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Using Shells to Determine Season of Occupation of Prehistoric Sites

Raewyn A. Sheppard

New Zealand Historic Places Trust, Wellington[1]

ABSTRACT

This paper reviews methods of studying seasonal changes in mollusc shells and their application in determining the seasonal use of archaeological sites. The mollusc shell is a complex structure that shows variations in growth in response to physiological and environmental events. An understanding of these growth fluctuations is implicit for any inferences about season of death of archaeological shells, and a summary of molluscan growth is presented.

Archaeologists have used three techniques in studying seasonal changes in mollusc shells: examination of whole shells, examination of transverse sections, and measurement of isotopic composition. Two further techniques of shell analysis (mineralogy and trace element content) have not yet been applied in archaeology. An assessment of these five techniques, with reference to New Zealand shells where possible, indicates that:

(1) isotopic analysis is feasible (based on overseas experience);

(2) microprobe analysis of trace elements has great potential but its usefulness in New Zealand has yet to be established; and

(3) a technique that ranks archaeological samples in thin section against a comparative collection of known cull season is satisfactory.

Keywords: MOLLUSC SHELLS, STRUCTURE, PHYSIOLOGY, SEASONALITY, OPTICAL TECHNIQUES, ISOTOPES, MINERALOGY, TRACE ELEMENTS, NEW ZEALAND.

INTRODUCTION

Studies of settlement patterns in archaeology depend on knowing the seasons of the year that individual sites were occupied. Although seasonal occupation would generally have related to the exploitation of available food resources, it is frequently misleading to use evidence of the surviving food remains to deduce the seasons in which a site was occupied: preservation and trade of food items often separate the season of collection from that of their consumption, and the chance difference in durability of food remains (fruit, birds, fish or mammals) that would have been available at different times of the year could remove, consistently, any evidence of one season's occupation. Remains of shellfish are an exception since shellfish decay rapidly unless they are preserved, and an important facet of shellfish preservation is the removal of the fish from the shell soon after collection, and the discarding of the shell. Furthermore, shells contain seasonal growth patterns and are found in many sites, and therefore are more reliable indicators of the season of occupation.

The season of collection of archaeological shells has been estimated by investigators using a variety of techniques developed in the disciplines of biology, geophysics and palaeontology. These include the analysis of whole and sectioned shells by x-ray, transmitted light and reflected light, acetate peel and thin section, and the analysis of the isotopic composition of the shell. (For example, Shackleton 1973; Coutts 1974; Koike 1979; Clark 1979). There are, however, other techniques including the analysis of shell mineralogy and trace element content that have not yet appeared in archaeological reports.

Since shellfish remains are a common component of archaeological sites in New Zealand, techniques of deducing patterns of subsistence from their analysis are of

great importance. The possibilities of analysis have been assessed by the writer in order to study shells from midden deposits excavated by the New Zealand Historic Places Trust and a summary of that assessment forms the basis of this paper.

STRUCTURE AND PHYSIOLOGY OF THE MOLLUSC

Before considering the possible methods of examination, it is first necessary to understand something of the physiology of the mollusc. Although the following has potential application to all molluscs with shells, most of the data has been drawn from studies of bivalves.

The mollusc shell (Fig. 1A and B) is a highly organised structure with mineral (calcareous) and organic components. In transverse section, from umbo to shell margin along the line of maximum growth, the calcareous component has two major kinds of stratification: shell layers and growth increments (Fig. 1C and 2A).

The shell may be divided into two or three layers (depending on the species), each formed from distinct structural and, sometimes, mineralogical units (Taylor et al. 1969). The main factor controlling the distribution of structural units is genetic, but environmental influences have also been recognised: periodic changes in structural type within a layer are correlated with seasonal and geographical variations (Lutz 1976b; Omori et al. 1976) and the degree of development of the inner layer in mytilids (mussels) is correlated with growth temperature (Dodd 1964; Zolotarev 1974).

Growth is apparent in transverse sections as incremental bands (Fig. 2A). The increments are repetitive units of contemporaneous growth detectable across all layers in an accreting tissue (Pannella and MacClintock 1968; Clark 1974; Rosenberg 1975). Each increment contains a layer of calcium carbonate and a smaller layer (or lamina) of organic material (conchiolin), and may be regarded as a periodic episode in calcium carbonate deposition; the organic lamella here corresponds to an interruption in calcification and the increment boundary is defined by the beginning of calcium carbonate deposition. Growth increments are best observed in the outer shell layer where the angle between the surface of maximum growth and growth increments is large (Pannella and MacClintock 1968).

