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Exploring shell midden formation through tapho-chronometric tools: A case study from Beagle Channel, Argentina

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Abstract

Time resolution of shell middens is normally addressed through estimation of shell accumulation rates, where calculations are based on radiocarbon analysis. Density values by volume or discard rates by time units are also normally estimated for comparative purposes. In this paper, we support the idea that time has many measurable properties in archaeological deposits. These can be used as tapho-chronometric tools (e.g., bone weathering, shell fragmentation, soil formation, etc.) to identify differential time-averaging in shell midden formation, and to evaluate their archaeological implications regarding the material record. One site in the Beagle Channel, Argentina, was chosen to (a) demonstrate how different processes that interact in shell midden formation can provide information on temporal resolution and (b) discuss the implications of the time-averaged properties of shell middens for different analytical approaches and methodological pathways. Results show that several factors involved in the formation of mounds should be addressed prior to advancing interpretations about different behavioral aspects of the past: a) shell deposits do not necessarily represent a gradual accumulation of waste; b) these middens can represent occupations of varied duration that are expressed independently of both the thickness of the deposit and the rate of accumulation of the material; c) the formation of shell middens includes the actions of several cultural and natural processes that occur over variable time spans; d) re-occupations modify the shell deposits produced by previous occupations in the same location. Finally, we argue that to explore shell middens as time-averaged records helps to clarify distinctive aspects of mound formation, which in turn have significant effects on archaeological interpretations.

Keywords

Cumulative palimpsests; Coastal archaeology; Niche construction; Time resolution; Tierra del Fuego

1. Introduction

Shell midden formation occurs at a variety of tempos, and involves behavioral, formational and evolutionary processes, among many others. These archaeological deposits, by virtue of their temporal structures, potentially capture processes operating over different time spans. Archaeological excavations in the Beagle Channel (Tierra del Fuego, Argentina) have shown that the formation of shell middens resulted from repeated occupations in the same place (Orquera et al., 1977; Orquera and Piana, 1986-87, 1996, 1999a; Yesner, 1990; Estévez and Vila, 1996, 2006, 2007; Piana, et al. 2004; Álvarez et al., 2009; Zangrando, 2010; Zangrando et al., 2016). These re-occupations are indicated both by short-term but continuously repeated accumulations of shells and/or by reuse of the same place after long-term hiatuses at the century or millennial scale. As such, shell midden formation has been seen as the result of long-term practices in which the accumulation of shell deposits promoted subsequent reuse (Mackie, 2001; Piana and Orquera, 2010). Shell middens form dense clusters extensively distributed along the coastlines of the Beagle Channel to such a degree that they represent a prominent anthropogenic feature in the coastal environment (Figure 1). These high-density patches of shell middens were functionally distinct nodes in the mobility patterns of hunter-gatherer-fisher societies. From an exhaustive survey undertaken in Cambaceres Bay (Bjerck et al., 2016), it is possible to estimate that shell midden formations cover approximately 10% of the surface between the limit of the maximum marine transgression of the Middle Holocene (Zangrando et al., 2016) and the current coastline. In turn, shell accumulations release a high concentration of $CaCO_3$ into the surrounding soil matrix, creating soils that modify growth conditions for local ground vegetation (Panigatti, 2010: 271). In this respect, the human exploitation of molluscs and the resulting shell accumulations in the Beagle Channel may be considered as a process of niche construction of benefit to future occupants, in which the cumulative discard of shell transforms the coastal setting (Zangrando, 2018). This long-term practice is the defining factor of shell middens and provides a good example of a cumulative palimpsest “in which the successive episodes of deposition, or layers of activity, remain superimposed one upon the other without loss of evidence, but are so re-worked and mixed together that it is difficult or impossible to separate them out into their original constituents” (Bailey, 2007: 204).

Figure 1. Panoramic view of an agglomeration of shell mounds at the Cambaceres Bay (Beagle Channel).

In the Beagle Channel, shell middens have been examined in different ways. For example, in some studies shell-matrix units have been amalgamated into components or phases in order to highlight long-term cultural and adaptation processes (e.g., Orquera and Piana 1999a). In other studies the shell-matrix has been sub-divided into smaller units in order to focus on day-to-day activities (e.g., Estévez and Vila, 2006). Here, we explore the structure of a shell midden from the Beagle Channel by utilizing different tapho-chronometric tools (Wandsnider, 2008), which operate over different time spans, as a way of demonstrating how different processes, interacting within shell midden formations, are informative about the temporal resolution of the deposits. This approach offers the opportunity to identify the most appropriate sorts of archaeological information that can be obtained from these deposits, given their temporal resolution (Bailey, 1981, 2007). We examine the processes involved in the formation of these cumulative contexts in the Beagle Channel through one case study. Based on our results, we then discuss the implications of time-averaged properties of shell middens for different analytical approaches and methodologies.

2. A tapho-chronometric approach

Time resolution in shell middens is normally addressed through different methodological strategies. Studies of the time-related accumulation of shell middens typically focuses on identifying the overall duration of the accumulation (Stein et al., 2003), mainly relying on radiocarbon analysis. The use of density values – quantities of material per unit volume – is also popular in shell midden research, used mainly to estimate the proportional representation of artefacts and faunal remains as a mean of reconstructing past human activities (Bailey, 1975; Buchanan, 1988; Cannon, 2001, Orquera and Piana, 1999a: 101, Zangrando, 2009: 140). However, it is also acknowledged that the use of these methods is not without issues. The main problem is the general assumption that the rate of shell deposition was uniform throughout the course of an occupation, or that it did not vary between different occupations at the same location or between different locations. Accordingly, it is assumed that the density estimates are independent of the rates of shell midden accumulation during which archaeological items were incorporated (Jerardino 1995). However, based on a variety of ethnoarchaeological and archaeological studies, it is clear that accumulation rates of shell middens can vary according to diverse social and mobility factors (Meehan, 1975; Waselkov, 1987; Claassen, 1991). Evidence for changing functions has been recorded in multicomponent shell middens, in which rates of shell discard varied through the sequences (Orquera and Piana, 2000, 2001). Recently, novel methods have been developed to improve estimates of temporal resolution in shell-bearing deposits. These include Bayesian modeling (e.g., Lombardo et al., 2013; Jew et al., 2015), micromorphology (e.g., Villagran, 2019), stable isotope analyses (e.g., Hausmann and Meredith-Williams, 2017), and photogrammetry (e.g., Sanger, 2015), among others.

