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Fracture and modification of Patella shells: Distinguishing human working

Brent Koppel
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Abstract

The role of stone tool production has long been used as a proxy for cognitive development in early human cultures. In the context of South-east Asia (SEA) and Australia a lack of 'advanced' examples of lithic technologies seen elsewhere in the world has led to the labeling of SEA and Australian cultures as simple and undeveloped. Arguments have been raised in an attempt to refute this claim, including the replacement of stone as a medium for artefact production with shell.

The differentiation between cultural and taphonomic modification in shell has been problematic, due largely to a lack of understanding of taphonomy the morphologies different species of shell on a micro scale and subsequently the fracture mechanics of molluscan shell under specific forces. The identification of artefactual shell specimens is sometimes based on little more than a hunch.

This project attempts to determine the difference between the resulting fracture patterns of cultural and taphonomic damage using high and low powered microscopy. The resulting fracture patterns from use-wear experimentation was compared to controlled fracture experimentation using low powered light microscopy and high powered scanning electron microscopy. The results show a variety of fracture patterns as well as a distinct difference in fracture patterns between the two sets of experiments. When these results are then compared to archaeological specimens from Golo cave in Gebe Island, a previously excavated site in the Maluku island group in Indonesia, similar fracture patterns are observed indicating the presence of culturally modified shell in the Golo Cave assemblage.

This project highlights the significance of micro scale analysis in the identification of shell artefacts as well as providing insight into the differing forms of mechanical failure in molluscan shell as well as depicting the suitability of shell as a medium for artefactual use

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**FRACTURE AND MODIFICATION OF
PATELLA SHELLS: DISTINGUISHING HUMAN
WORKING**

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3280470

Supervisor: Dr. Katherine Szabó

(Revised by the author May, 2011)

ABSTRACT

The role of stone tool production has long been used as a proxy for cognitive development in early human cultures. In the context of South-east Asia (SEA) and Australia a lack of 'advanced' examples of lithic technologies seen elsewhere in the world has led to the labeling of SEA and Australian cultures as simple and undeveloped. Arguments have been raised in an attempt to refute this claim, including the replacement of stone as a medium for artefact production with shell.

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Chapter 1

Aims

The specific aims of this research project are as follows:

- 1) Investigate the nature of non-lithic technologies in Island Southeast Asian early modern human assemblages.
- 2) Establish criteria for isolating early modern human modification of molluscan shell
 - a. Determine natural structure/microstructure of *Patella flexuosa* and how the shells respond to different forces
 - b. Conduct a variety of human modification experiments to create a framework for interpretation of worked or potentially worked shell surfaces.
- 3) Utilising the results and understandings generated in 2 (a) and (b), analyse early shell material from the archaeological site of Golo Cave, Gebe Island, Molucca island group, Indonesia.
- 4) Contextualise the results of analysis from Golo Cave into wider regional and global issues of non-lithic tool use by early modern humans.

This project aims to document fracture and fragmentation tendencies, as well as traces of human working of *Patella flexuosa*. Specifically designed experiments will attempt to recreate both natural breakage environments and active modification by early modern humans (EMH). The central objective is to identify criteria that allow us to distinguish between natural and cultural modification of shells, and thus clearly identify worked shell in the archaeological record. These new criteria will be tested on the early modern human (~32,000 – 28,000 ka BP) shell assemblage from Golo Cave. Based on prior results (Szabó et al. 2007), it is anticipated that a variety of approaches to shell-working will be identified that will significantly contribute to our understandings of non-lithic technologies in early modern human culture.

Chapter 2 discusses the background in archaeological concepts while at the same time contextualizes the case study of Golo Cave and why the site is relevant. Chapter 3 introduces the target species that will take part in this study, and explains their ecology as well as defining

features and structural morphologies that characterize the specimens. Chapter 4 outlines the experimental method that was undertaken in collecting sample species, cataloguing and accessioning, as well as taphonomic assessments. Also in Chapter 4 is an explanation of the different experiments, such as XRD and INSTRON analyses as well as the experimental working tests that will be undertaken to best achieve the aims of the research project. Chapter 5 presents the results from the experiments described in Chapter 4. Chapter 6 discusses the results, interprets them and places them in their place in the global archaeological community.

Chapter 2

Background

One of the defining features that make humans more than just an animal is the ability to manipulate our surroundings for our own personal gain an advantage (Oakley, 1958). One of the most fundamental aspects of this concept is the modification of raw materials into tools. While not solely confined to humans and hominins, as seen in the use of twigs and sticks for the extraction of insects by the great apes and sea otters using collected rocks to break open molluscs (Clark, 1971), the cognitive process of looking at a raw material and exhibiting creative thought to modify it for a specific purpose or ultimate goal is uniquely human. By far the most studied form of hominin tool and tool production focuses upon stone as a medium.

While modern day cultures that are reliant upon stone tools still exist (Clark, 1971 and Oakley 1958), most stone tool technologies are associated with prehistoric hominin and human cultures and, as such, have become the most common proxy for determining the level of cultural technological complexity, and therefore cognitive development of prehistoric humans and their cultures. Over time, stone tools and related artefacts have taken the form of scrapers and cleavers, to more 'advanced' spear tips and arrowheads. Stone tools that have been chipped into shape are generally made from rocks whose crystal structure is microscopically small leading to a constant and regular, conchoidal fracture ('isotropic'). This structure is seen in cryptocrystalline rocks and is exhibited in chert, flint and some basalt (Oakley, 1958) as well as volcanic glass such as obsidian (Barton et al., 1998) and minerals like vein and crystal quartz (Smith et al., 1991). This consistency is ideal for tool formation and reduction in general as fracture is predictable and regular, exhibiting conchoidal breakage patterns and generating sharp edges. Larger grained rocks such as sandstone and rocks with a much larger crystal matrix are unable to form such sharp usable edges but are also utilised, particularly as grinding tools as opposed to cutting, chopping and scraping functions.

Until the 1860's, the concept that man had not existed on Earth earlier than approximately 4004 BC had not been considered by the present academic community (Oakley, 1958). Historical

interpretations were largely based on historic and biblical records. For example, about 1690, a pointed piece of flint lying adjacent to the bones of an elephant was explained by antiquarians as “a British weapon made of a flint lance like unto the head of a spear” (Oakley, 1958, pg. 3). It was then reasoned that the flint blade was used by a Briton while attacking a war elephant utilised by the Roman emperor Claudius. It was not until 1797 when John Frere recognized the implication of chipped flint pieces buried 12 feet below the surface of a brick quarry (Oakley, 1958). These chipped flint pieces were quoted by Frere as “used by people who had not the use of metals” (Oakley, 1958, pg. 4) and were termed Cromerian industries (Clark, 1971). Counterarguments were made in response to Frere’s finds, describing the discovery as stones fractured under natural processes, such as glacial movement (Oakley, 1958). Thus, these inferred artefacts, termed eoliths, from the “Cromerian industry” were not considered with any certainty at least, as tools modified by man, but merely chance fractures from natural processes such as wave action and soil creep (Oakley, 1958). Further discoveries of eoliths continued well into through the 19th century and into the 20th century (Trigger, 2006).

While not often mentioned in modern day studies, and largely discredited, eoliths represent the possibility of the earliest examples of ancestral man’s manipulation of his environment (O’Connor, 2003). Whether or not eoliths were formed by naturally occurring processes or actively modified by early hominins has endured as one of the major archaeological conundrums. It is commented that the overall simplicity of ancestral man’s first attempt at tool making, when compared with stones that have been fractured through natural processes such as soil creep and the effects of glaciation, would render them indistinguishable from each other (Trigger, 2006 and Oakley, 1958). It is here that the distinction between tool-user and tool-maker is drawn. There is irrefutable evidence of contemporary cultures in South Australia that still utilise rocks as tools that have fractured under natural processes and, by chance, formed shapes and edges suitable specific purposes (Oakley, 1958, Allchin, B., 1957 and White, 1977). It is also a known concept in archaeology that finding the first or last of anything, for example the

link between man and the apes famously referred to as 'The Missing Link', is infinitely unlikely. So pinpointing the precise artefact that can safely and with confidence be labeled as the first stone tool modified by ancestors of present day humankind is nigh impossible.

This seemingly grey area of identifying irrefutable hominin artefacts exists today. Olduvai Gorge in northern Tanzania saw the first conclusive examples of hominin formed artefacts (Clark, 1971), in the form of stone chipped to a sharpened edge. First discovered by a German entomologist and then properly studied by the Leakey family in the early 1930's, this site proved to have great archaeological importance as it represented the first example of tool production by ancestral man. Further excavations throughout central Africa have yielded similar examples of artefacts and have been dated to approximately 2.6 to 2.5 million years old. (Semaw et al, 1997). While still very simple in their form, the claim of the artefacts being made by hominins can be said with some certainty as they were found adjacent to remains of fireplaces and living areas. Attributed to the hominin *Homo habilis* (Clark, 1971), these artefacts have been named after the location where they were discovered; Oldowan technology. Artefacts sharing similar structural forms have also been discovered in central Africa, and have thus been categorised into the group of Oldowan technology. Since then, the term Oldowan technology has been used to describe all stone tools sharing similar morphological features to the original finds in Olduvai Gorge.

Modern day intellectual nature drives us to categorise things that we find, and place them in their allotted place in an overarching, continuous and usually temporal progression. This is very true for archaeological artefacts discovered and collected. The knowledge of where this tool-making behaviour originated, how it has developed and the transition points between industries has been the focus of a lot of attention since the early beginnings in archaeology. Since the Olduvai Gorge discovery, artefacts that typically show novel and more complex production techniques have been grouped, once again into categories of tools sharing similar morphological

features. These new categories have, like the Olduvai Gorge discovery, been named after the location they were found, like the Acheulian industry, named after St. Acheul in France and Mousterian industries named after Le Moustier, also in France.