The mantle controls shell growth: it allows calcium, calcium bicarbonate and carbon dioxide to pass into the extrapallial fluid between it and the inner shell surface to form crystals of calcium carbonate. It also secretes organic material which forms the matrix, on and within which the crystals orient and grow (Wilbur 1976). The mechanism whereby calcification is interrupted has yet to be resolved but several hypotheses have been suggested:

(1) Crystal formation is reduced, either as the rate of secretion of organic material is increased (Wilbur and Simkiss 1968) or as the rate of secretion of nacreous matter is reduced (Wada 1972);

(2) Crystal formation is inhibited, either by the periodic secretion of an insoluble organic matrix (Watabe 1965), or by a reduction in pH caused by crystal precipitation during periods of high pH (Wilbur 1972);

(3) Organic lamellae result because of valve closure; either the withdrawal of the mantle into the shell allows the growing shell edge to come into contact with the accreting periostracum (outer organic layer) where conchiolin has not yet entirely polymerized (Thompson 1975), or previously deposited shell is dissolved to neutralise the succinic acid produced during anaerobic metabolism (Crenshaw and Neff 1969; Lutz and Rhoads 1977; Gordon and Carriker 1978).
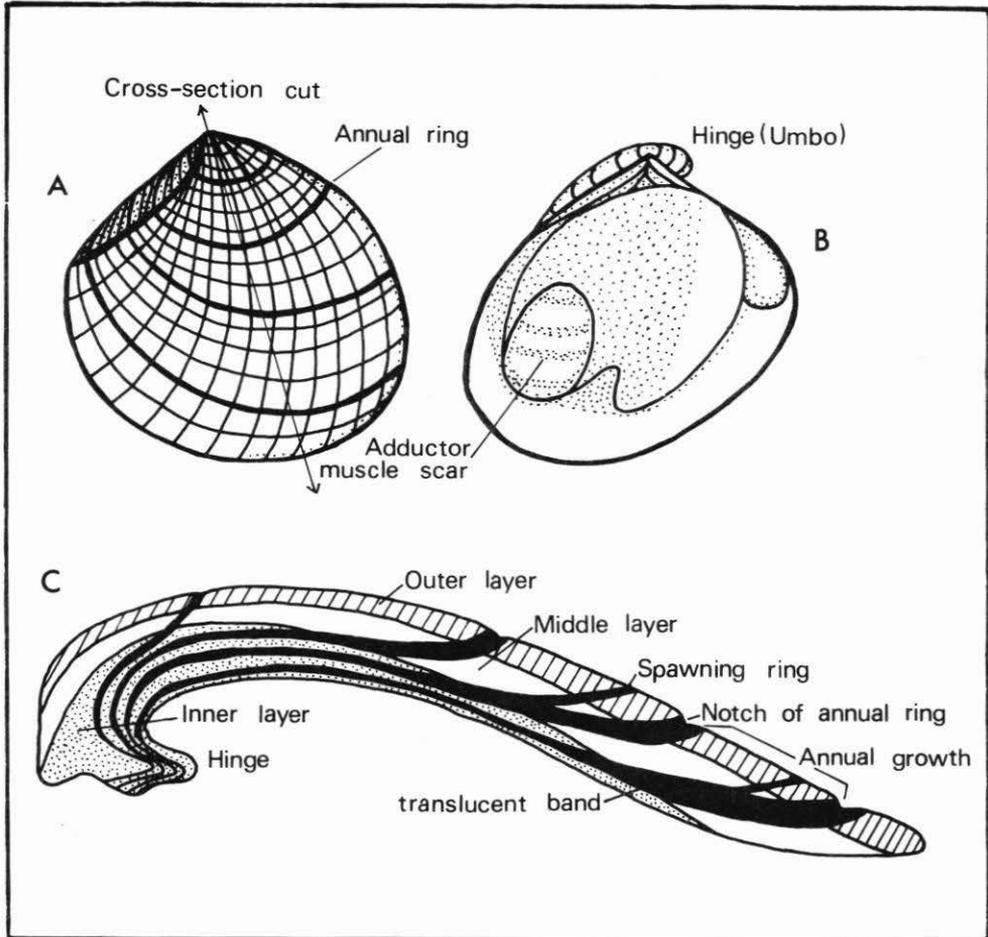
Figure 1: A. Outer surface of shell valve showing annual rings and line of maximum growth. B. Inner concave surface of shell valve showing rings on adductor muscle scar. C. Diagrammatic transverse section of shell showing internal structure: layers (inner, dotted; middle, clear; and outer cross-hatched) and growth patterns (spawning band and annual band. Banding in inner shell layer and hinge is also illustrated).