In this paper, we emphasize two related factors arising from a time-perspective approach (Bailey, 2007; Bailey and Galanidou, 2009). The first is *duration*, which refers to the tendency of any kind of archaeological object of collection of archaeological materials to persist through time, something which cannot easily be measured by radiocarbon analysis. The second is the *resolution* of an archaeological deposit, something which, in principle can be measured by absolute dating methods, but where the accuracy of the available dating methods, especially radiocarbon dating, may be inadequate to resolve a rapidly accumulated shell mound into its individual constituent episodes of shell deposition (Hausmann and Meredith-Williams, 2017). These concepts highlight the need to focus on tapho-chronometric tools (Wandsnider 2008), which can measure time-related transformations in archaeological deposits and thus reveal processes at play in shell midden formation operating in modes and tempos that cannot be captured by radiocarbon analysis.

2.1. Pedogenesis

When shell accumulation is interrupted, the prolonged stability of the surface of the midden will encourage pedogenesis. This process includes the contribution of organic matter from vegetation that colonizes stable (non-depositional) sectors of a site, and this in turn encourages the activity of soil organisms. Soil formation is also conditioned by climatic variables such as quantity and annual distribution of rainfall, among other factors (Buol et al., 1998). Weathering alters the texture and composition of sediments, shells and bones which remain on the surface, and it is likely one of the main factors that helps to identify stratified layers in shell middens (Stein, 1992: 136). As part of the basic weathering cycle, clay minerals absorb water molecules and react with organic matter (Limbrey, 1975:3-6; Buol et al., 1998: 116).

When shell deposition is interrupted, this primary process of soil formation potentially results in layers that are darker and contain more clay, but this effect is not always visible in the stratigraphy at a macroscopic scale of observation. As such, measuring the proportion of clay and organic matter content in sediments is necessary to identify the incipient processes of soil formation (Crowther, 2002; Holliday and Gartner, 2007), and thus to identify episodes of stability in the formation of the midden deposit. This process is identifiable from textual and organic content analyses, and should be distinguished from accumulation of sediments in midden deposits because of leaching by the passage of groundwater, as seen, for example, in deposits on the Northwest Coast (Stein, 1992; Sullivan, 1993). Soil phosphorus analyses can also significantly contribute to these discussions of shell midden formation; organic phosphorus strongly binds to clay minerals as organic matter and is highly stable and may persist in soils for a long time (Holliday and Gartner, 2007). The development of incipient soils in shell-matrix sites can also be identified through micromorphological studies (Balbo et al., 2010; Villagran, 2019).

2.2. Shell fragmentation

Shell fragmentation can be used as a sensitive tool to measure variations in the history of shell-midden formation (Claassen, 1998; Bourke, 2004; Balbo et al., 2010; Jerardino, 2018). Highly fragmented shell is likely to be caused by diverse factors after initial discard, such as weathering or trampling (Muckle, 1985; Gutiérrez Zugasti, 2011; Estévez et al., 2014; Hammond, 2014; Zangrando et al., 2017; Pérez, 2020). When the rate of shell deposition is interrupted or much reduced, higher shell fragmentation rates are expected, since shell on the midden surface is exposed for long periods to weathering or to disturbance by humans and other animals, among other taphonomic factors that alter shells. As shells of different taxa have different degrees of hardness and resistance, the rate of shell fragmentation can also vary by taxonomic composition (Muckle, 1985; Waselkov, 1987).

2.3. Bone weathering

According to Behrensmeyer (1978), the bone weathering process involves mechanical and chemical changes to the original integrity of bones over time. She provided observable criteria (e.g., fractures and flaking) to identify different stages of bones exposed on a surface and the duration of their exposure (but see Lyman and Fox 1989), measurable in years (plus or minus 15 years). Comparable weathering stages for bones in a savannah environment at Amboseli National Park have been observed (Behrensmeyer 1978). Although this location can be considered a suboptimal analogue for the sub-Antarctic environments of Tierra del Fuego, the bone weathering processes recorded in Fuegian settings are similar to those observed in Kenya (Borrero, 1990, 2007; Alunni et al., 2017).

A long-term experimental study carried out in Buenos Aires Province (Argentina) has shown that all the skeletal parts of guanaco (*Lama guanicoe*) show some degree of weathering after two years of exposure (Gutiérrez et al. 2016). Bone weathering stages are used in this paper as relative indicators, not as precise time measures of the duration that bones have been exposed on the surface. In this sense, bone weathering is employed to strengthen interpretations of the temporal resolution of archaeological deposits, and to show differential time-averaging among assemblages (Stern, 1993).

2.4. Hearth structures

The location of hearth features indicates the reoccupation or renewal of an abandoned surface. Hearths and the related materials of these features can be used to explore intra-site and inter-site variations in the overall time structure of the archaeological record (Estévez and Vila, 2006; Wandsnider, 2008; Bailey and Galanidou, 2009; Piana and Orquera, 2010; Villagran et al., 2011a). Large areas of burning identified on extensive surfaces of shell middens from the Beagle Channel (Orquera and Piana, 2001; Piana et al., 2004) also play a prominent role in determining the use histories of these cumulative palimpsests. According to ethnographic information (Hyades and Deniker, 1891: 379; Orquera and Piana, 1999b: 288), these burnings could be related to the preparation of the place for its reoccupation.

