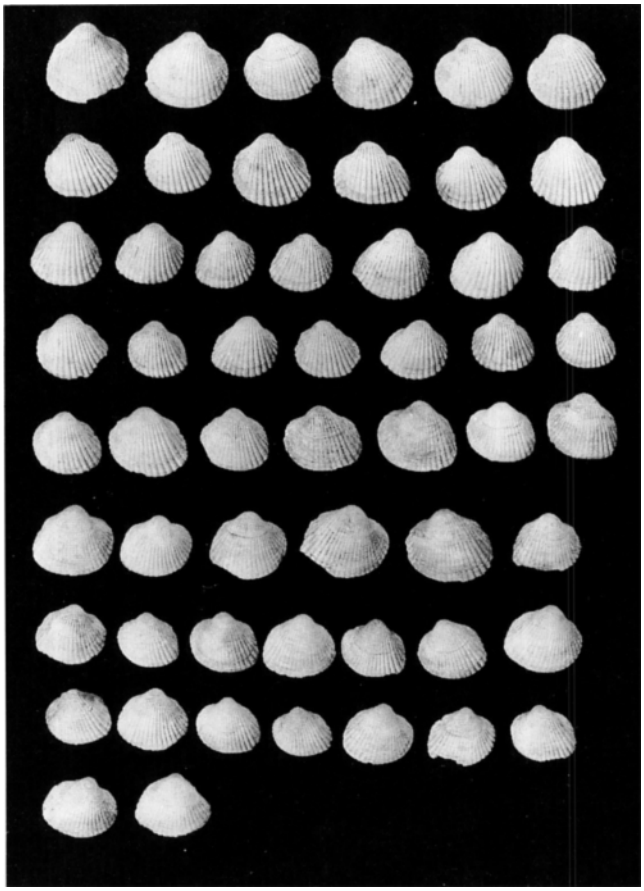

Fig. 2. Shells of *Cardium lamarcki* (mostly in 2nd, 3rd, and 4th row) and *C. edule* from the Ertebølle Køkkenmødding layer 13N (age of layer determined by means of C-14 analysis: 5540 + 95 y B.P.).

	Year 2		Year 3		Year 4	
Locality	A	E	A	E	A	E
No. of micro-growth bands	537	630	379	423	322	330
	436	505	336	369	310	
	500	550	367	365	287	
	453	317	437	355	255	
		289	404	400	221	
				250		
				533		

Table 3. Individual microgrowth band formation for three age classes of sympatric *Cardium edule* from Aggersborg (A) and Mesolithic Ertebølle (E). Note the pronounced whithin-group variation.

Microgrowth band formation in *Cardium* is age and habitat dependent (Bourget and Brock, 1990) and in order to compare the midden material with comparable recent material the Aggersborg cockles were chosen for this comparison too. Table 3 shows that the numbers of microgrowth lines between two annual growth bands for different yearclasses at Mesolithic Ertebølle agree with the results from the present Aggersborg population. Table 3 also shows the tendency that the older cockles form fewer bands during a growth season than the younger. Fig. 4 shows the microgrowth band formation during the forth growth season for *C. edule* and *C. lamarcki* at Aggersborg (1980). The equations are based on counts of bands formed after last annual growth mark related to actual sampling dates including the last sampling date with zero bands. These equations are independent of any assumptions of whether microgrowth band be formed daily throughout the year (House and Farrow, 1968) or twice a day induced by tidal cycles (e.g. Richardson et al. 1979, Lønne and Gray, 1988). For a discussion of how different factors influence upon micro band formation, see Bour-

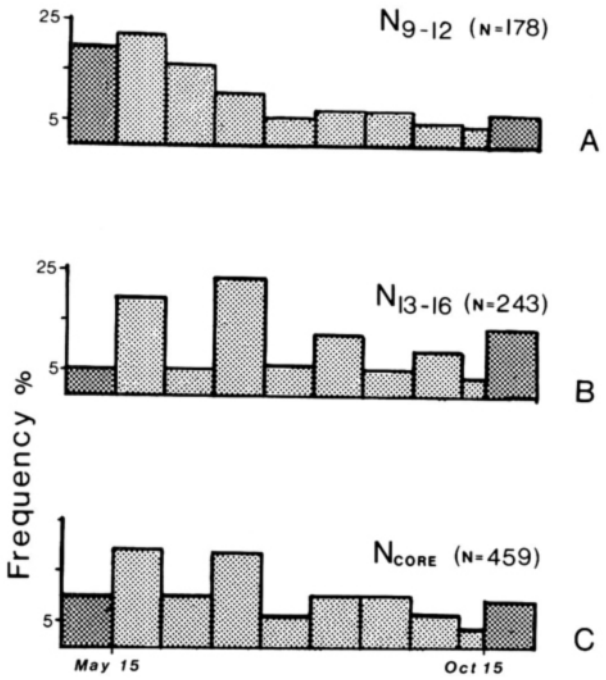

Fig. 3. Time of collection/death for sympatric *Littorina* Sea *Cardium edule* and *C. lamarcki*, B, and C: date related frequency diagrams obtained from comparisons of length increments in cockles from the N-core of the Ertebølle midden with standard data from modern populations at the Aggersborg locality. Collumn width: 20 days.

get and Brock (1990). The results suggest that countable microgrowth bands did not form during the first three months of the year.