Graham Clark took this concept of categorising similar lithic technologies and attempted to apply it on a global scale (1971). This created a simple model by which the technological complexity of prehistoric cultures could be gauged simply by identifying and comparing similar morphological features of the associated lithic artefacts. Seeking to do away with the traditional terminology which he saw as an unnecessary number of labels describing technologies at the same level of complexity, Clark created an overarching set of criteria that could be used to define morphological variances of lithic artefacts, whatever their provenance. Clark suggested that despite being separated by vast distances, generalities could be identified in the methods by which the artefact was created, thus making them comparable based on a sliding-scale of complexity (Foley and Lahr, 2003). These groupings of technologies are termed 'Modes' (Clark, 1971) with Mode 1 technology being the simplest through to Mode 5, representing the most 'advanced' lithic technologies. The Oldowan technology can thus be labeled Mode 1. The five 'Modes' and their defining characteristics are shown on the following page.

Despite the general simplicity of Clark's model, he does make the comment that this overarching global classification system could not be global in its application; "...although these modes were homotaxial they were by no means universal." (Clark, 1971, page 30). He recognises that, over time, and as ancestral humankind spreads across the world, hominins were required to adapt to a broader range of environments and a broader range of materials that these environments provide. A difference in raw material selection for tool production between two separate cultures would lead to different morphological features despite being at the same relative level of technological complexity (Clark, 1971, page 30). Clark also comments on the importance of competition. One culture in direct competition with another was considered to be a factor in



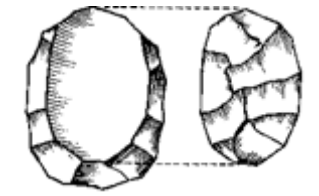
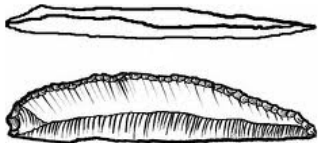
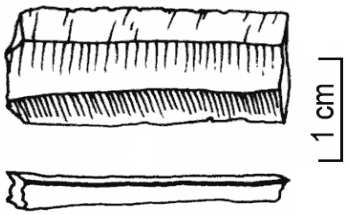
MODE	COMMON NAME	DESCRIPTION	PICTURE
1	Oldowan Industry	Earliest examples of tool creation. Created by striking a hammerstone against rounded stone, commonly river-rolled pebbles creating one sharpened edge and often a sharp point	
2	Acheulean Industry	Also known as a biface or handaxe that displays flake scars on both sides. Typically, the tool is symmetrical along anterior/posterior axis. Retouching/resharpening of the edge has been identified in some specimens	
3	Mousterian Industry	Replacing the Acheulean technologies, a core is prepared by flaking to a predetermined shape, and then a large flake is struck from the core. What separated this technology is that the flake is the desired item, as opposed to the core.	
4	Aurignacian Industry	Characterised by blades instead of flakes, which by definition need to be more than twice as long as they are wide. Like Mode 3 tools, blades are struck from blade cores with a softer hammerstone.	
5	Magdalenian Industries	Similar to the blades from Aurignacian technologies in both form and production, but on a much smaller scale (typically 12mm). What separates this technology is the hafting of multiple tools to form one composite artefact such as an arrow or harpoon.	

Table 2.1 : Descriptive table of Graham Clark's 'Modes'.

driving technological advancement as one tries to out-compete the other. With cultures in remote locations, inaccessible to others, older and simpler technologies would survive due to the lack of competition and the lack of any real need to develop beyond the very basic (Clark, 1971).

Even with the passage of time, as well as Clark himself describing the limitations of his categorisation model and a continued tradition of research, Clark's system continues to be utilised in the description of lithic artefacts in contemporary studies (e.g. see Mellars, 2006 and Foley and Lahr, 2003). This consistent labeling of prehistoric cultures by method of Clark's modes has, explicitly or implicitly, become a proxy for describing the technological, and by extension cultural complexity of the given prehistoric culture.

The Movius Line is a theoretical division of central Asia, running through north-western India first noted by Hallam L. Movius. The Movius Line represents a noted lack of advanced stone tool artefacts to the east, compared to more sophisticated examples of stone artefacts to the west in Europe and Africa. East of the line simple

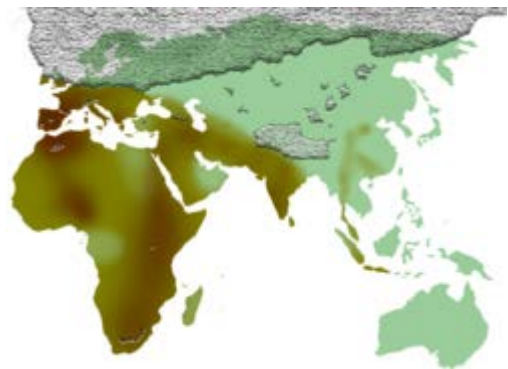


Fig. 2.1 : Map showing the extent of the hypothetical 'Movius Line'.

chopping tools with isolated examples of bifaces being discovered, but the progression to higher order tools such as microliths and advanced core technology is not apparent (Mellars, 2006). Since its discovery, the Movius Line has led to the assumption by contemporary archaeologists that cultures east of the line, especially south east Asian cultures, were not as developed as those west of the Movius Line. Paul Mellars mentions the lack of upper Paleolithic technologies in the Australasian record and refers to this as an enigma (Mellars, 2006). Movius himself refers to cultures east of the line as "a marginal region of cultural retardation" (Movius, 1969). Going one step further, Graham Clark refers to the lithic technologies of Australian prehistoric cultures

as “...crude and colourless” and “...issued from the most unenterprising parts of the late Pleistocene world” (Clark, 1968). These sentiments are shared by not only these academics, as J.P. White refers to a large number that have published similar articles and opinions (White, 1977) which depicts an overall bias towards the argument of the underdeveloped south east Asian region in the archaeological community.

Arguments attempting to explain the lack of advanced lithic artefacts in the Southeast Asian region include J.P. White’s principle of last effort. He states “If wooden spears and fire could kill off Australia’s Pleistocene megafauna, what is the conceivable necessity for stone spear points?” (White, 1977, pg. 26). This statement was a direct response to a quote from Graham Clark implying that the “cult of excellence” has driven man to perfect his creations (Clark and Piggot, 1965). White continues to argue that majority of elaborate stone tools are unnecessary from a utilitarian perspective as their less sophisticated predecessors were suitable for the job (White, 1977). Paul Mellars raises an alternative theory for the lack of advanced lithic artefacts in the Southeast Asian region. He states that there is a lack of high quality, cryptocrystalline rock throughout the south east Asian region which is required for higher order stone tools (Mellars, 2006), and despite localised areas of suitable materials, cultures would have to adapt to what is more available. Thereby decreasing the dependence of stone as a resource and somewhat stunting the progressive complexity that would otherwise have developed. Other arguments include the lack of specialisation in Southeast Asian and Australasian tools as further fuel-to-the-fire in the debate of the simple cultures of the region (Hayden, 1977). There is also arguments for the failure in recognising alternative forms of tool production, seen in Hayden’s (1977) study of tool production and the identification of ground edge axes, compared to the traditionally thought European method of percussion chipping and pressure flaking. Arguments derived from the discovery of bifacial hand-axes in river terraces in China have implied that cultures were more advanced than initially thought, though the discoveries are not substantial enough to entirely refute the Movius Line concept (Keates, 2002).

Mellars' argument of the replacement of stone as the primary medium for artefact production has become an important issue in this topic. One of the most argued responses to the labeling of Southeast Asian cultures as less developed than their western counterparts is the replacement of stone as the primary medium for stone tool production. Mellars writes that towards the upper Paleolithic, hominins started increasingly started utilising bone and antler for artefact production (Bar-yosef, 2002). Probably the most convincing theory that follows on from this line of argument is the use of bamboo as the primary medium for artefact production. Bamboo is abundant in the regions in question, and structurally, it contains up to 70% pure silica (Jones, Milne and Sanders, 1966). This gives the plant structural stability and when split, gives the edge a glass-like sharpness that could very plausibly cut through animal flesh (Jahren et al., 2007). As well as this, bamboo in a South East Asian context is an incredibly abundant resource so procurement of bamboo material is simple (Choi and Driwantoro, 2007). This line of argument is one of the most plausible; however the perishable nature of plant material makes preservation within the archaeological record and therefore archaeological proof near impossible. Intuition and ethnographic information is really the only basis for this argument. It has also noted that little direct forms of archaeological evidence, such as microwear have been found and a dependence on negative evidence being established (Szabó, Brumm and Bellwood, 2007).

Recently, the argument over the replacement of stone as the primary resource for stone artefact production has begun to include shell. It has been said that the most probable colonisation route followed by the first settlers into Southeast Asia and Australasia would have generally been a coastal route (Mellars, 2006). Thus the settling cultures would have had to adapt to the primary exploitation of coastal resources such as fish, shellfish and marine mammals with a minor dependence on hunting larger game (Mellars, 2006).

The position of mollusc shell as a medium for artefact production is widely known though is nearly entirely restricted to ornamental and decorative use. The excavation in Blombos Cave,

Southern Africa yielded 41 *Nassarius kraussianus* shells showing consistent perforations in the dorsal lip of the shell were found. This form of perforation occurs very rarely in a natural context which implies that the perforations were deliberately created. The discoveries at this site, which included other artefacts such as engraved ochre tablets, are undisputedly the earliest examples of symbolic behaviour in ancestral man (Henshilwood et al., 2004). Other studies describing shell use for ornamental purposes are abundant (Bouzouggar et al., 2007, Vanhaeren and d'Errico, 2006; Balme and Morse, 2006 among others). This notable bottle-necking of focus draws attention away from shell being used as an alternative to the traditional mediums of artefact production in fields outside of the ornamental.

Recent excavations in Indonesia have yielded the earliest example of modified shell, coming from the Molluccan site of Golo Cave, found on Gebe Island in eastern Indonesia (Bellwood et al., 1998). At this site, dated at 28– 32 thousand (uncalibrated) years old, reduced *Turbo mamoratus* shell and flaked *T. mamoratus* opercula were found as well as cut sections of *Nautilus pompilius* shell (Szabó et al., 2007). The operculum of the *T. mamoratus* exhibits removal of sequential flakes from the shell edge in a clockwise direction (Szabó, 2010). No clear evidence of flake utilisation has been noted which implies that the operculum itself was created for a purpose (Szabó et al., 2007). The shell of the limpet *Patella flexuosa* is one of the most abundant shell species in the Golo Cave assemblage (Szabó, 2010). Wear and fracture patterns seen in some of the *P. flexuosa* specimens are not consistent with breakages expected through natural environmental process such as wave action or compaction after burial, which leads to the conclusion that they were possibly used for some purpose (Szabó, 2010).