3. Case study

Heshkaia 35 is an archaeological site located at the southern tip of South America in the Moat Bay (Tierra del Fuego, Argentina; Figure 2). The coastal landscape of Moat was widely affected by the action of the Last Glacial Maximum. Along the coast, a field of drumlins covers approximately 80 km^2 (Borromei et al., 2014), appearing as rounded hills. Trees of *Nothofagus* sp. (Southern Beech) are patchily distributed from the coast to the hills, and are interspersed with bogs and shrubby areas.

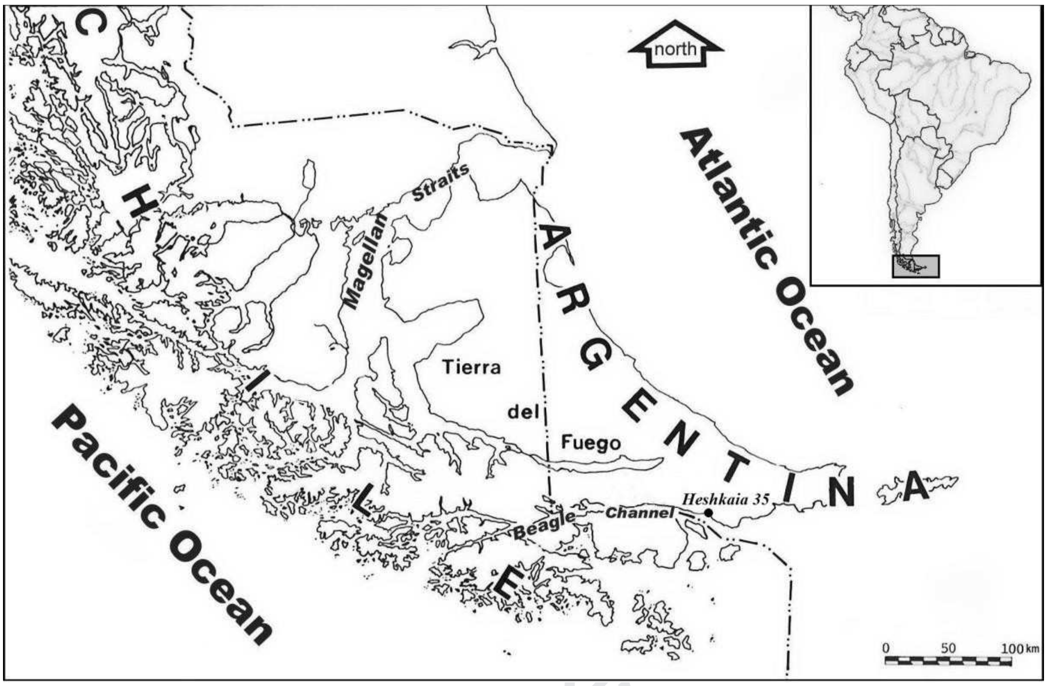

Figure 2.Geographical location of the Heshkaia 35 archaeological site.

Heshkaia 35 is a shell-bearing midden situated 20 m above present sea level and 200 m from the current shoreline (Figure 3). This site covers a surface of 120m^2 and includes a mound with a maximum height of 0.7m. A total surface area of 19m^2 was recently excavated to the underlying glacial deposits in order to obtain archaeological and palaeoecological information (Zangrando, 2010; Alunni and Zangrando, 2012; Zangrando et al., 2014; Zangrando et al., 2017), including an 8 m^2 trench (Trench II). The excavated deposit was sieved through 1.5 mm mesh.

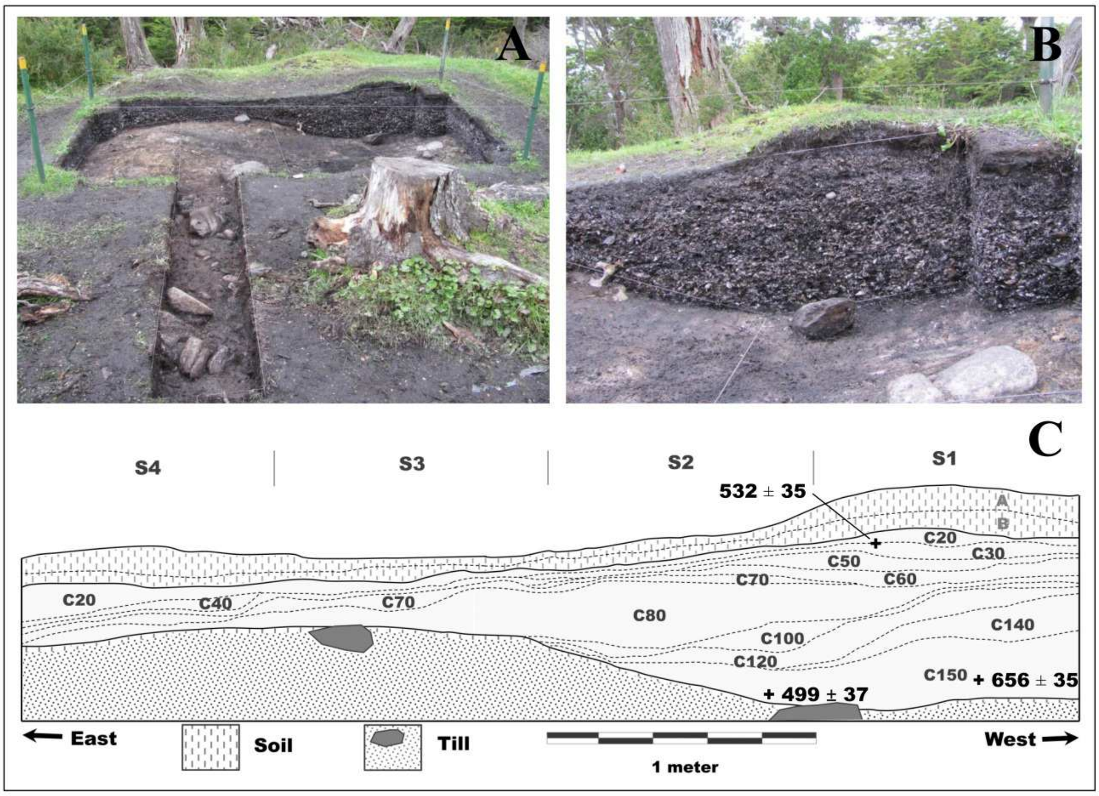

Figure 3 A. Lateral section of the shell mound (Trench II) of Heshkaia 35. B. Shell midden section of sectors 1 and 2 (Trench II). C. Drawing of lateral section of Trench II including subunits of Layer C and locations of radiocarbon dates.