Out of 41 examined midden *C. edule*, the acetate peels of the end bit (= micro growth bands formed after the last annual growth mark) was countable for 20 individuals, and of 11 *C. lamarcki* the end bit could be counted for 1. The sampling dates of individuals of the two species in their fourth growth season (n=10) were calculated by means of the equations in Fig. 4. For the C. edule in their second growth period (n=10), sampling dates were determined assuming that formation of countable microgrowth bands started day 106 and ended day 365 as was found for the older *C. edule* and assuming that 1.8 bands per day were formed during this period (mean of total numbers of microbands formed between 2nd and 3rd annual growth mark, see Table 3). The sampling dates of the 20 midden *C. edule* and 1 *C. lamarcki* thus determined were: April 29, May 4, 11, 16, 17, 27, 30, June 1 and 28, July 2, 7, 10, 27, 29, August 15 and 26, September 12 and 18, October 6 and 10, and December 12.

The accuracy of the determinations of sampling date by both methods for 8 *C. edule* sampled at known dates in their 3rd growth season was determined separately and in combination (multiple regression). The standard error of the determination of sampling dates by both methods (for *C. edule*, n=8, sampled at known dates in their third growth season) was estimated separately and in combination (multiple linear regression). Table 4 shows that date estimates based on measurements of shell increment are as precise as of date estimates based on microgrowth line counts, and that only little extra precision is gained by combining both methods.

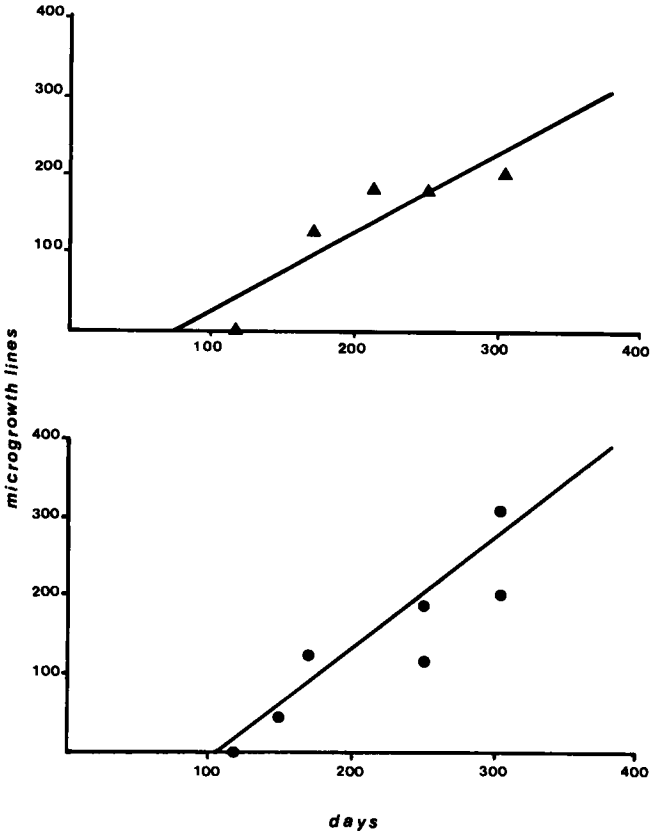

Fig. 4. Microgrowth lines for *Cardium edule* (circles) and *C. lamarcki* (triangles) from Aggersborg sampled during their fourth growth period. The equations for number of lines (y) related to number of days counted from the initiation of micro growth band formation (x) is based on the date and holds no assumption of when micro growth band formation starts, ends, or how many bands that are formed per day.
Cardium edule: Y = 1.23x – 130.6; r = 0.92
Cardium lamarcki: y = 1.01x – 74.95; r = 0.79

Model	Independent variable	R^2	R^2 change
1	Microgrowth bands	0.849	
2	Increment (mm)	0.979	0.0006
3	Increment and Microgrowth bands	0.979	(F = 0,14)

Table 4. Multiple linear analysis with the three time-related variables: number of microgrowth lines, shell increment in mm, and days. *Cardium edule* (3+; n=8) from Aggersborg.
Model 1 (bivariate): y=(0.69+0.12)x + (121.4+18.9)
Model 2 (bivariate): y=(44.1+2.7)z + (108.6+7.5)
Model 3 (multivariate): y=(0.047+0.125)x + (41.51+7.44)z + (108.5+8.1)
(y=days, x=microgrowth bands, and z=mm shell increment).