Stiner's analysis into the ecology of *Homo neandertalensis* revealed shell artefacts that used as tools in a similar fashion to that of stone (Stiner, 1994). The shell of the marine clam *Callista chione* has shown evidence of modification through the application of pressure to achieve a desirable fracture (Stiner, 1994). This modified shell was then utilised as a simple scraper (Stiner,

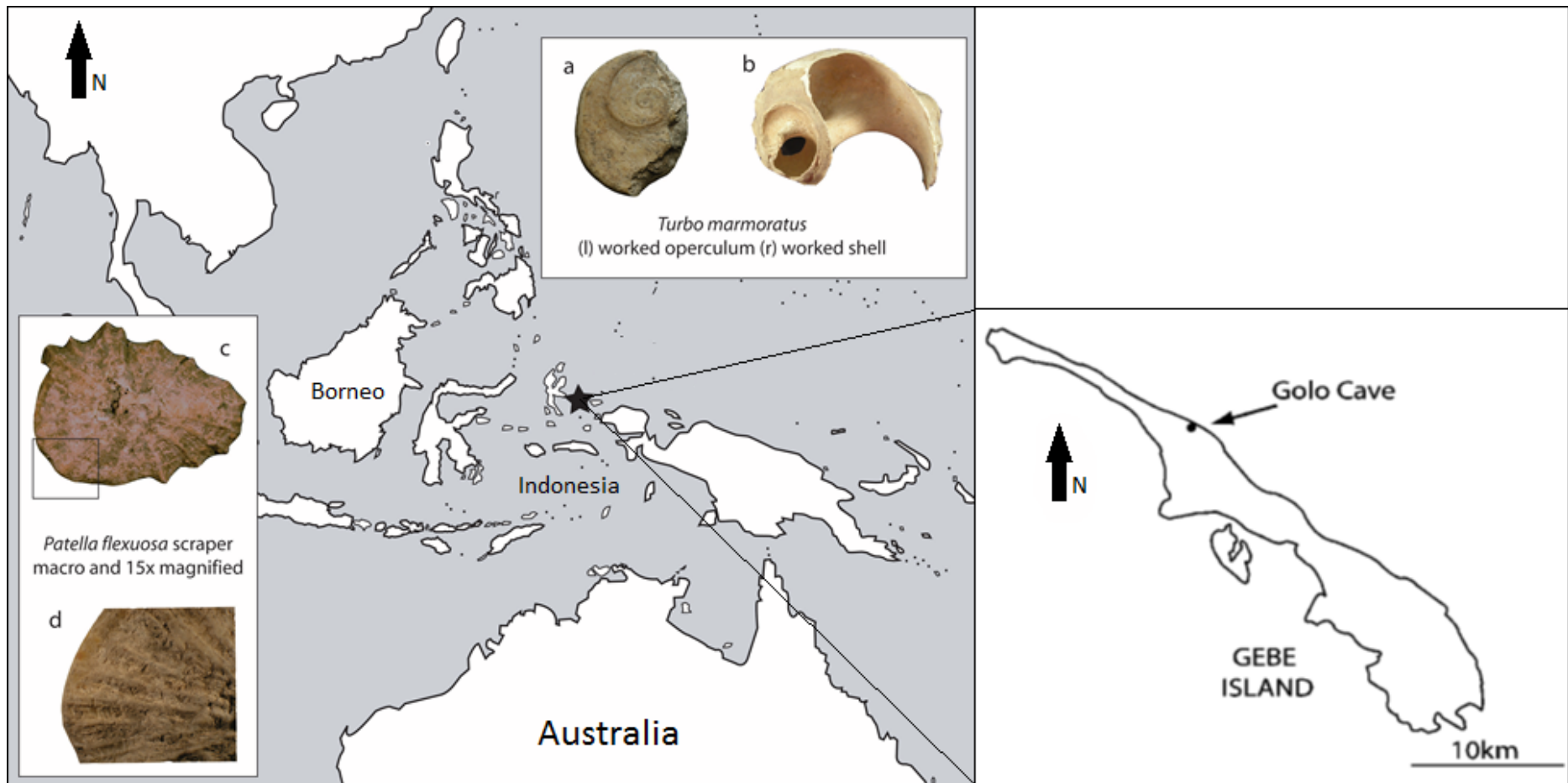


Fig. 2.2 : Examples of potentially worked shell artefacts, as well as map describing location of Gebe Island (adapted from Szabó, 2010 and Szabó et al. 2007)

1994). This implies that the Mousterian cultures of the time recognised that other materials besides stone could be used and modified for specific use (Stiner, 1994). Stiner later goes on to say that a lack of publication into the use of shell as a tool creates a false impression that the resource is not used for that purpose at all. As well as this, she states that despite some examples being recognised little to no systemic taphonomic study or framework for identification is being undertaken (Stiner, 1994).

A study conducted by Choi and Driwantoro outlines the use of shell as a raw material for tool production based on hypothesised cut marks on preserved animal bones. They argue that clam shells were used in the butchering of animals by the hominin *Homo erectus* (Choi and Driwantoro, 2007). Several points about this study highlight the view the way the contemporary archaeological community views shell as a raw material. At the forefront are the incorrect assumptions being made of shell structure, particularly microstructure, variation in form between taxa and even incorrect or vague identification of molluscs as well as assumptions in fracture patterns and fragmentation.

Molluscan shell is a highly variable material. While it can be easy to think of shell as a homogenous material, it is actually made of several layers, which are in turn comprised of various microstructures and organic matrices. Indeed the term shell in a material context should be deconstructed into three categories; macrostructure, microstructure and organic content throughout the overall shell structure. Each of these categories play a vital role in the overarching composition that is a mollusc shell and each will affect the nature of the shell's breakage patterns and mechanical strength.

The macrostructure of a molluscan shell is the most obvious and characteristic part of the organism. Comprised of calcium carbonate in the form of a ratio of calcite and aragonite (Chateigner et al., 2000) as well as an amount of organic material that varies between species

(Watabe, 1988), the macrostructure of the shell is the first line of defence against predators and also as a means to prevent desiccation (Branch, 1985). The morphology of the shell also serves a specific purpose in terms of mechanical strength. Mollusc shells, especially in limpets, are designed to be significantly stronger in certain orientations (Currey, summarised in Vermeij, 1993). As the shell's main purpose is to prevent damage to the internal tissue of the animal, and as the vast majority of striking or crushing attacks from predators occur from the external inwards, compressional strength is much higher versus tensional strength (Currey, summarised in Vermeij, 1993), meaning pushing of the shell is much less likely to yield a break than force applied in the opposite direction. This directional strength is achieved through a number of different factors, some being shell thickness, elevation, surface area-to-volume ratio and others. Other features such as spines, vertices and ridges all serve to strengthen the shell (Vermeij, 1993).

At the microscopic level of the molluscan shell structure is an underlying series of arrangements layered on top of each other creating the overarching shell structure. Often there is more than one microstructure utilised in the shell (Watabe, 1988) and these microstructures all play a part in how the overall shell structure reacts to forces. For example, a striking force on a *T. mamoratus* shell creates a crack that easily travels through the outer prismatic layer parallel to the prism structures, but is stopped almost immediately as it reaches the inner nacreous layer (Currey, 1988). This is due to the orientation of the microstructure's crystal matrix. The prismatic crystals run parallel with the direction of force, so the crack follows a path of least resistance, whereas the nacreous layer is comprised of offset blocks cemented with organic proteins forces the crack to take a much more arduous route, thereby halting the progression of the crack (Currey, 1988). In saying this however, the strength in the nacreous layer is dependent on the direction of force and the condition of the organic material cementing the crystal matrix together. Nacreous microstructures easily fall apart into sheets should the organic content of the

microstructure degrades or decomposes, whereas a prismatic microstructure, and the relatively low organic content in it retains its structural integrity even after millennia (Sazbó, 2010).

It is apparent that molluscan shell tissue is a complex material, and this should be taken into account when using it for detailed scientific analysis. The study conducted by Choi and Driwantoro (2007) however, shows little emphasis on the microstructure of the target taxa, even though the entire study is based on microscopic traces left on bone. Indeed, a number of assumptions concerning shell as a raw material in the study further question the reliability of their results. Assumptions such as the generic use of the term 'clam' throughout the paper, and the substitution of one of the species of shell for a North American species (Choi and Driwantoro, 2007), despite the fact that the analysis is based on a south east Asian context. These assumptions highlight the current viewpoint of shell as a raw material in the contemporary archaeological community. While experimentation into the mechanical strength and properties of shell microstructures has been undertaken (Currey, 1988, Watabe, 1988, Carter and Clark, 1985, Currey and Taylow, 1974, Bruet et al, 2005, Currey, 1980, 1980), little application of this knowledge has been applied in an archaeological context.