Although the relationship between physical variations in the shell and fluctuations in the environment was recognised as early as 1923 (Weymouth), very little research was carried out until interest was stimulated by the publication of two papers, one suggesting that daily increments in fossil organisms could be used as geochronometers (Wells 1963), and the other pointing out that shell growth patterns could be classified and correlated with environmental variables (Barker 1964).

Recent research has indicated that incremental shell growth in bivalves correlates well with valve movements. When the valves are closed, calcification is interrupted. Valve closure appears to be controlled by an endogenous cycle that is responsive to fluctuations in the environment, such as the cycles of solar and lunar days, while growth is also affected by seasonal fluctuations in temperature, food, light and wave

activity. Changes in shell growth are characterised by variations in increment thickness, crystallography, pigmentation and translucency, as well as topographical variations such as grooves or notching on the surface of the shell (Pannella and MacClintock 1968; Clark 1974; Berry and Barker 1975; Evans 1975; Hall 1975; Thompson 1975; Odiete 1976; Omori *et al.* 1976; Wada and Fujinuki 1976).
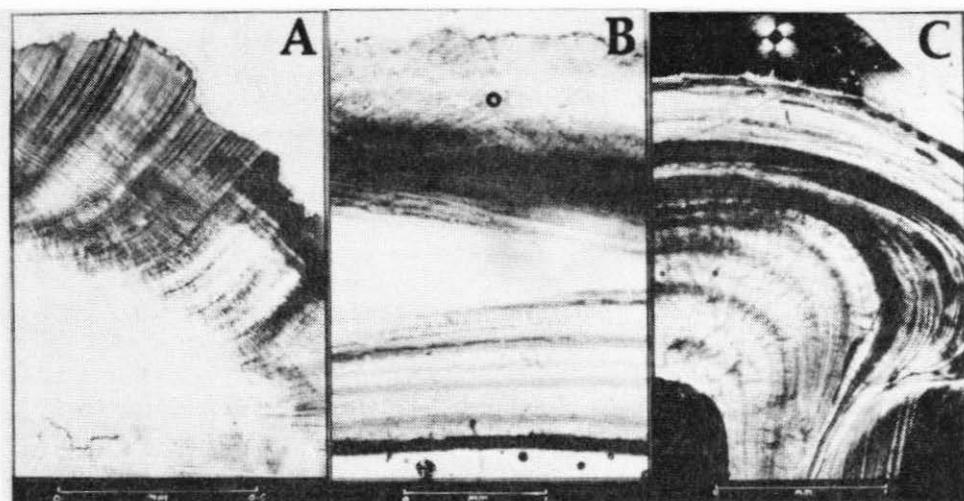

Figure 2: A.Photograph of transverse section through shell (*Chione stutchburyi*) showing two layers (outer and middle) and the growth increments in the outer layer. B. Photograph of transverse section through shell (*Chione stutchburyi*) showing three layers, and within the inner layer the shell growth patterns. C. Photograph of transverse section through hinge (*Chione stutchburyi*) showing shell growth patterns in inner layer.

In addition to direct environmental influences, shell growth is affected by physiological events such as gametogenesis and spawning, and could be affected by the physiological rhythms of feeding and digestion, and oxygen consumption. These physiological periodicities are themselves modified or triggered by environmental factors (Ansell 1961; Bayne *et al.* 1977; Mathers *et al.* 1979).

The relationship between interacting physiological and environmental variables and shell growth has been shown by various authors to be more complex than initially supposed, and is complicated by variation between species, and with age, latitude, and local environment (Crabtree *et al.* 1980). A complete understanding of the complexities of a mollusc's growth is not necessary for archaeological research however, only those aspects that have been accepted as indicators of the season of its death.