DISCUSSION

In contrast to oysters and mussels which attach to hard surfaces, cockles burrow in the sediment. Since it is difficult to maintain them alive in larger quantities in well-boxes or cages (Brock 1980) and since experienced cockle collecters (as the settlers at Ertebølle probably were) rarely mistake dead for live cockles we assume that the midden shells mainly represent cockles collected for immediate consumption and thus, that their date of death represent the collection date. However, some midden shells may have a different origin. On soft and sandy shores mussel attach to stones and shells of dead cockles that protrude from the bottom. Therefore, whole aggregations of stones, shells and mussels held together by mussel byssus can be collected quickly during wading or diving and sorted out later at the coast. Extensive occurrence of small stones in the midden which has puzzled the archaeologists (S. Andersen, pers. com.) may well origin from such aggregations, and it is plausible that also some of the cockle shells we have studied were brought to the settlement as parts of such quickly gathered mussel aggregations (Fig. 5).

It may seem contradictory that this work deals whith two different growth periods, one for microgrowth formation that is considerably longer than the one for shell increment formation. The explanation is simple. During the period where microgrowth bands are formed whithout addition of the shell length, the microgrowth bands are very narrow and adds only to the thicknes of the shell, not to the length (Deith 1985). This explanation conform with our finding that the edge of the cockle shells are generally thicker in spring than in the fall. It is not the goal of this study to offer a precise model which describes cockle growth during a growth season but an adequate tool with easy applicabilities. The determination of very small increments is difficult, therefore the linear growth equations are based exclusively on material sampled after June 1. For midden material with y-values > 0 but smaller than what correspond to June 5 there is no date determination. Such material is simply referred to the period May 15 – June 5.

Since the shell part used for the determination of collecting date is the most fragile, this and therefore micro growth bands may easily have been eroded away. Therefore, we have avoided inclusion of shells with damaged outline. Our findings reject the theory that this type of seafood was used by the Ertebølle settlers mainly in periods of malnourishment, it is more probable that sea food supplemented their other food items during summer. This is supported by the finding (Fig. 3) that sampling was less intense in the middle of the summer where cockles are less valuable due to their gamete release.

Reference populations must be chosen with care since environmental factors as well as the age of the cockle strongly influence the microgrowth band formation (Bourget and Brock, 1990). A future study of archaeological cockles sampled in an area with pronounced tidal impact should for example not be compared with material sampled at the less exposed Aggersborg locality. The pro-

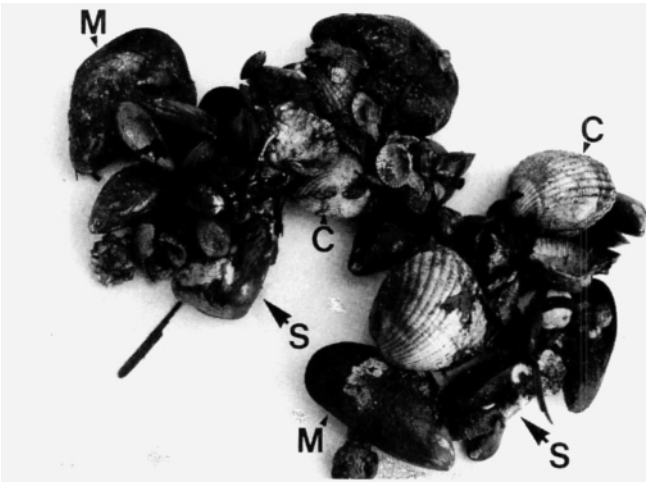

Fig. 5. Mussel aggregations held together by byssus threads. M: mussel, S: stone, C: cockle. Photo by Terkel T. Due.

blem of finding recent populations with growth rates comparable to those of the archaeological material one wants to study is facilitated when winter marks can be identified and annual shell increments measured. Growth rates can then become compared by use of the van Bertalanffy growth equation (Bertalanffy, 1957). Choice of a modern control environment is supported if species specific growth rates of more species are compared and found similar (Brock *et al.* 1987). Since time studies on *Cardium* shells from archaeological deposits can be studied with comparable error levels by means of shell increment measurements and microgrowth band counts in the period June to mid October, and since the former requires less equipment and skills we recommend this method for future studies whenever more exact information concerning the period mid October to mid May is unimportant.

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