As mentioned previously, the excavation of Golo Cave headed by Peter Bellwood uncovered shell specimens that have probably been used, if not modified for use as tools. Golo Cave is located on Gebe Island, between Halmahera and the western end of New Guinea, in

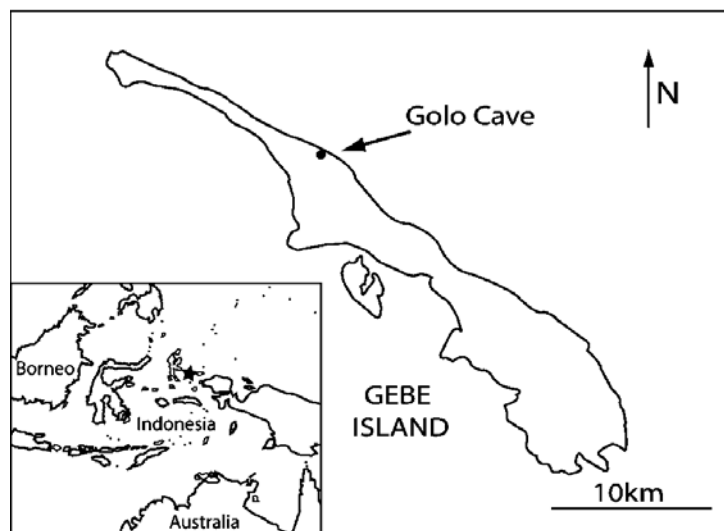


Fig. 2.3 : Map showing location of Gebe Island and Golo Cave (Sazbó et al., 2007)

Maluku Utara Province, eastern Indonesia (Szabó et al, 2007). The cave itself is located in uplifted coral, approximately 60 metres from the shoreline and 8 metres above sea level. Approximately 7 m² of material was excavated and sieved with the main excavation reaching a depth of 240cm (Szabó et al, 2007). Due to the difficulty in discerning natural sedimentary horizons, arbitrary 5cm spits were utilised in the excavating of material (Szabó et al, 2007). Four phases of occupation was identified for the cave using AMS radiocarbon dating of various materials including charcoal and marine shell. The range of ages over the four phases of occupation are 32,210±320 years BP for the first occupation to the most recent being 3,230±80 years BP. Initial colonisation of this area is credited most likely to that of *Homo sapiens* as opposed to earlier hominins such as *Homo erectus* or *Homo floresiensis* of which there is no evidence of them reaching the area (Szabó et al, 2007).

Of the material excavated, a broad range of artefacts were identified. Towards the earlier occupational phases of Golo Cave, between 150 and 240cm deep in the excavated site, 51 examples of stone artefacts were collected, the most common being flake shatter comprising 27% of the total number (Szabó et al, 2007). Very simple in morphology, the stone artefacts seem to have been made for use as sharp edged cutters or scrapers. No evidence of intentional retouching or the creation of formal tool types. In comparison, worked pieces of the pearl oyster *Pinctada margaritifera*, the chambered nautilus *Nautilus pompilius* and the snail *Turbo mamoratus*, among others were found. Concentrated at a stratigraphic area similar to that of the stone artefacts mentioned previously is a collection of pieces of the operculum of *T. mamoratus* that shows evidence of intentional shaping.



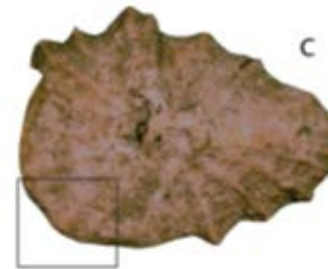
Fig. 2.4 : Reduced T. marmoratus operculum and flakes from Golo Cave (Szabó et al., 2007)

These operculum specimens and flakes are concentrated towards the very bottom and therefore oldest parts of the assemblage, between 195 – 235cm and 32,210±320 years BP. In the deposits above 195cm, only one example of worked *T. marmoratus* operculum and one amorphous shell fragment are found, though these have been presumed to be reworked through the assemblage. Analysis of the edge of the shaped opercula shows that flakes were removed from the edge in a unidirectional fashion creating a steeply angled edge in the same direction as the spiral shape of the operculum. As well as the opercula, the actual shell of *T. marmoratus* from two specimens were also recovered (Szabó, 2010). These shells show evidence of reduction around the aperture and the apex, leading to the creation of a sharp point. This form of reduction was most likely achieved with a sharp point (Szabó, 2010).

Shell fragments of *Nautilus pompilius* were also found. These fragments show evidence of working in the form of at least one cut edge well as bevelling and regularity of the edge (Szabó, 2010). In contrast to the various limpet species found in the Golo assemblage which in all probability were collected as a food resource, the *Nautilus* could not have been collected for this reason. The basic ecology of *Nautilus* species consists of paleoic existence in the open ocean.

Specimens only rise to the surface once dead and one washed up on the shoreline the flesh is either spoiled or been scavenged by crabs or birdlife. Using this reasoning, the *Nautilus* shells must have been collected for the use of their shells.

Patella flexuosa is another shell specimen found in the Golo Cave assemblage. While most of the samples identified are either complete or fractured concentrically around naturally occurring growth lines, a number of specimens show wear patterns and fracture not conducive with natural processes such as sand abrasion, wave action or movement within the stratigraphic profile. Areas around the shells perimeter show very regular rounding. This stands in contrast with the naturally irregular edge of the *P. flexuosa* shell. This localised rounding of the edge has been thought of as being created through scraping of material. Should this hypothesis prove correct and these rounded *P. flexuosa* Specimens prove artefactual, the implications of this conclusion will provide an excellent example of the utilisation of midden shell as a raw material in artefact, specifically tool production.



Patella flexuosa scraper macro and 15x magnific



Fig. 2.5 : Potentially worked *Patella flexuosa* specimen from Golo Cave (Szabó et al., 2007)

Chapter 3

Ecology

3.1 - LIMPET ECOLOGY

The limpet is one of the most common of organisms found in marine and shoreline environments. Members of Phylum: Mollusca and Class: Gastropoda, limpets are characterized by a conical shell that covers the internal body mass of the animal. Most limpets grow no bigger than 6 centimetres though have been known to grow to up to



Fig. 3.1 : Patella vulgata on rocky shoreline.

35 centimetres in specific species such as *Patella mexicana* (Branch, 1985 and Abbott and Dance, 1986). The limpet is found below the high tide mark along rocky coasts across all of the world's oceans. The limpet is often found adhering to rocks by a thick muscle called the foot which is also the animal's mode of locomotion through controlled, coordinated contractions. Adhesion to the substrate is achieved not through suction force as commonly thought, but through a pedal mucus that is excreted and acts as an adhesive. This greatly increases the holding power of the animal, but also significantly reduces mobility (Denny and Gaines, 2007). Feeding is conducted with an organ called the radula, which is likened to a tongue. This chitonous ribbon is comprised of teeth which are used to scrape algae towards the animal's oesophagus for consumption.

Limpets commonly form home scars, which are gouges or depressions in the rocky substratum that the limpet shell grows to suit exactly. It is also known for the limpet to erode a section of rock with the shell or radula to create a depression. This home scar is important as it provides a first line of defence against desiccation during low tide when the limpet is entirely exposed to the sun and dry wind. By sealing off all contact that the moist internal body mass has with agents of desiccation, like wind and sun, drying out is a much reduced risk. It has been stated that limpets which are denied their home scar suffer a much higher mortality rate during low tide as

a result of desiccation (Branch, 1985). The importance of the home scar is such that in some species, like *Scurria stipulate* experience a 33% mortality rate if the animal is denied access to its home scar after a single tide cycle (Branch, 1985).

One of the defining features of the limpet is the conical shell. The shell is constantly growing with the limpet and can be repaired when damaged. The shape of the shell is perfectly suited for the high energy environments that the limpet inhabits. While the general shape of the limpet shell is the same, there are slight adaptations between species which are better suited to specific environments and conditions. The location of the apex of the shell is just such an environmental adaptation. Limpets which adhere to substrates which are not fixed in place and sway freely, such as kelp, have an apex that is located much closer to the posterior of the organism (Vermeij, 1993). This is due to the direction of water current that the limpet experiences and the structural adaptation that followed to reduce the amount of force that water flow has on the shell, termed drag. The substrate sways in time and direction with the water current, leading to a unidirectional water flow at any point on the structure, or the shell constantly orientated in the direction of water flow (Vermeij, 1993). The stretched and streamlined shape of these “swaying” limpets greatly reduces drag and therefore the forces that are exerted on the animal. The effects of the streamlined shell are reversed however, should the direction of flow change (Vermeij, 1993).

In limpets which adhere to rocky substrata the water flow is less predictable, as water flow is travelling in a number of directions over a period of time, which is dependent on the topography of the surrounding area. Because of this constantly changing direction of flow, and the inability of the limpet to alter its orientation to maintain a relatively constant direction of flow in time for the next change in flow direction, rock dwelling limpets have developed a more centralized apex (Vermeij, 1993). This shape best suits the constant assault of water flow from all directions.

There are other adaptations that are employed in an attempt to further reduce the drag in high energy marine environments. The elevation of the shell also affects the forces experienced by the limpet. The height of the shell is indicative of the environmental energy levels. The higher the elevation, the greater the surface area for water flow to contact, and thus the greater the drag that the animal is subjected to. The opposite is true for limpets with a much lower shell elevation, which experience lower forces brought on by drag in environments with high levels of water energy (Vermeij, 1993). The texture of the limpet shell is also thought to have an effect on the level of drag caused by water flow. Small ribs or nodules on the external shell surface decrease the turbulence over the shell and reduce the low pressure system that develops behind the shell, therefore reducing the suction force that pulls on the limpet's shell.

The shape of the shell also protects against water loss. Being primarily located above the low tide mark, and below the high tide mark, limpets experience a period of time when they are not submerged for part of the tidal cycle. During this time, the limpet is exposed to the full force of the sun, wind and other agents that advance desiccation. Limpets have thus developed adaptations that combat water loss and increase their chance of survival (Branch, 1985). One of the simplest of these adaptations is increasing shell height. This increase in height leads to an increase in volume in the shell which is used to store water. Some species such as the *Patella vulgata* further this principle by increasing the angle of the shell to the substrate to a more perpendicular position as the animal matures, which slows the increase in shell circumference. This not only assists in the increase in shell height, but also the reduction of the ratio of shell height to surface area of the substrate that the animal is contacting. This decreases the amount of water loss even more.

Coupled with water loss, heat energy is a problem for limpets that are not immersed in water. The heat energy that collects in the rocky substrate from the sun is transferred into the limpet through the foot which is in almost permanent contact with the rock. This increase in body

temperature can be fatal as rocks exposed to sunlight can reach temperatures of up to 60° Celsius (Denny and Gaines, 2007). Specific species such as *Scurria stipulata* and *Siphonaria gigas* elevate their shell and curl the foot over, allowing air flow into the shell cavity. While this does reduce the temperature of the animal by up to 5° Celsius (Denny and Gaines, 2007), it also dramatically increases the effects of desiccation, however the positive aspects of this behaviour appear to outweigh the negatives. It has also been stated that the texture of the shell affects thermoregulation in limpets. Limpets with sculptured shell surfaces are more prevalent in warmer, sunnier environments than limpets who exhibit smooth shells (Branch, 1985).