ANALYTICAL TECHNIQUES

Numerous techniques have been developed to study the development of molluscs. Not all are applicable to archaeological research but some are of considerable importance. The discussion that follows is of techniques that have been applied to material from archaeological sites, and of others that hold promise for future

application. They all require the samples of shells to conform to five basic requirements:

(a) The shells must be well preserved with no obvious diagenetic alteration.

(b) The shells must reflect clearly observable seasonal periodicities in growth.

(c) Shell growth should occur for most, or all, of the year.

(d) Growth rate has to be sufficient to allow identification and measurement (by sampling or otherwise) of discrete growth increments right up to the outer edge of the shell.

(e) There must be an understanding of the relationship between the growth pattern and local environmental or physiological variables to establish at what time of the year particular periodicities occur and how much growth can be expected to occur at different times.

TECHNIQUES ALREADY APPLIED TO ARCHAEOLOGICAL RESEARCH

1. Physical Examination of Whole Shells

Concentric grooves or rings on the surface of shells (Fig. 1A) have long been interpreted as marking an annual cessation of, or reduction in growth, usually in winter. Crescent-shaped rings in the adductor muscle scars of the inner shell surface (Fig. 1B) have been similarly interpreted (Larcombe 1971; Butler and Brewster 1979). The analysis of rings on the outer shell surface has had wide application in biological investigations and more recently in archaeological studies. Archaeologists have used the annual rings to determine patterns of prehistoric shellfish exploitation: intensity of exploitation, chronological sequence of middens, and season of exploitation. Several techniques for recognising annual rings have been used: reflected light—where annual rings are visible as grooves (Ham and Irvine 1975; Swadling 1976, 1977); transmitted light—in shells held in front of a strong light source the annual rings show up as translucent bands (Weide 1969; Ham and Irvine 1975); and transmitted x-rays—where the annual rings show up as dark bands. This latter technique was used to examine echinoderms (Coutts and Jones 1974).

The use of annual rings for determining rates of growth and season of death requires an understanding of the nature of their formation and of the season of occurrence in the species under study. Observers have noted, while sampling populations or observing marked individuals, that "disturbance" rings (related to storms for example) and spawning rings occur that are often difficult to distinguish from annual rings. Furthermore, annual rings are obscure in shells from warm waters, in the vicinity of the umbo (hinge) where shells are often abraded, and in old shells where recent rings become crowded. These difficulties have been noted by several authors, including more recently, Rhoads and Pannella 1970; Farrow 1971; Lutz 1976a; Taylor and Venn 1978.

In an attempt to overcome the problem of identifying disturbance rings, Craig and Hallam (1963) measured all visible growth rings and plotted a size frequency histogram in which annual rings were distinguished as peaks. However, this method requires large numbers of shells and the difficulty in distinguishing compact rings remains. Furthermore, the inability to identify an annual ring until rapid growth has commenced (Swadling 1976) reduces the precision of any estimates of season of death based on the position of surface rings. Ham and Irvine (1975), reviewing techniques of analysis, conclude that the analysis of surface growth rings using transmitted or reflected light is not sensitive enough either to locate annual rings on the ventral edge of the shell valve, or to measure small amounts of growth after the

most recent annual ring, making it difficult to infer a correct season of death; they recommend examining growth patterns in a transverse section through the shell, a method that has been advocated by several other researchers (including Pannella and MacClintock 1968; Farrow 1971; Lutz 1976; Clark 1979), and used by many more.

2. Study of Growth Patterns in Transverse Sections

Growth patterns as viewed in the transverse section (Fig. 1C) tend to show as rhythmic changes in pigmentation, translucency, crystallography and increment size. During a seasonal growth-decline the shell becomes pigmented and translucent, crystals tend to become crossed-lamella in structure, and increments become closely spaced. Notching of the outer shell layer may also occur (Clark 1979).

The season in which a shellfish died is determined by measuring the distance or the number of increments from the shell margin to the most recent periodic pattern (such as a seasonal growth-decline) and comparing the amount of growth with an analogous modern shell for which the collection date is known. Such estimates have been obtained for archaeological collections of shellfish, from "absolute" counts of growth increments (Coutts and Higham 1971; Coutts 1974; Koike 1979) or by estimates of the amount of annual growth that has occurred (Ham and Irvine 1975; Rowland 1977; Clark 1979).