3.1. Stratigraphy and bulk sediment sampling

The stratigraphy comprises four main units (Figure 3C): the current soil (horizons A and B), the shell-bearing level defined as layer C, and the glacial till deposit at the base. The natural soil layer on the surface comprises an upper layer, A, with a high density of roots and accumulation of organic material (e.g., leaves, pieces of bark), and layer B characterized by a dark brown silt matrix. Archaeological materials were recovered from Layer B. The excavation of the shell midden (or layer C) was performed following the method proposed by Orquera and Piana (1992). Stratigraphic units were differentiated by litho-stratigraphic characteristics, which included both the composition of the sedimentary matrix and the composition and condition of shells. Thus, a superimposed series of 10 dense and extensive shell-bearing levels or subunits was identified.

Bulk sediment samples were obtained from contiguous sectors of Trench II from each subunit of layer C to assess variability in shell-midden composition throughout the stratigraphic sequence. Ten samples with an original volume of 4 litres were sorted and analyzed in the laboratory using methods described in Orquera and Piana (2000). A comprehensive report on the composition of the shell midden and molluscan assemblage has already been published (Zangrando et al., 2017). More than 95% of the shell-midden matrix is composed of valves and fine sediment in similar proportions throughout the sequence. Higher frequencies of fine sediment were observed in C20 and C30, which is to be expected, given that these are the subsurface stratigraphic units in contact with Layer B (Zangrando et al., 2017).

3.2. Chronology

All radiocarbon analyses were performed by the Arizona AMS Facility (Table 1). Three radiocarbon dates have been obtained, two from the bottom of Layer C (656 ± 35 BP on *Nothofagus* charcoal, and 499 ± 37 BP on guanaco bone) and the third from the top of layer C (532 ± 35 BP on *Nothofagus* charcoal). A fourth radiocarbon sample from a hearth feature located outside the shell midden area provided an older radiocarbon estimate (816 ± 35 BP on *Nothofagus* charcoal), indicating a feature used prior to the formation of the shell mound. The dates from the guanaco bone from the base of the midden and the charcoal date from the upper level are very similar, suggesting a relatively rapid accumulation of shell within the margins of error of radiocarbon dating (Figure 3C). However, the charcoal date from the base of the midden is significantly older. In interpreting these dates as evidence for rates of accumulation, we need to take account of two potential sources of error. The first is a marine offset in the date of the guanaco bone because of the possible incorporation of seaweed in the guanaco diet (Yesner et al., 2003). However, that possibility can be rejected, given the $\delta^{13}C$ value of the sample (Table 1), which is consistent with a terrestrial diet. The second potential source of error arises from the fact that *Nothofagus* is a long-lived tree and charcoal samples taken from the same tree can vary in date by as much as several hundred years depending on whether the wood sample came from the inner or the outer rings of the tree. That is a possible reason for the large difference between the basal guanaco and charcoal dates even though they come from the same subunit of Layer C.

Calibration of the radiocarbon dates, taking all three at their face value, gives a maximum temporal range between the top and the bottom of the shell midden deposit of 653 to 497 cal. BP (Calib 7.1 [2σ - SHCal13], Hogg et al. 2013). Using the difference between the calibrated median probability ages gives a temporal range of approximately 82 years, indicating an accumulation rate of ca. 73 cm /100 yr in this particular area of the site. However, in spite of the short time range involved, this rate of accumulation does not necessarily mean that the accumulation of shell midden deposit can be assumed to have been a continuous process.

It is also relevant to note that the occupation of the site occurred during the climatic episode of the Little Ice Age (700–100 cal. BP) (Moreno et al., 2014). In the region of the Fuegian Andes, this is associated with a neoglacial advance (Menounos et al., 2013), and has been identified in the pollen records from Tierra del Fuego by a decrease in *Nothofagus* pollen (Heusser, 1989; Borromei et al., 2010, 2016; Musotto et al., 2016). In the Beagle Channel area, *Nothofagus* declined to reach a minimum between ca. 680 and 300 cal. BP (Borromei et al., 2010, 2016). Considering the short temporal range of the shell midden and its formation during this climatic episode, significant fluctuations in precipitation that might have affected pedogenesis or aeolian processes within the deposit can be ruled out.

Lab number	Trench	Layer	Material / taxa	$\delta^{13}C$	^{14}C age BP	Calib. age BP	Median Probability
AA90434	II	C150	charcoal/*Nothofagus*	-26.2	656 ± 35	548 - 653	605 cal. BP
AA98121	II	C20/C30	charcoal/*Nothofagus*	-25.5	532 ± 35	497 - 550	523 cal. BP
AA103903	II	C150	bone/*Lama guanicoe*	-21.7	499 ± 37	463 - 546	510 cal. BP
AA98119	I	B	charcoal/*Nothofagus*	-25.9	816 ± 35	660 - 743	702 cal. BP

Table 1. Radiocarbon and calibrated ages from Heshkaia 35 site (Calib 7.1 [2σ - SHCal13], Hogg et al. 2013).