Limpets predominantly consume algae, which is scraped off the substrate with a toothed, rope like organ called the radula. These scraping tools are not uniform throughout limpet species. Patellid limpets (Family: Patellidae) have a radula that contains larger, but fewer individual teeth. These teeth have a higher concentration of iron oxide towards the tips which greatly increases their strength. The hardened teeth are capable of removing not only the surface algae, but also the surface of the rock which contain algal sporelings. Other limpet taxa, such as the siphonarids (Family: Siphonariidae) do not have similarly hardened teeth as seen in patellid limpets, and as such are only capable of remove surface algae (Vermeij, 1978).

As can be inferred, limpets have a direct effect on the algal populations in an environment. In controlled experiments, when limpets are removed from an environment, there is a large increase in algal density (Vermeij, 1978; Branch, 1985). The individual effects that each species of limpet are, like the radula, not the same. This mainly comes down to the extent to which each limpet species feeds. As mentioned earlier, patellid limpets are capable of consuming not only existing algal colonies, but also the sporelings released by algae. This has a detrimental effect on algal populations as existing colonies are being attacked as well as new colonies failing to be established (Vermeij, 1978). This is then compared with other limpet species, such as the siphonarids, who only graze on existing algal colonies. These species generally have little to no

effect on algae densities and the abundance of colonies. This is only a generalisation however, as the patellid limpet *Acmaea scutum* does not have a major effect on algal densities, while the siphonariid *Siphonaria gigas* does (Branch, 1985). Not all algae are negatively affected by limpet predation. Some encrusting coralline types of algae rely on limpets to control the populations of foliose algae (Denny and Gaines, 2007) which would otherwise have smothered them (Branch, 1985).

Alternative and more energetic methods of feeding occur in *Patella argenvillei*. This species raises its shell in a mushroomed stance, and slams itself down when it senses a piece of kelp sliding underneath. The limpet maintains its grip then relying on the combination of wave action tugging at the captured kelp and sharp serrations along the edge of the shell to eventually tear off the captured section of kelp from the rest of the organism. This leaves the captured piece of kelp with the limpet which then consumes its prize (Denny and Gaines, 2007). Cooperative 'hunting' has also been noted with *P. argenvillei*, in which multiple individuals clasp onto a single kelp leaf. This is an example of how higher densities of individuals are an advantage compared to species who scrape algae of rock (Denny and Gaines, 2007).

Most limpets have a homing response to a fixed site on the rock platform. This homing site is the location of its home scar. As the limpet matures, the shell grows to conform tightly to the contours of the home site. Over time, the animal also erodes a depression into the rock (Morton, 1958). All these factors come together to form what is called a home scar. The behavioural adaptation of a home scar is thought to be a way to reduce desiccation, as well as a way to prevent predation. This is due to the increased effort and energy required to remove an animal that is embedded into the rock compared with one that is merely overlying the rock surface (Morton, 1958).

The complexity of this homing response is seen in research undertaken which test the homing abilities of limpets. Experiments have been undertaken which involve rotating the scar, as well

as a portion of the rock surrounding the scar to which the limpet will successfully re-orientate itself with the scar's new position (Morton, 1958). It was initially thought that pheromones or other chemical trails were laid down by the limpet as it left its home scar, and that these trails were followed until it reached its home site (Denny and Gaines, 2007). This has been disproven as experiments undertaken showed that limpets can return from a different route and still successfully locate its home scar (Morton, 1958 and Denny and Gaines, 2007). This concept of homing implies a sense of appreciation for topography or spatial memory that cannot be explained with our current understanding of the animal's sensory organs (Morton, 1958).

Another specialized behaviour seen in some limpet species is farming of algal colonies. This behaviour is usually restricted to the physically larger species of limpets, though is apparent in *Patella flexuosa* (Lindberg, 2007). These limpets have developed intimate relationships with algal colonies in the immediate vicinity of their home scar to the point of developing a protective mind-set of their algal colony. Limpets have been known to territorially defend their algal colony against other grazers by thrusting itself into intruders until they retreat (Denny and Gaines, 2007).

While the term 'farming' may be criticized, it actually proves fairly accurate. Limpets maintain their patch of algae in much the same manner as a gardener tends to their vegetable patch. Limpets control unwanted algal species by selectively grazing them away from the main body of the garden. Fertilizing also occurs through their ammonia rich excreta, and watering also occurs during exposed periods by the slow release of stored fluids from inside the shell cavity (Denny and Gaines, 2007). The limpet also grazes the algae patch, keeping the algae in a short, but fast growing stage of development where the tissues are highly nutritious. This behaviour of farming creates a sustainable and highly efficient and productive food source for the animal, and accurately suits the label 'farming' (Denny and Gaines, 2007).

Like the vast majority of marine and coastal organisms, predation is a constant reality. The limpet is no exception. Animals that readily prey on limpets include starfish, crabs, predatory whelks, fish and only recently humans. Of course the first line of defence against predators is the shell. Dropping the shell to the rock surface proves a much greater challenge for predators to pry the animal loose. This behaviour of clamping against the substrate is even more effective when the limpet is in its home scar, as the shell fits so tightly to the substrate. Fatal attacks are much more likely away from the home scar, when the clamping response cannot achieve a perfect fit on unfamiliar ground (Branch, 1985). Another structural adaptation to prevent predation is size. Adhesion power not only increases with size, but the proportion of predators that are physically large enough to eat a limpet of increased size decreases. A behaviour seen in large specimens is retaliation against predators. By raising the shell and bringing it down on the predator is one way in which a retreat response can be achieved (Branch, 1985). This retaliation only works however, on smaller predators such as whelks that do not move faster than the limpet.

Ways to combat predation are not exclusively active responses. Passive responses prove just as effective. Camouflage is effective though is restricted to predators that rely on sight to identify prey. Engaging almost exclusively nocturnally where a reduced activity in predators is experienced. This is not reliable as most limpet activity is defined by tides, particularly the coming of high tides (Branch, 1985). Possibly the most effective method to reduce predation is for the limpet to make itself undesirable to predators. Some siphonarids are poisonous, and predators such as fish, whelks and birds, refuse to attack these siphonarids even when they are readily available (Denny and Gaines, 2007). Relying on the desirability of other species, while not by definition a response or adaptation is another way that some species avoid predation. The predatory whelk *Morula marginalba* actively attacks *Patelloida latistrigata* while largely ignoring other species, such as *Cellana tramoserica* (Denny and Gaines, 2007).

3.2 - MOLLUSCAN SHELL

The shell of mollusc species serve a number of roles, as mentioned previously in this chapter. First and foremost in its roles is the protection of the soft tissue of the animal itself. Molluscan shell tissue is generally comprised of an outer organic layer termed the periostracum (Watabe, 1988). This thin layer of organic materials not overly strong and in older animals this layer is completely removed due to attritional erosion and other forces the animal is exposed to. A centre prismatic layer called the outer ostracum and an inner layer that is either porcelainous or nacreous depending on the microstructure, termed the inner ostracum (Scott and Kenny, 1998) form most of the shell by weight and volume. Overall the shell is calcium carbonate (CaCO_3) however there is always a proportion of proteinaceous material in the shell structure which forms the organic material of the periostracum and forms part of the shell's microstructure. This proportion has been placed at between 0.1% and 5% by weight (Currey, 1980). The relative thicknesses of the previously mentioned layers differ, though it has been noticed that the thickness of the periostracum is thicker in freshwater molluscs (Scott and Kenny, 1998). New shell, referring to all three layers, is created from the outer edge of the mantle and new shell is continued to be deposited throughout the animal's life. Rate of growth is not constant as the amounts of calcium carbonate needed for shell growth is entirely dependent on the environment and absorption calcium carbonate occurs through feeding on algae and absorption through the ambient environment (Day et al, 2000). Growth lines are also apparent on nearly all molluscs.

3.2.1 - MICROSTRUCTURES

Molluscan shell tissue is not a homogenous material. The forms that are observed are arranged into several distinct categories dependent on the crystallographic structures that naturally form. Each of the microstructures discussed are apparent in more than one of the six orders that make

up the class Mollusca (Currey, 1980). Significant amounts of study have been conducted on the nature of microstructures in molluscan fauna (Watabe, 1988, Bruet et al, 2005, Chateigner et al, 2000, Currey, 1980 and 1988, Carter and Clark, 1985, Day et al, 2000, Kaplan, 1998 and others). In the average mollusc shell there are millions of individual crystals formed. Differences in crystal arrangement, both within the individual layers and the separate layers combined create a material much stronger together compared with their individual constituents (MacClintlock, 1967). While up to ten separate microstructures have been identified (Kobayashi and Samata, 2006, Watabe, 1988, MacClintlock, 1967), the major recurring forms are described below.

3.2.1a - Nacre

Nacre, also known as mother-of-pearl, is pre- dominantly aragonitic and forms the middle or inner layer of molluscan shell (Watabe, 1988). While composed of weak constituent materials, nacre as a material provides good mechanical performance including stiffness, strength and impact resistance (Bruet et al. 2005). Referred to as having a 'brick-and-mortar' structure (Bruet et al. 2005, Carter and Clark, 1985), consisting of hexagonal mineral tablets surrounded by a thin (0.05μ) layer of organic material that acts as a cement holding the structure together (Watabe, 1988, Scott and Kenny, 1998). Individual tablets are approximately 10μ in diameter and between $0.2-2\mu$ thick (Watabe, 1988). The nacreous microstructure is laid down parallel between the inner ostracum layer and the shell edge itself (Bruet et al, 2005). It has been noted that nacre as a complete structure has strength that is of 3-4 orders of magnitude higher than that of homogenous calcium carbonate (Kaplan, 1998). Nacre can be one of

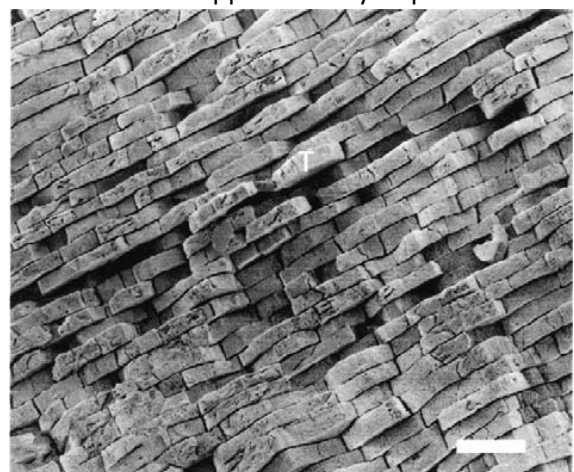


Fig. 3.2 : Nacreous microstructure under high powered scanning electron microscope

several different forms, all sharing the same basic pattern of the 'brick-and-mortar' structure yet differ in the stacking of nacreous tablets;

- Sheet nacre sees the nacre tablets developing in offset positions from the tablets immediately below (Watabe, 1988).
- Columnar nacre exhibits the crystal tablets stacked on top of each other forming regular vertical columns. Immature layers of nacre of the very innermost layer of the shell form steep cone shaped columns (Chateigner et al, 2000).
- Lenticular nacre is another structure that occurs occurs when the central portion of the nacre tablet expands forming a lens shape (Watabe, 1988).