Crabtree et al. (1980) investigated the consistency of growth-line recognition between researchers and found that, although there was excellent agreement in the ranking of specimens using line counts, absolute line counts varied significantly. The writer has also found that there is difficulty in delineating objectively the beginning or end of a periodic pattern, and the timing of the pattern varies from year to year. In addition, comparisons should not be made between analogous populations from different geographical locations, since environmental events and genetic influences may be locally distinct: one population may undergo a reduction in growth rate in winter whereas another population could show a growth reduction response to summer conditions (Larcombe 1971; Clark 1979). In combination these factors could produce significant errors in any analysis, and claims for high levels of accuracy cannot be justified using this technique in its present state of development.

Techniques for viewing transverse sections range from looking at polished shell segments to detailed microscopic examination of thin sections or acetate peels (Sheppard 1984). Staining of the shells can accentuate differences in carbonate and organic composition and may form a preliminary to any of the techniques. (However, in the writer's experience, its value is somewhat dubious because clarity varies with shell species). Polished sections reveal pigmentation and can be used in microprobe analyses. Acetate peels and the scanning electron microscope record microtopography and are used in growth increment and crystallographic analyses. Thin sections show pigmentation, translucency, mineralogy, crystallography and growth increments.

The acetate peel technique is rapid once the optimum etching time is established and is widely used, but the optimum etching time varies for different layers (Wise and Hay 1968) thus requiring several peels of the same section to be taken to obtain clear replicas of all layers. The peel does not show variations in pigmentation or translucency. Thin sections, on the other hand, are time-consuming to prepare and first require an optimum thickness of section to be established. This varies with shell species, individual shells and to some extent the layer under study. In the writer's experience, the ideal thickness appears to be between 60 and 100 microns, in contrast

to the standard geological section of 30 microns. However, the important advantage of thin sections is that they do record pigmentation, translucency and detail of the microstructure on a single preparation.

The vagaries of individual criteria have led the writer to favour a method for obtaining seasonal estimates of death by comparing archaeological specimens with shells of known cull season using modern specimens regularly collected over a period of at least a year. Crabtree *et al.* (1980) found excellent agreement among researchers in a ranking approach and, in the writer's experience, this technique, although apparently less sophisticated than the detailed analysis of growth increments, has proved more satisfactory.

Ranking procedures are not limited to shells with complete margins. A periodicity in shell growth patterns has been observed in some shells in the inner shell layer near the hinge (Lutz 1976a) (Fig. 2B) and within the hinge itself (Merrill *et al.* 1966) (Fig. 2C); analysis and ranking of these patterns could prove very useful in archaeological investigations where many shells are fragmented or have eroded edges.

Ranking of shells can be carried out using any of the described techniques for observing transverse sections. However, since ranking is facilitated when a number of variables are considered together (increment size, pigmentation, translucency and crystallography), the thin section technique has the most potential, combining as it does all these variables on a single preparation.

3. Chemical Analysis

Chemical analysis of shells from archaeological sites is based on variations in their isotopic composition. These variations are related to environmental conditions.

Shell is formed in isotopic equilibrium with the surrounding water (Eisma *et al.* 1976) and changes in the isotope ratios of carbon ($^{13}C/^{12}C$) and oxygen ($^{18}O/^{16}O$) in the water are reflected in the shell carbonate. The isotopic composition of water varies with salinity (for example, freshwater is deficient in ^{18}O and ^{13}C compared with sea water) and temperature (for example, the lighter ^{16}O isotope is more readily evaporated than ^{18}O, so at high temperatures water becomes enriched in ^{18}O). The $^{13}C/^{12}C$ content of water is also influenced by biological activities such as photosynthesis and decomposition (Lloyd 1964; Stuiver 1970; Fritz and Poplawski 1974; Eisma *et al.* 1976).

Temperature-dependent fractionation of isotopes between shell carbonate and water (where lighter isotopes tend to be incorporated in shells as the water temperature rises), compensates to varying degrees (depending on local conditions and shell species) for the effects of temperature on the isotopic composition of water (Lloyd 1964; Stuiver 1970; Eisma *et al.* 1976). Nevertheless, oxygen isotopes in shells have been successfully used in palaeotemperature analyses and in the identification of seasonal environmental fluctuations (Urey *et al.* 1951; Epstein and Lowenstam 1953; Keith *et al.* 1964; Shackleton 1970, 1973). Carbon isotopes have been used to a lesser degree and only in conjunction with oxygen isotopes because factors governing the carbon isotopic composition are complex and in many instances make interpretation of results difficult (Urey *et al.* 1951; Keith *et al.* 1964; Yapp 1979).