3.3. Archaeological assemblages

Technological and zooarchaeological assemblages show the development of multiple activities at Heshkaia 35 (Table 2). The zooarchaeological evidence indicates a significant exploitation of guanaco (Alunni and Zangrando, 2012; Alunni, 2018) and the use of smaller coastal resources (birds, fish and molluscs) (Zangrando et al., 2014). Given the minimal representation of pinniped and cetacean remains, it was inferred that the exploitation of marine mammals was generally very limited (Martinoli, 2018). Cetacean bones were introduced to the site mainly as raw material for the production of bone artefacts (Christensen 2016). Remains of canids and rodents are also represented in the assemblage in low numbers.

Different kinds of scrapers comprise the major group of tools. Lithic assemblages also include microlithic points, fishing-line weights, choppers, and bifacial artefacts. Flakes and other lithic debris were also recovered from the shell midden assemblages, but in lower frequencies than in areas adjacent to the mound. Locally available lutite, rhyolite, and silicified rocks were used for making stone artefacts (Zangrando et al., 2014). Finally, the use and production of diverse bone artefacts was documented in the midden, including different types of wedges made from cetacean and guanaco bones, and awls made from bird bones (Zangrando et al., 2014; Christensen, 2016).

Subunits	Volume (m^3)	Zoarchaeological assemblage (NISP)									Technological Assemblages	
		Total bone remains	Guanaco	Pinniped	Cetacean	Rodent	Canid	Mammalia	Bird	Fish	Bone technology	Lithic technology
C20	0.213	430	150	2	0	77	0	78	28	95	8	22
C30	0.129	325	137	0	0	1	0	48	11	128	4	19
C40	0.063	80	39	0	2	7	0	14	4	14	1	3
C50	0.153	371	168	3	1	0	0	80	27	92	7	21
C70	0.242	341	193	1	0	0	0	12	30	105	1	29
C80	0.526	1799	373	3	3	2	1	135	105	1177	2	35
C100	0.141	144	43	2	0	0	0	10	80	9	2	14
C120	0.168	78	32	0	0	0	1	12	19	14	1	2
C140	0.177	267	101	0	0	0	0	39	24	103	0	4
C150	0.265	377	33	1	0	0	0	141	101	101	1	8
Total	2.106	4212	1269	12	6	87	2	569	429	1838	27	157

Table 2. Volumes of deposit and numbers of animal bones and artefacts from different subunits of Layer C.

4. Methods

Sediment samples were taken from each subunit for analysis of texture and organic matter content, using an Alein sieve for the coarse material, and a laser-granulometer (Malvern Mastersizer 2000) for the size distribution of sediments <1000 µm. Percentages of organic matter were obtained using the loss-on-ignition method following Heiri et al. (2001).

Shell fragmentation rates were determined for each subunit. In the Beagle Channel, bivalves tend to fracture more easily than the various species of gastropods due to their greater surface area for a given unit of mass (Waselkov, 1987). In fact, a tendency for higher shell fragmentation in blue mussels compared to gastropods has been reported in several sites on the Beagle Channel (Orquera and Piana, 2001; Zangrando et al., 2017; Pérez, 2020). In the present analysis, a proxy for blue mussel shell fragmentation is established by measuring the ratio of the weight of mussel shell fragments (< 8mm [0.312 inch]) to the total weight of shell remains (Zangrando et al., 2017); with values near 0 indicating very low fragmentation, and values near 1 indicating a high degree of fragmentation. Given that *Mytilus edulis* is the dominant mollusc throughout the deposits (Zangrando et al., 2017), we consider that this method is appropriate for comparing shell fragmentation between different layers of the deposit.

For measuring the degree of weathering on the guanaco bones, we used Behrensmeyer's (1978) weathering stages. Recent taphonomic studies in Tierra del Fuego (e.g., Borrero, 2007) have demonstrated the usefulness of this proxy for analysing bone assemblages in southern latitudes. Alunni (2018) has already demonstrated its usefulness in a study of the Heshkaia 35 guanaco bone assemblage, and validated its application in the Heshkaia locality by modern control studies on the weathering of modern guanaco carcasses (Alunni et al., 2017).

5. Results

Textural variations as measured by grain size and content of organic matter show only minor variations between subunits (Table 3). Sand is very significant in all cases, but the contribution of silty material is also substantial, forming a predominantly loamy sand texture throughout the stratigraphy. This characteristic is due to the contribution of aeolian processes, but prehistoric human activities (e.g., shell gathering and shell discard) could also have introduced sand.

The contribution of clay is low, although there are minor variations reflecting the complexity of soil dynamics and chemistry, with the highest proportion in the upper deposit (C20), the basal unit (C150) and one of the intermediate units (C100) (Table 3). The higher values in the uppermost and basal units are to be expected given their contact, respectively, with the topsoil and the subsoil beneath the midden. However, the C100 result is significant, since it occurs in the middle of the stratigraphic sequence. Organic matter shows a similar pattern with higher values in the upper deposits (C20–C30), in the basal unit (C150), and in the intermediate unit C100.

The relative proportions of shellfish taxa are fairly uniform throughout the sequence with an obvious predominance of blue mussels in all subunits (Table 4). However, the shell fragmentation indices show significant variation, with the highest rates of fragmentation in the uppermost (C20, C30) and lowermost (C150) subunits and in the intermediate C100 subunit, and the lowest rates in C40 to C80 (Table 4).

Subunit	Mastersizer 2000 E						Alein Sieve			OM (%)
	CLAY	SILT	SAND VF	SAND F	SAND M	SAND C	SAND VC	GRAVEL F	GRAVEL	
	< 2 µm	2 - 50 µm	50 - 100 µm	100-250 µm	250-500 µm	500-1000 µm	1000-2000 µm	2000-4000 µm	> 4000 µm	
C20	1.82	31.06	7.78	11.77	9.01	21.80	16.63	0.13	0.00	12.36
C30	0.47	15.44	7.73	12.95	7.56	6.62	49.23	0.00	0.00	13.87
C40	0.27	15.14	8.34	11.52	5.84	5.01	53.71	0.18	0.00	9.00
C50	0.86	23.42	6.21	9.94	8.89	7.19	42.06	0.52	0.90	8.65
C70	1.23	22.81	6.03	10.79	8.06	7.86	42.65	0.26	0.31	8.99
C80	1.22	24.94	6.69	8.67	6.95	8.95	42.53	0.04	0.00	10.74
C100	1.78	27.88	5.83	9.86	3.56	4.44	46.59	0.06	0.00	13.22
C120	1.02	25.32	6.30	8.62	6.23	7.62	44.85	0.06	0.00	10.13
C140	1.18	28.92	5.82	8.88	5.05	5.84	44.27	0.04	0.00	8.70
C150	1.80	29.35	6.47	7.94	2.77	4.96	46.62	0.09	0.00	11.79

Table 3. Textural composition and organic matter content (OM%) for different subunits of Layer C.