3.2.1b - Prismatic

Prismatic microstructures uniformly oriented prisms encased in an organic sheath of approximately 5μ (Watabe, 1988). The aragonitic or calcitic prisms can be quite large, between $10\text{-}200\mu$ across and may be several millimetres long (Currey, 1980, MacClintock, 1967). Typically a polygonal shape is exhibited (Watabe, 1988). Four major subdivisions have been recognised;

- Simple prismatic layer (Watabe, 1988) is the simplest form of the prismatic microstructure. Each prism is comprised of stacks of disc shaped subunits surrounded by organic matrix sheets (Watabe, 1988). It has been noted that the difference between aragonitic and calcitic based prisms is the former exhibits diverging longitudinal striations, giving a feather-like appearance while the latter exhibits transverse striations (Watabe, 1988).

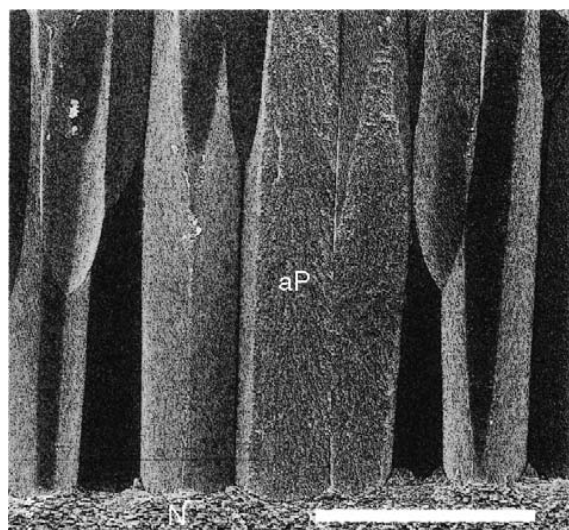


Fig. 3.3 : Prismatic microstructure under high powered scanning electron microscope

- Fibrous prismatic microstructure is a rather specialised variety of the prismatic microstructural form seen only in *Mytilus edulis* and other acmaeid molluscs (Watabe, 1988, MacClintock, 1967). Layers with this structure are composed of prisms that have a high length-width ratio (Watabe, 1988) with a rather constant diameter (MacClintock, 1967). Being so specialised, fibrous prismatic microstructure has been classified as an independent form by a number of authors (MacClintock, 1967, Kobayashi, 1971 and others).
- Composite prismatic structures are composed of a collection of separate prisms, individually made out of elongate rectangular rods (Kobayashi and Samata, 2006). Large horizontal prisms, termed first-order prisms are in turn comprised of second-order prisms radiating out in three dimensions towards the depositional surface from the central longitudinal prism (Watabe, 1988). Growth bands are also apparent (Watabe, 1988 and Kobayashi and Samata, 2006).
- Spherulitic prismatic structures, also known as radiated prismatic layer (Watabe, 1988), is characterised by prisms having elongate substructures radiating in three dimensions originating from a single point (Watabe, 1988).

3.2.1c - Foliated

A predominantly calcitic layer comprised of lamellae consisting of elongated parallel crystals uniformly dipping over large areas of the depositional surface (Watabe, 1988). Very similar in form to the nacreous microstructure in terms of individual crystal tablets laid in a regular fashion forming an overlapping blades resembling a shingled roof

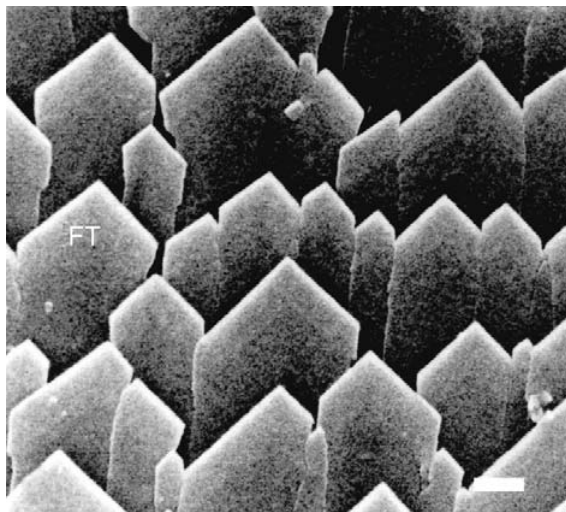


Fig. 3.4 : Foliated microstructure under high powered scanning electron microscope

(Watabe, 1988). Individual crystal tablets are approximately 2-4 μ in size (Kobayashi and Samata, 2006). Where nacreous and foliated microstructures differ is in the organic content. Where nacreous microstructures are comprised of approximately 5% weight of organic material, foliate microstructures have about 0.5-0.6% of total weight comprising of organic material (Watabe, 1988 and Bruet et al, 2005). As mentioned earlier, dipping is also an important characteristic. When viewed in vertical section it looks similar to crossbedding in geological terms (Kobayashi and Samata, 2006).

3.2.1d - Crossed Lamellar

One form that crossed lamellar microstructures can take is simple crossed lamellar. This structure is comprised of three separate orders of lamellae coming together to make up the overall crossed lamellar microstructure. Each lamellae has a near rectangular form, with the long axis oriented parallel to the shell surface with the short axes in a predominantly vertical position (Watabe, 1988). Elongate crystals, termed crystallites (Kobayashi and Samata, 2006) measuring approximately 10 μ wide and 0.3-2 μ wide form the third-order lamellae. These third-order lamellae are surrounded by a homogenous or a fibrous organic matrix membrane (Watabe, 1988). These third-order lamellae come together to form second-order lamellae, which in turn bundle together to form first-order lamellae which then go on to make up the structure of the layer (Kobayashi and Samata, 2006). Third-order lamellae join together in a parallel fashion forming a steeply angled block like second-order lamellae which then gets deposited in sequential sequence inclined in

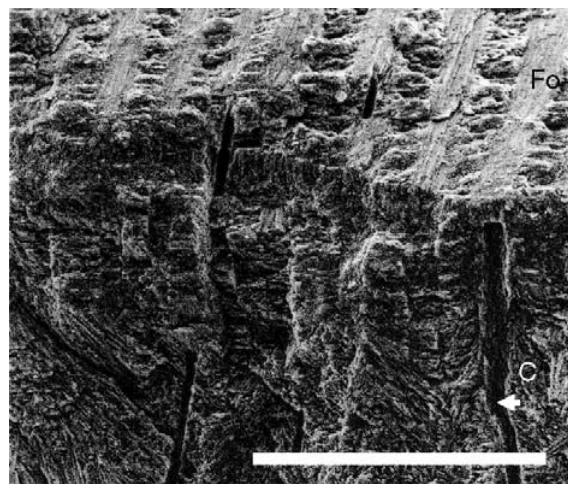


Fig. 3.5 : Crossed lamellar microstructure under high powered scanning electron microscope

opposite directions, near 90° (Currey, 1980), from each other forming first-order lamellae. This produces the criss-cross pattern that characterises the crossed lamellar microstructure (Watabe, 1988).

Complex crossed lamellar is still predominantly comprised of crystallites, however instead of forming blocks, they are arranged in such a way to form cones that are laid down perpendicular to the depositional surface or form acicular second-order lamellae having different dip directions (Watabe, 1988). The diameter of these cones is no more than 200μ with an incline of 45°. Each crystallite has a width of approximately 0.5μ (Kobayashi and Samata, 2006).

3.2.1e - Homogenous

When no particular structural pattern occurs, the microstructure is said to have a homogenous form. This microstructure consists of minute crystals of either aragonite or calcite and should not be larger than 5μ in diameter (Watabe, 1988). Currey (1980) referred to this microstructure as “really a very fine scrabble”. The organic matrix is also identified as tenuous (Currey, 1980). It should also be noted that de-

pending on the author, the grained structure that is sometimes apparent in homogenous microstructures is independent of true homogenous structures, claiming that the larger grain size is enough to separate it into its own microstructural category (Watabe, 1985), though this is dependent on authors.

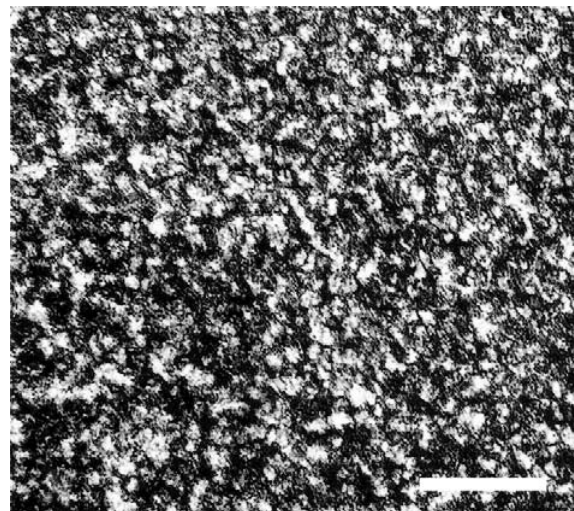


Fig. 3.6 : Homogenous microstructure under high powered scanning electron microscope

3.3 - TARGET TAXA

The target taxa chosen for this study are *Patella flexuosa*, *Patella peronii*, *Cellana tramoserica*, *Cellana solida* and *Siphonaria diemenensis*. This selection of species is based on a number of factors described below.