The isotopic analysis of shells has been applied in archaeology to determine:

(1) where the shells were collected (Shackleton and Renfrew 1970);
(2) what environmental conditions prevailed during the lifetime of the molluscs (Emiliani *et al.* 1964; Shackleton 1970; Yapp 1979); and
(3) what season the shells were collected (Shackleton 1970, 1973).

The usefulness of shells in seasonality studies depends on the local hydrological cycle, seasonal temperature changes, and whether shell growth is continuous throughout the year or restricted to a limited range of conditions, such as water temperature. Although landsnails have recently been shown to be isotopically sensitive to changes in humidity (Yapp 1979), they have no application in seasonality studies in archaeology except where consumed by prehistoric man.

The relative abundance of carbon and oxygen isotopes is determined by mass spectrometry using shell sample of less than 1 mg (Tite 1972). This microanalytical technique allows sequential sampling of sectioned shells right up to the shell edge. Furthermore, the technique is sensitive enough to detect seasonal changes in water temperature if the annual range in temperature is greater than the week-to-week variations: in marine shells ^{18}O decreases about 0.2% for every one degree C rise in temperature (Shackleton 1973), with a standard deviation of about 0.1% (representing approximately half a degree C) (Shackleton and Renfrew 1970). Freshwater shells show greater variability in their response to temperature changes, depending on local conditions (Stuiver 1970). The technique therefore offers promising possibilities for seasonality studies.

There are several problems associated with the measurement of isotopes in seasonality studies of archaeological shells. Firstly, physical and chemical changes associated with diagenetic alteration occur when post-mortem shells are exposed to an environment differing from that in which they lived. In the event of recrystallisation or the conversion of aragonite to calcite, the isotopes in the shell exchange with the isotopes in the groundwater; this generally produces a decrease in ^{18}O (Shackleton 1973). Changes in mineralogy indicate that diagenetic alteration has occurred but, since changes in the isotopic composition may occur before there is any obvious mineralogical change, it is more reliable to assess the isotope measurements with respect to independent seasonality determinations, such as variations in structure. Although diagenesis does not appear to have been a significant factor in archaeological investigations to date, it is a process that could affect archaeological shells.

Another problem is associated with drilling samples for analysis. Although the sample required is less than 1 mg, the growth interval incorporated in a single sample can be as much as one month, particularly in the sample from the shell edge (Shackleton 1973). Filing the edge to obtain material for analysis could produce a much narrower interval between the time of death and the sample estimate, provided no recrystallisation has occurred. At least two sequential samples must be taken from a shell to determine when a shellfish died, since the value for one season may be identical to that for another and the preceding sample indicates the direction of change.

A third problem arises in a number of species with differences in isotopic content between shell layers that cannot be correlated consistently with the aragonitic or calcitic form of the shell (Keith *et al.* 1964). Although the isotopes in aragonite and calcite behave differently under experimental conditions, the relationship in molluscs is not straightforward and, as Eisma points out, "deserves further study, primarily by growing molluscs in tanks under well controlled isotopic conditions" (Eisma *et al.* 1976:49). To eliminate variations in isotopic content between shell layers, samples should be taken from a single layer; the small sample size makes this quite feasible.

Not all shells are suitable for isotopic analysis, but the technique is very promising for seasonal analysis of shells from archaeological sites provided the shells:

1. are isotopically sensitive either to seasonal changes in water temperature or to seasonal variations in the isotopic composition of water;
2. have continuous shell deposition throughout the year at a rate of growth sufficient to allow discrete sampling of growth increments; and
3. appear to have no diagenetic alteration.

TECHNIQUES NEW TO ARCHAEOLOGICAL RESEARCH

1. Mineralogy

Molluscan shell mineralogy, usually determined by powder x-ray diffraction, is dominated by two crystalline forms of calcium carbonate: aragonite and calcite. Although calcite is the most stable form (Wilbur 1964), no bivalves are known to possess a wholly calcitic shell; shells are either aragonitic or contain both aragonite and calcite (Taylor *et al.* 1969). Shell mineralogy is genetically controlled but may be modified by environmental conditions at the time of shell deposition (Kennedy *et al.* 1969): several investigations have established a correlation between temperature variations and percentage aragonite in the shell (Lowenstam 1954; Wilbur and Watabe 1963; Dodd 1963, 1964). Estimates of season of death of archaeological shells may therefore be possible for temperature-sensitive shells that contain both calcite and aragonite.