Subunit	Bivalvia			Gastropoda						Chiton (Poliplacophora)	Fragment weight (g)	Total weight (g)	Fragmentation index
	Mytilus edulis	*Brachidontes* sp.	*Aulacomya atra*	*Nacella deaurata*	*Nacella magellanica*	*Siphonaria* sp.	*Fissurella* sp.	*Acanthina monodon*	*Pareuthria plumbea*				
C20	97	95	1	42	26	0	1	3	0	6	170.8	216.3	0.79
C30	207	73	0	10	12	14	0	5	0	1	360.4	479.0	0.75
C40	359	155	0	35	23	5	1	14	0	3	466.6	812.8	0.57
C50	269	93	1	19	20	21	3	5	0	4	391.2	590.4	0.66
C70	392	178	0	54	60	5	2	5	0	1	355.8	800.7	0.44
C80	342	179	0	11	16	11	2	3	1	1	632.1	996.3	0.63
C100	76	7	1	7	7	0	1	28	0	2	395.6	444.9	0.89
C120	323	39	2	20	18	11	3	1	0	1	789.8	1124.9	0.70
C140	476	56	0	5	5	15	1	5	0	1	730.8	1174.9	0.62
C150	332	21	1	5	4	8		5	0	2	749.2	1047.0	0.72

Table 4. Proportional representation of molluscan taxa (MNI) and shell fragmentation indices of blue mussel (*M. edulis*).

These results, when combined, show a high degree of correlation (Figure 4). In the uppermost part of the sequence, C20 and C30 show high values of clay, organic matter and shell fragmentation. As one progresses downwards though the sequence, these values become progressively smaller until C70, increase again to a peak in C100, then decrease again in C120 and C140, with intermediate values in the basal C150 unit. This pattern shows a consistent trend, indicating in C100 an episode of stabilization of the surface and cessation of shell accumulation. This, in turn, shows that shell accumulation was not a continuous process throughout the temporal span of Layer C. Indications of fire in subunit C100, representing potential hearth features, also coincide with this episode of discontinuity in midden formation.

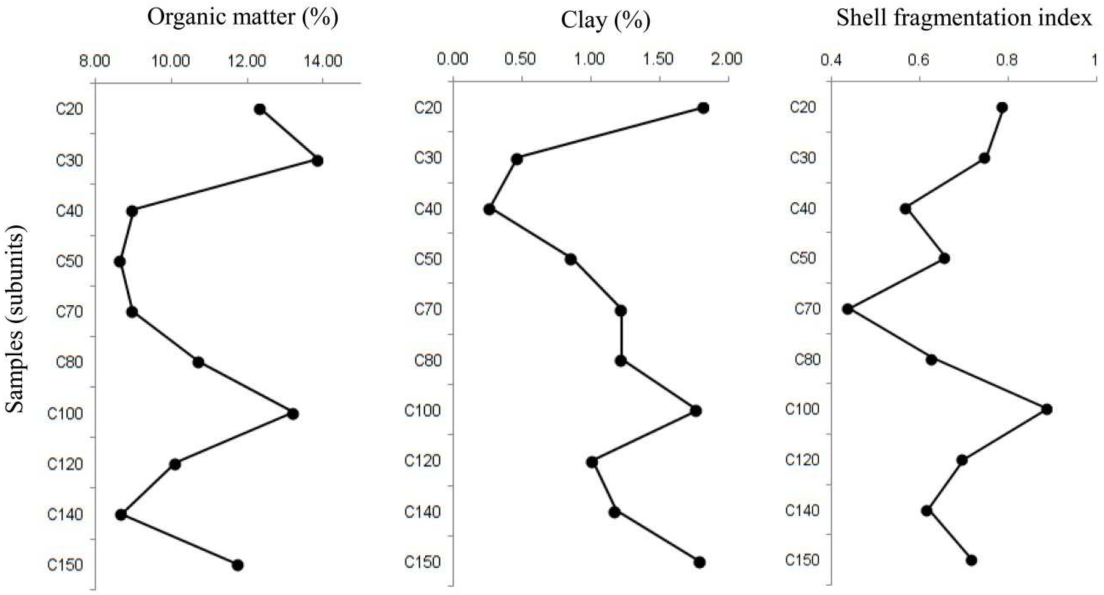

Figure 4. Comparison of percentage variations in organic matter and clay, and variations in shell fragmentation indexes throughout the archaeological sequence of Heshkaia 35.

This evidence of discontinuity in midden formation is not visible in the section profile (Figure 3A and B) nor was it recognised during the course of excavation and thus calls into question the standard method of using radiocarbon dates to calculate accumulation rates (e.g., Stein et al., 2003). What is needed is a more sensitive method for detecting short-term changes, and this is where bone weathering can be used as a relative chronometric tool. A relatively high indication of bone weathering (Behrensmeyer's stages 1 to 3) is present in C20 to C100, indicating a relatively prolonged period of exposure on the ground surface, whereas no bone weathering is recorded in subunits C120 to C150 (Figure 5). This result indicates that shell accumulation was faster in the lower part of the deposit, compared to the upper deposit above C100.