Species: *Patella (=Scutellastra) flexuosa*

Family: Patellidae

Microstructure: Inner radial crossed lamellar (Chateigner et al, 2000); however MacClintock (1967) identifies predominantly cross foliate microstructures throughout *Patella spp.*

Specimens collected from west Java, Indonesia and Bohol Islands, the Philippines. *P. flexuosa* has been chosen for experimentation because this species makes up a large number of limpet remains discussed early last chapter in Golo Cave, Indonesia (Szabó, 2007). As the species that exhibits the probable working patterns using this species in experimentation and analysis was a logical choice (Szabó, 2007). One note to make, average shell size of *P. flexuosa* that make up the Golo Cave midden assemblage are notably bigger than the size of contemporary specimens (Branch, 1985). While an argument can be made that puts forward that the samples that make up the Golo Cave assemblage are larger than normal, we argue that while contemporary *P. flexuosa* specimens are notably smaller, a regression in animal size may have occurred due to reliance on the animal as a food resource and subsequent over collection.

As well as these reasons, being a tropical molluscan species the study will be able to discern differences between temperate and tropical shell specimens and the potential differing of fracture mechanics between the two regions.

Species: *Patella (=Scutellastra) peronii*

Family: Patellidae

Microstructure: Inner radial crossed lamellar (Chateigner et al, 2000); however MacClintlock (1967) identifies predominantly cross foliate microstructures throughout *Patella spp.*

Patella peronii was selected as it shares a common heritage with *P. flexuosa* at a genus level. Structurally it is typically a limpet so in a morphological sense it is similar to *P. flexuosa* while at the same time having defining structural features on its own. Collection of specimens occurred along rocky parts of coastline between Headland's Beach, Coledale and North Beach, North Wollongong, New South Wales. Size ranges up to 52mm length, though is commonly found to be 35mm (Beechey, 2004).

Species: *Cellana tramoserica*

Family: Nacellidae

Microstructure: Inner irregular complex crossed lamellar with nacreous interior (Chateigner et al, 2000).

Living on all rocky shores apart from the locations of highest wave energy, *Cellana tramoserica* is one of the most abundant limpet species found on the south coast of New South Wales (Koppel, Pers. obs). Collected between Headland's Beach, Coledale and North Beach, North Wollongong, New South Wales, *C. tramoserica* grows up to 65mm long, though is commonly around 50mm (Beechey, 2004). Still a true limpet, *C. tramoserica* is related to *P. flexuosa* and *P. peronii* at an Order level.

Species: *Cellana solida*

Family: Nacellidae

Microstructure: Inner irregular complex crossed lamellar with nacreous interior (Chateigner et al, 2000).

Cellana solida shares the same distribution as the previously mentioned *C. tramoserica* and *P. peronii*. As before, specimens were collected between Headland's Beach, Coledale and North Beach, North Wollongong, New South Wales. Related to *C. tramoserica* at a Family level and *P. flexuosa* and *P. peronii* at an Order level is still classified as a true limpet. While possessing some degree of variability in shell morphology, when compared with *C. tramoserica*, *C. solida* exhibits a thicker, more robust shell with a more even length-elevation ratio (Koppel, Pers obs).

Species: *Siphonaria diemenensis*

Family: Siphonariidae

Microstructure: Presently unknown

Collected on rocky shorelines between Headland's Beach, Coledale and North Beach, North Wollongong, New South Wales, *S. diemenensis* represents the smallest size range of the target taxa, having a size range of 10-26mm in length (Koppel, Pers. Obs.). Of the species of gastropod selected for this research project, *S. diemenensis* is the only one that is not a true limpet. Where true limpets have gills under the mantle cavity, Siphonariids are air-breathers and respiration is achieved with a lung (Stanisic, 1998). This species was selected as an example of convergent evolution. While being quite removed from the previously mentioned species in a taxonomic sense, all have a calcium carbonate shell with rather similar morphological features, all inhabit the same environments and all function in a strikingly similar way not usually expected with species only joined at the Class level.

Chapter 4

Methodology

As of yet, there is no standard methodological approach for confidently identifying worked shell. Identification of shell tools by analysts is usually based on their own knowledge, experience and intuition (Szabó, in press). The overarching trend seen in studies that involve shell as a raw material is that conclusions are drawn on a very individual and case-by-case basis. Study needs to be undertaken in an attempt to create a broadly applicable methodology in shell tool identification. Very little controlled experimental work has been conducted in regards to recognising the effects shell has on other material in the context of tool production, or of observing the traces of working on the shell itself. While some studies have employed an experimental approach (e.g. Choi and Driwantoro, 2007; Spennemann, 1993a, b), fundamental issues with the assumptions used and/or a general lack of control mean that the analysis and identification of shell artefacts utilised as tools remains problematic.

This thesis will attempt to pilot a new method for the identification of culturally-modified shell. By conducting a series of experiments focused on use-wear, controlled breakage experiments and followed by detailed scanning electron microscopy (SEM) analysis, patterns should emerge that would ultimately allow us to discern a difference between natural breakage patterns and breakage/wear patterns formed through cultural use. Understandings gained from the experimental work will then be applied to the archaeological *Patella flexuosa* specimens from Golo Cave (Szabó et al., 2007), Indonesia, which have been detailed previously.

Use-wear analysis, which is the central core to this study, has received a lot of attention in the archaeological literature and has been the focus of a number of studies. Significant research into use-wear has been conducted; dominantly on lithic artefacts (Lawn and Marshall, 1979; Kealhofer et al., 1999 and Andrefsky Jr., 2005). However these will not be consulted based on the now hopefully clear basis that shell does not act in the same way as stone as implied by some studies (e.g. Cleghorn, 1977 and aspects of Smith 1991). The forces acting upon the

material will cause stone and shell to react differently, thus creating different patterns. It is this fact that means that the wear patterns exhibited on shell are going to diverge from those seen on stone, and thus interpretations will generally not be transferrable between the two materials. For these reasons, this thesis has not drawn upon the use-wear literature in archaeological lithic studies, so as to avoid potential bias and unwarranted assumption.

The experiments undertaken in this thesis involve the working of a variety of materials believed to be relevant in a Southeast Asian context and temporally appropriate to the artefactual evidence found at Golo Cave. It should be stated at the outset that materials were chosen not only for their regional relevance, but also because they presented a variety of textures for working. It is recognised that any potential 'matches' between experimental and archaeological specimens do not necessarily indicate the working of that particular material, but such matches potentially inform upon the type and texture of material being worked. While emphasis is placed on using materials as authentic as possible to a Southeast Asian context, most of the materials cannot be exactly replicated. Contemporary shell specimens cannot be expected to be identical with specimens found at Golo Cave. As well as this, the constantly changing morphological characteristics that species experience over time will also affect characteristics between the separate time periods.

The experimentation stage of the research project has been broken up into a number of stages, each having a specific aim;

4.1 - COLLECTION

Initial gathering of samples began with a mass collection of all limpet species obtained from rocky beaches between Coledale and North Wollongong beach, on the New South Wales Southeast coast. The collected specimens were sorted by species with the most abundant species forming the assemblages that would eventually be used in the experimental part of this

research project as detailed below. Specimens were collected dead with all size classes gathered, as well as whole and fragmented shells, to allow the best representation of naturally occurring assemblages of shell. Specimens were only cleaned under running water, and were not refined in any way prior to analysis and experimentation.

Collection of the target shell species was conducted along rocky portions of coastline between Scarborough and North Wollongong beach, on the south east coast of New South Wales, Australia. Based on the rather broad range of limpet species that inhabit this piece of coast, the target taxa were isolated to three species of limpet; *Cellana tramoserica*, *Cellana solida* and *Patella peronii*. To allow a direct comparison to the Golo Cave shell assemblage, *Patella flexuosa* specimens were acquired from west Java, Indonesia and Bohol Island, Philippines. *Siphonaria diemenensis*, of family Siphonariidae was also chosen to be part of this study. While not a true limpet *S. diemenensis* is an excellent example of convergent evolution. While only being related at the class level (Gastropoda), *S. diemenensis* and the above mentioned limpet species all share a common habitat of rocky coastline, all have a shell made of calcium carbonate and all share remarkably similar morphology. Where they differ is the limpet species use gills in respiration whereas the Siphonariidae use a lung to absorb oxygen (Denny and Gaines, 2007).

This combination of species gives three different genera (*Cellana*, *Patella* and *Siphonaria*) as well as a range of microstructures, as seen in the table above. As mentioned earlier, the location of the shell, be it tropical or temperate in climate will often affect the aragonite to calcite ratio of the shell and this will in turn effect the response of the shell to force. For further details regarding aragonite-calcite ratios, please refer to the x-ray diffraction in Chapter 5.

Species	Microstructure	Temperate/Tropical
<i>Cellana solida</i>	Inner irregular complex crossed lamellar with nacreous interior (Chateigner et al, 2000).	Temperate
<i>Cellana tramoserica</i>	Inner irregular complex crossed lamellar with nacreous interior (Chateigner et al, 2000).	Temperate
<i>Patella peronii</i>	Inner radial crossed lamellar (Chateigner et al, 2000), however MacClintock (1967) identifies predominantly cross foliate microstructures throughout <i>Patella</i> spp.	Temperate
<i>Patella flexuosa</i>	Inner radial crossed lamellar (Chateigner et al, 2000), however MacClintock (1967) identifies predominantly cross foliate microstructures throughout <i>Patella</i> spp.	Tropical
<i>Siphonaria diemenensis</i>	Unknown as of yet – investigated as a part of this research	Temperate

Table 4.1 : Summary of the target species for this study, presently identified microstructures and the type of climate the animal inhabits

4.2 - ACCESSIONING, MORPHOMETRIC ANALYSIS AND TAPHONOMIC ASSESSMENTS

Specimens collected were sorted by species and each given a unique accession code and stored separately. This was done for ease of recognition and recollection when needed for experimentation or reference, and for general organization. A total of 353 individual shell specimens were collected spread over five species excluding the Golo Cave samples. Proportions of the total sample assemblage are displayed in the graphs and charts on the following page.