The overall mineralogy of shells is normally determined by powder x-ray diffraction but, because of sampling difficulties, this technique is not satisfactory for seasonality studies: analysis is required of a series of samples from a single shell, with each sample ideally including material that encompasses an entire growth increment; to take such a sample is virtually impossible. However, internal variations in shell mineralogy could be detected either by observing and measuring percentage aragonite in stained sections (Fiegl's solution stains aragonite black) (Allman and Lawrence 1972) or by identifying and measuring ratios of different structural types that reflect differences in mineralogy (e.g. nacreous aragonite/prismatic calcite). This latter method has the advantage of being unaffected by unsuspected diagenesis because when aragonite converts to calcite, the original morphology still remains (Dodd 1964, 1966; Omori *et al.* 1976).

The feasibility of using shell mineralogy in seasonality studies is limited by the availability of archaeological temperature-sensitive shells containing both calcite and aragonite. Four species of shellfish that are common in Maori middens around New Zealand have been analysed by the writer using powder x-ray diffraction. Three of the species *Chione stutchburyi, Paphies (Mesodesma) subtriangulata*, and *Turbo smaragdus* are purely aragonitic; only *Amphibola crenata* contains both aragonite and calcite, but the amount of calcite is very small (1 percent) and no attempt was made to ascertain the sensitivity of this species to seasonal changes in temperature. Three other species of shellfish occasionally found in Maori middens contain both aragonite and calcite: *Pecten novaezelandeae, Ostrea* sp., and *Crassostrea* sp. (Taylor *et àl.* 1969) but their relative scarcity limits their usefulness. Mytilids are temperature-sensitive (Dodd 1963, 1964, 1966) and are common in New Zealand middens, but they are generally too poorly preserved to be analysed.

It appears that the relative scarcity of potentially sensitive shell species and poor shell preservation mitigate against the use of mineralogical determinations for seasonality studies in New Zealand. However, these problems may be less acute in other countries.

2. Trace Elements

The abundance of trace elements (especially magnesium and strontium) in mollusc shells has been the subject of many investigations. Trace elements may be associated with the crystalline components, be attached to the organic matrix, or be included in certain organic molecules such as pigment molecules that contain iron and bromine (Fox 1966). Factors that determine trace element content have been described by various authors, and include: shell mineralogy, physiology and biochemistry, genetics, and environment (temperature, salinity and the availability of trace elements in water) (Dodd 1967; Wilbur 1972; Eisma *et al.* 1976).

Fluctuations of magnesium, strontium and sulphur in shells are correlated with seasonal variables (Dodd 1965; Hallam and Price 1968; Rosenberg and Jones 1975). Seasonal variations in calcium (not classed as a trace element) have also been observed (Rosenberg 1972, 1973; Rosenberg and Jones 1975).

Trace element analyses can be carried out in several ways: optical emission spectrometry, atomic absorption spectrometry, x-ray fluorescence spectrometry, neutron activation analysis, the electron microprobe (Tite 1972) and proton microprobe (Bosch *et al.* 1978; Cookson 1979). Microprobe techniques have the most potential for seasonal analysis because they scan very small areas of polished shell sections and avoid the need for removing small samples. Sampling is a problem with other geochemical techniques because for seasonal analysis it is necessary to analyse a series of samples from a single shell and there is difficulty in removing adequate material from a single layer, especially a discrete growth area. Inconsistent results for strontium analyses in *Cardium edule* have been attributed to sampling difficulties (Hallam and Price 1968), and although Dodd (1965, 1966) detected seasonal variations in samples of *Mytilus*, only the edges of shells collected at different times of the year were analysed.

Herein lies the advantage of microprobe techniques: whole transverse sections of shells can be scanned to detect variations in elements over small areas from which reasonably accurate estimates could be made of season of death. Moberly (1968) used a microprobe to measure the magnesium content of *Aequipecten irradians* and *Crassostrea virginica* and found a correlation with seasonal changes in growth rate; Rosenberg (1972, 1973) detected calcium fluctuations in *Chione undatella* that may be seasonally related; and Rosenberg and Jones (1975), analysing *Spisula* and *Cardium edule*, detected seasonal and tidal fluctuations in sulphur and calcium.