These results also have important implications for estimating densities of artefacts and animal bones per unit volume. Using data from Table 2, we observe an increase in values from C100 to the upper subunits (Figure 5). However, we know from the analysis of bone weathering that the bones in the upper deposits from C100 upwards show more weathering. This is evidence of more prolonged surface exposure of bones and therefore evidence of lower discard rates of shells. Therefore, the higher densities of material recorded between C20 and C100 may simply reflect lower rates of shell accumulation rather than higher rates of bone and artefact discard.

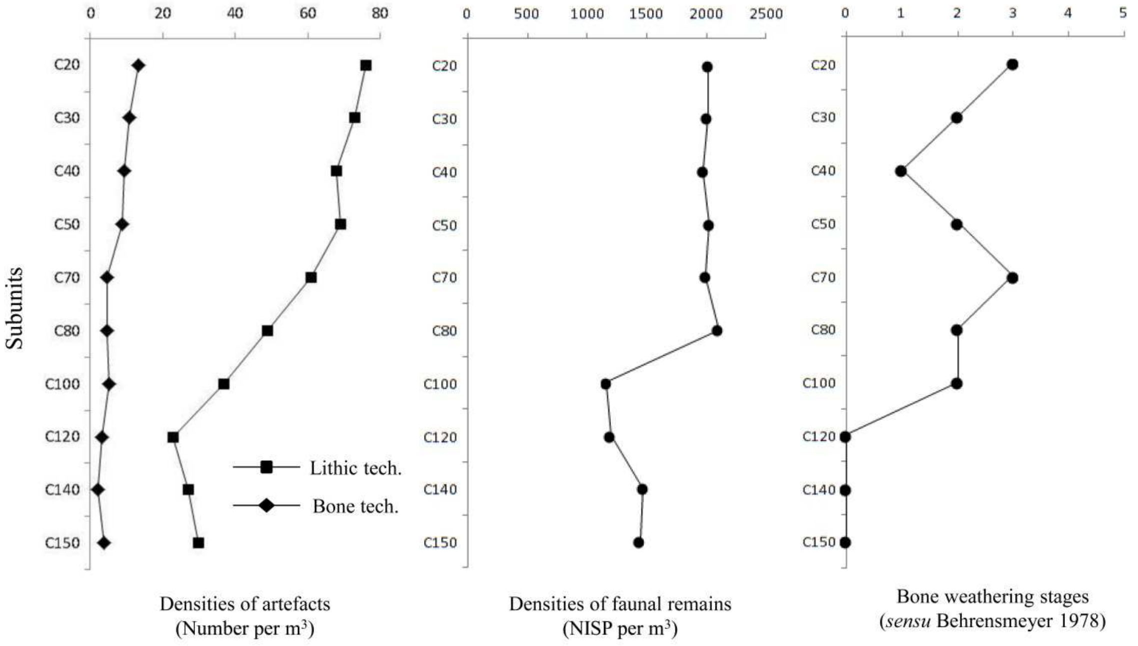

Figure 5. Densities of artefacts and archaeofaunal remains expressed as cumulative curves, and bone-weathering stages (sensu Behrensmeyer 1978) throughout the archaeological sequence of Heshkaia 35. Behrensmeyer's bone-weathering stages are on a five-point scale ranging from 0 (no weathering) to 5 (high degree of weathering).

6. Discussion

Two conclusions follow from the analysis presented above. First, the formation of Heshkaia 35 was not continuous, despite the short temporal duration identified from the radiocarbon dates. Second, the accumulation of shells varied throughout the formation of the midden, being faster in the basal stratigraphic subunits. Therefore, two tapho-chronometric components are present, a basal one comprising subunits C150 to C100, and an upper one between C100 and C20, each with different implications for time-averaging. This highlights an important variable in the temporal structure of the archaeological record, with profound consequences for the interpretations of artefact and faunal assemblages.

The development of specialised excavation techniques in the Beagle Channel has encouraged archaeologists to believe that they can subdivide palimpsests into individual events of deposition or occupation (Orquera and Piana, 1992; Estévez and Vila, 2006; Briz et al., 2011). For example, using these techniques, Estévez and Vila (2006) used the superimposition of hearths in the central area of the Túnel VII site, identified as a dwelling space, to examine the pattern of intra-site utilization. Subsequently, micromorphological studies of two shell midden columns from this site, one located in the central area and the other adjacent to it, demonstrated different patterns of occupation and phases of abandonment (Balbo et al., 2010; Villagran et al., 2011a, 2011b; Villagran, 2019). It is clear that successive site-use resulted in a spatial structure similar to that described in ethnographic records of the Beagle Channel (see also Orquera and Piana, 1989-90, 1999a). However, the sequential use of the site also materially transformed the structure of previous occupations by re-using the same features and facilities (Balbo et al., 2010; Villagran et al., 2011b). Under such circumstances, it is not possible to unravel the contribution of individual occupation events to the palimpsest. As we have seen, hearth features can be used to explore intra-site variation in the overall temporal structure of an archaeological deposit (Wandsnider, 2008; Bailey and Galanidou, 2009). However, it is quite another matter to use these features to identify short-term events in the archaeological record, and then to associate these with archaeological assemblages. It has also been suggested that microstratigraphic data rarely provide information about the contemporaneity of associated clusters of archaeological debris (Stern, 1993). However, the problem does not lie with the techniques used, but rather with misconceptions about the time-averaged nature of shell midden deposits.

This perspective is also pertinent when considering other sources of evidence and the attempts by archaeologists to improve the identification of stratigraphic relations and spatial patterns on the assumption that the ideal of a high-resolution shell midden chronology is achievable (e.g., Briz et al., 2011). However, there is no universal depositional history for shell middens, and even different sections of the same deposit can present different temporal resolutions. We can observe this situation in the shell midden formation of Heshkaia 35, where different deposits in the same sequence accumulated at different rates: more accelerated in the basal deposits and less so in the upper deposits.