In any investigation of trace elements in archaeological shells, consideration must be given to diagenesis since cultural deposits of shells, being out of their normal environment, are susceptible to this process. Since Hudson (1968) reported high strontium values in fossil *Praemytilus* compared with modern mytilids, Walls *et al.* (1977) have shown that the degree and direction of alteration of trace element content is influenced in part by shell mineralogy: aragonitic shells tend to become enriched in strontium and depleted in magnesium with age, while calcitic shells seem to be depleted in both strontium and magnesium with age. Although mineralogy can indicate diagenetic alteration (e.g., if a purely aragonitic species has converted partially to calcite in fossil form), its usefulness as an indicator is limited because of the variety of factors which can affect the mineralogy of a living shell. Furthermore, diagenetic alteration of trace elements may occur before there is any apparent change in mineralogy or structure (Turekian and Armstrong 1961; Pilkey and Goodell 1964; Walls *et al.* 1977). However, if reputed diagenetic tendencies are considered (such as the depletion of magnesium with age and therefore increasing difficulty in detection) and if observed variations in trace elements could be

correlated with independent seasonality determinations (such as structural variations), the effects of diagenesis in seasonality studies of archaeological shells could be minimised. A second potential error resulting from variations in trace elements between different shell layers, is minimised if the analysis is carried out on a single shell layer.

In order to investigate the potential of trace element analyses of shellfish common in middens in New Zealand, the writer carried out a preliminary investigation of trace elements in four species of shellfish (*Turbo smaragdus, Chione stutchburyi, Amphibola crenata*, and *Paphies (Mesodesma) subtriangulata*) using atomic absorption spectrometry. The results, based on whole shells, indicated that the ratio of strontium:magnesium was nearly 10:1 (approx. 0.1% Sr, 0.01% Mg) in all species except *Amphibola* where the ratio was 10:2 (0.02% Mg). Even though *Paphies* was collected from an exposed sandy beach at Otaki (west coast, North Island) and the other species were collected from a harbour environment at Porirua (also west coast, North Island), there is a marked similarity in the concentrations of strontium and magnesium. Furthermore, this similarity exists between bivalvia (*Chione* and *Paphies*) and gastropoda (*Turbo* and *Amphibola*).

An attempt was made to determine whether seasonal fluctuations in trace elements occurred and could be measured. Polished transverse sections of *Chione* shells (archaeological and fresh specimens) and *Paphies* shells (fresh specimens only) were analysed using a proton microprobe. No trace elements were detected, apart from a small amount of strontium, and there were no measurable differences between the different species or between the archaeological and fresh specimens. These results are inconclusive since they may be due to the selection of insensitive species for study, the collection of shellfish from well buffered environments where seasonal fluctuations in trace element content would not be very great, or some other factor.

The proton microprobe is more sensitive to light elements than the electron microprobe, and if trace element concentrations are too low to be measured by the proton microprobe, there is less chance of their being measured by the electron microprobe (G. Coote, pers.comm.). Since the electron microprobe has already been used successfully in trace element analyses of shells, the technique would appear to be quite feasible for determining season of death of shellfish. Its lack of success in New Zealand may be worthy of note at this stage, but it is not yet possible to determine whether this suggests:

(a) a need for New Zealand's practitioners to refine their techniques;
(b) that the samples on which it is used in New Zealand do not respond to microprobe analysis; or
(c) that their trace element content does not conform to the predicted pattern.

CONCLUSIONS

The techniques examined in this paper are based on five different approaches to studying seasonal changes in a mollusc's physiology.

A. Techniques that involve mechanical sampling are prone to contamination from adjacent growth areas. This problem is particularly acute at the shell edge where the growth increments become increasingly compact with age. Nevertheless, isotopic analysis has been used with apparent success to indicate season of death.

B. Optical techniques are widely used and those based on the analysis of a thin section have the greatest flexibility. Since detailed analysis is very time-consuming

and objective observation is difficult to achieve, a simple ranking procedure appears to be a satisfactory method when deducing season of death.

C. Microprobe techniques avoid the problems associated with mechanical sampling techniques and optical procedures and could be used to obtain an accurate record of a mollusc's life; however their value in New Zealand contexts has yet to be established.

NOTE
1. Present address: Department of Community Health, Wellington Clinical School of Medicine, Wellington Hospital, Wellington.

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