In the Beagle Channel, density values (quantities per unit volume) of faunal remains have been used to explore long-term patterns in human subsistence (Orquera and Piana, 1999a; Estévez et al., 2001; Zangrando, 2009), as well as to study fishing activities at individual sites (Juan-Muns i Plans, 1992; Zangrando, 2003, 2007). This method is used to compare frequencies of archaeological remains from different sites or stratigraphic units involving different volumes of deposit. To this extent, the method offers an improvement over other methods of quantification, such as reliance on absolute or relative quantities, when attempting to produce standardizing measures in comparative studies. But use of density values is not without issues. In the case of Heshkaia 35, there appears to be an increased intensity of exploitation of vertebrate animals in the upper deposits according to the higher figures for density values. However, this increase is illusory because it coincides with a reduction in the rate of shell accumulation. Interpretations based on the densities and relative abundance of bone remains are frequently used in zooarchaeological studies to standardise comparisons between deposits of different volume (e.g., Cannon, 2001; Orquera and Piana, 1999a: 101; Zangrando, 2009: 140). However, our Heshkaia 35 data show that the results may be seriously in error if they do not also take account of variations in rates of shell accumulation.

Density values are also affected by other processes, notably variable degrees of compaction of shell-midden deposits, which are not usually taken into consideration (but see Holdaway et al 2017). Compaction can vary both within and between sites, depending on various cultural and natural processes. After the initial deposition of shells, progressive compaction of midden deposits can occur because of: a) external pressures of various kinds (from trampling to geological factors); and b) lowered resistance due to leaching and loss of calcium carbonate (especially if there is acidity in the water and the temperature is cold) (Claassen, 1998). In the Beagle Channel, Orquera and Piana (2001) calculated the degree of compaction in middens of different ages. They reported a reduction of between 44 and 23% of the initial volume for shell middens of Mid-Holocene date, but only 7 to 2% for more recent shell middens of Late Holocene date. Differential compression may also occur at the intra-site scale due to more intensive activities in different areas of a site or in different periods of its occupation, for example because of continuous use and trampling in some areas compared to others, resulting in differential compaction of different stratigraphic units (Balbo et al., 2010; Villagran et al., 2011b). Mass compaction of shell middens can also occur because of modern activities or settlements (e.g., Thomas and Thomson, 1992; Orquera and Piana, 2000).

Typically, in previous studies, rates of accumulation have been calculated by taking the thickness of the deposit and the timespan as indicated by the median radiocarbon ages from at least two points in the deposit and assuming a constant rate of accumulation between these two points (Stein et al., 2003; for similar procedures see Borrero, 1993; Jerardino, 1995, 2018). More recently, Bayesian analysis of radiocarbon dates has been used to achieve greater accuracy in estimating rates of accumulation of individual layers (Lombardo et al., 2013; Jerardino, 2016; Jew et al., 2015), but is nonetheless applied on the assumption that rates of accumulation are constant. It has also been suggested that the use of discard rates (number of items per unit of time) would be more appropriate for comparative purposes, since these do not depend on the volume of deposit but on time spans (Jerardino, 1995). These methods have been shown to be useful to evaluate cultural processes in a number of shell midden contexts, but at least two other factors should also be considered when interpreting these results. First, thickness or size of a shell midden does not always positively correlate with the intensity and/or recurrence of occupation at a site. Nor does it take account of the possibility that rates of accumulation may vary within individual shell middens or even individual layers, as our Heshkaia 35 results have demonstrated. Secondly, when accumulation of deposits is especially rapid, radiocarbon dating cannot differentiate between the beginning and end dates of such short-term deposits. These cases need to be addressed in other ways by using geoarchaeological, taphonomic or seasonal proxies more appropriate to the time scale of the deposits under investigation (Bailey, 2007; Wandsnider, 2008; Hausmann and Meredith-Williams, 2017).

Finally, while our results demonstrate the usefulness of tapho-chronometric processes to construct the depositional history of a small site, the use of this approach for larger sites, such as the one illustrated in Figure 1, would require data from many parts of the site and probably more sophisticated techniques of investigation, such as percussion coring and 3D site mapping (Letham et al., 2017).

7. Conclusion

Shell middens have been systematically studied over the last 45 years in the Beagle Channel in the framework of different archaeological projects, and from several sub-disciplines (Orquera et al., 1977; Figuerero Torres and Mengoni Goñalons, 1986; Orquera and Piana, 1986-87, 1989-90, 1996, 1999a, 2000, 2001, 2009; Estévez and Vila, 1996, 2006, 2007; Yesner, 1990; Piana et al., 2004; Balbo et al., 2010; Zangrando, 2010; Briz et al. 2011; Villagran et al., 2011a, 2011b; Bjerck et al., 2016; Zangrando et al., 2014, 2016; Tivoli et al., 2019; among others). The variety of the analytical techniques applied in recent decades in the region includes the exploration of the spatial arrangement of activity areas, the use of specialized excavation methods and micromorphology studies, and the use of density values in the analysis of long-term variations in subsistence.

The central position of this paper is that, by treating and investigating shell middens as time-averaged deposits, we are able to clarify distinctive aspects of mound formation that have significant implications for our interpretations. Beyond radiocarbon data, these archaeological deposits are rich in temporal information, which can be addressed through tapho-chronometric tools. By considering the time factors represented in archaeological deposits, crucial information about shell midden formation can be obtained. Using this perspective, what we have shown here is that, even in shell middens accumulated over short periods of time, the deposits do not necessarily represent a gradual and continuous accumulation of deposits, but can represent occupations of varied duration that are expressed independently of the thickness of the deposit and the rate of accumulation of the material. Time resolution of shell middens is normally addressed through the estimation of shell accumulation rates, and the use of density values (quantities per unit volume) or discard rates (quantities per unit of time) for comparative proposes. However, we need to recognize the effects of differential time-averaging in different deposits. Far from being considered a conceptual inconvenience, the presence of time-averaging provides additional information and an interpretative framework for identifying new problems and appropriate research strategies for their investigation.

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