Each individual shell was then measured, recording length, width, elevation and the distance of the apex from the posterior edge. These measurements were then put through the statistics program 'Primer 6' in an attempt to see if there is a notable difference in measurements between the five species that make up the sample.

Species	Accession Code	Quantity
Cellana tramoserica	Cet	82
Cellana solida	Ces	80
Patella peronii	Pap	52
Patella flexuosa	Paf	31
Patella flexuosa (Golo Cave)	PafGC	81
Siphonaria diemenensis	Sid	27
	Total	353

Table 4.2 : Quantities of each of the target species being used in this project

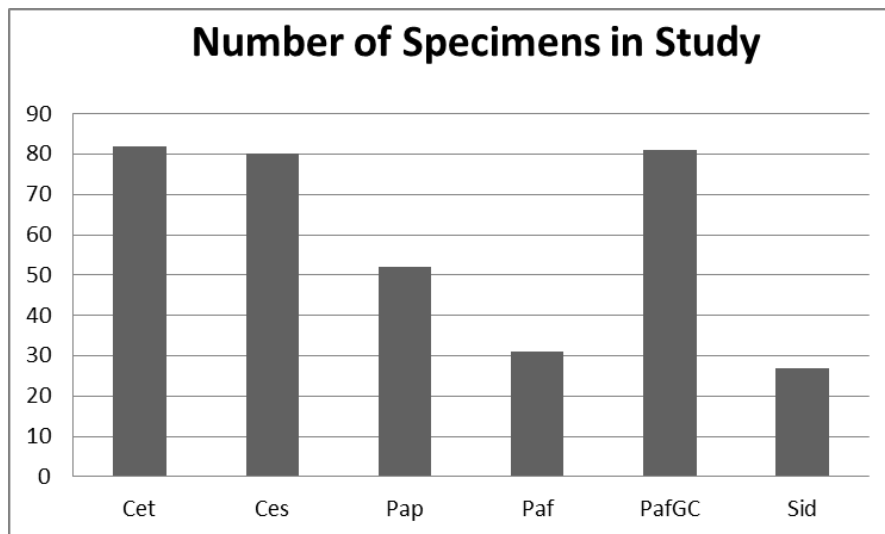


Fig. 4.1 : Bar graph depicting the quantities of each of the target species being used in this project

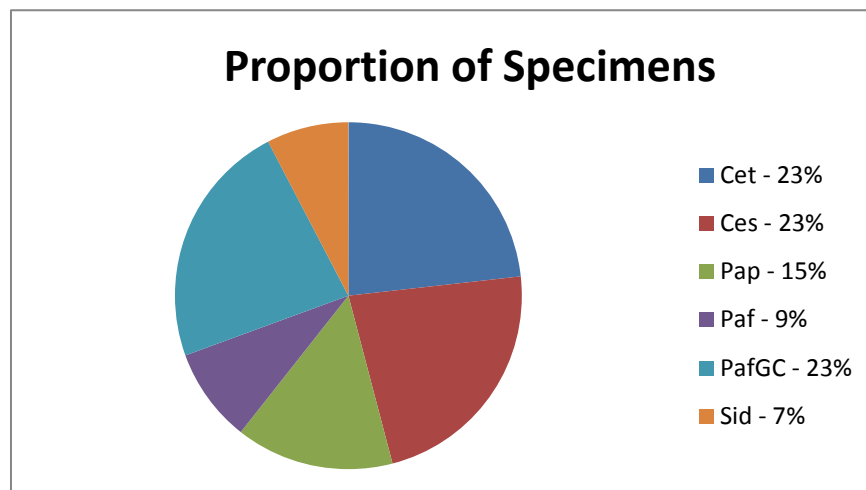


Fig. 4.2 : Pie chart depicting proportion of species being used in the project

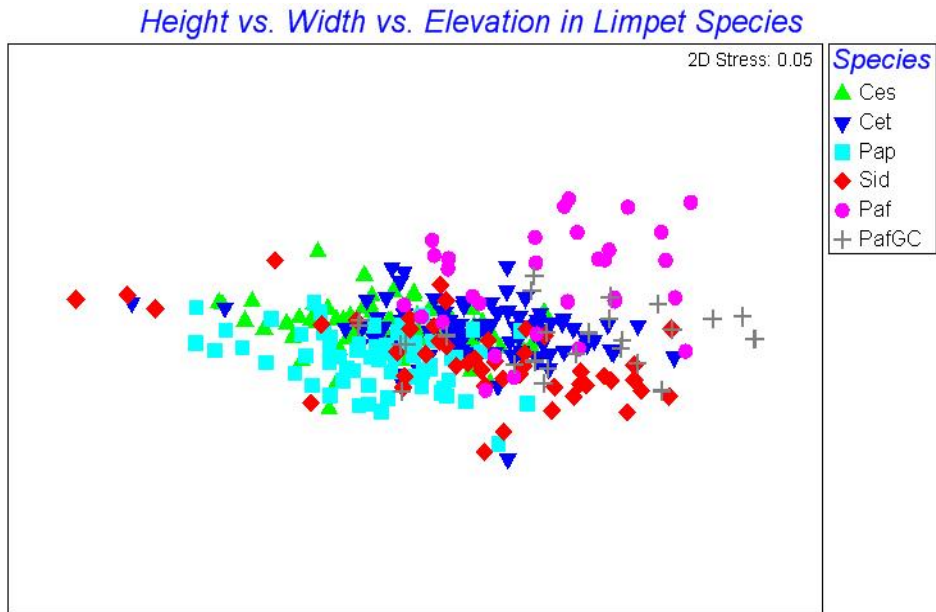


Fig. 4.3 : Diagram above shows scatter plot of limpet specimens graphed where height, width and shell elevation are variables. As can be seen species cluster for the most part in species similar groups. ANOSIM analysis indicates a large significance between species (Significance level of sample statistic 0.1%).

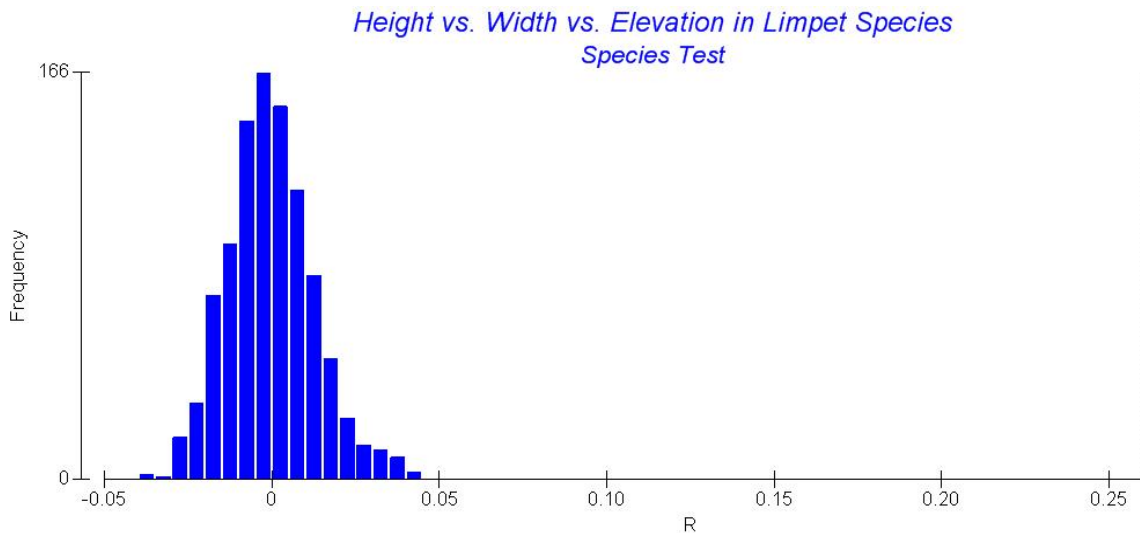


Fig. 4.4 : Diagram above shows distribution of limpet species in a classic bell curve shape, indicating an even sampling of specimens and morphological characteristics.

As the shells that were collected are going to be subjected to controlled force, any faults, flaws or features that have altered the general morphology of the shell will affect the shell's reaction to said force. Taphonomy is the study of factors that affect material remains after death/deposition, and in the case of the mollusc shells, this may include wave action causing cracks and fractures, sand blasting and water-rolling causing attrition (Day et al., 2000). Animals such as annelid worms and certain species of molluscs and sponges bore into mollusc shell weakening the structure (Scott and Risk 1988), while calcareous adhesions in the form of worm casts and barnacle plates are common in the collected assemblage (Denny and Gaines, 2007; Pers. Obs Koppel, 2010). Regardless of the type of modification the shell experiences, any alteration will affect the strength and mechanical properties of the shell. In attempt to classify at the outset what damage has occurred to the shell prior to collection, each shell used in an experiment was taphonomically assessed with any damage or adherent structure on the shell surface noted and recorded (refer to appendix 1).

4.3 - X-RAY DIFFRACTION (XRD) ANALYSIS

As mentioned earlier, molluscan shell is comprised of either calcite or aragonite. The ratio of these two forms of calcium carbonate in the shell is to some degree tied to the latitude in which the shell lives, with tropical shells generally having a higher proportion of aragonite to calcite compared to temperate species whose structure is more calcite dominated. As a mix of temperate and tropical limpet species and one species from the Siphonariidae are present in the research project, x-ray diffraction (XRD) analysis will identify various elements and chemical compounds present in the shell, and once defined and isolated, can pinpoint the quantities of calcite versus aragonite in the shell.

Specimens were prepared by first crushing whole shells into smaller fragments. Grinding down samples with a mortar and pestle occasionally adding acetone to reduce the shell fragments into

a powder with the consistency of talc is necessary for XRD analysis. The samples were then processed by José Abrantes of the School of Earth and Environmental Sciences at the University of Wollongong and results interpreted with assistance from Associate Professor Brian Jones.

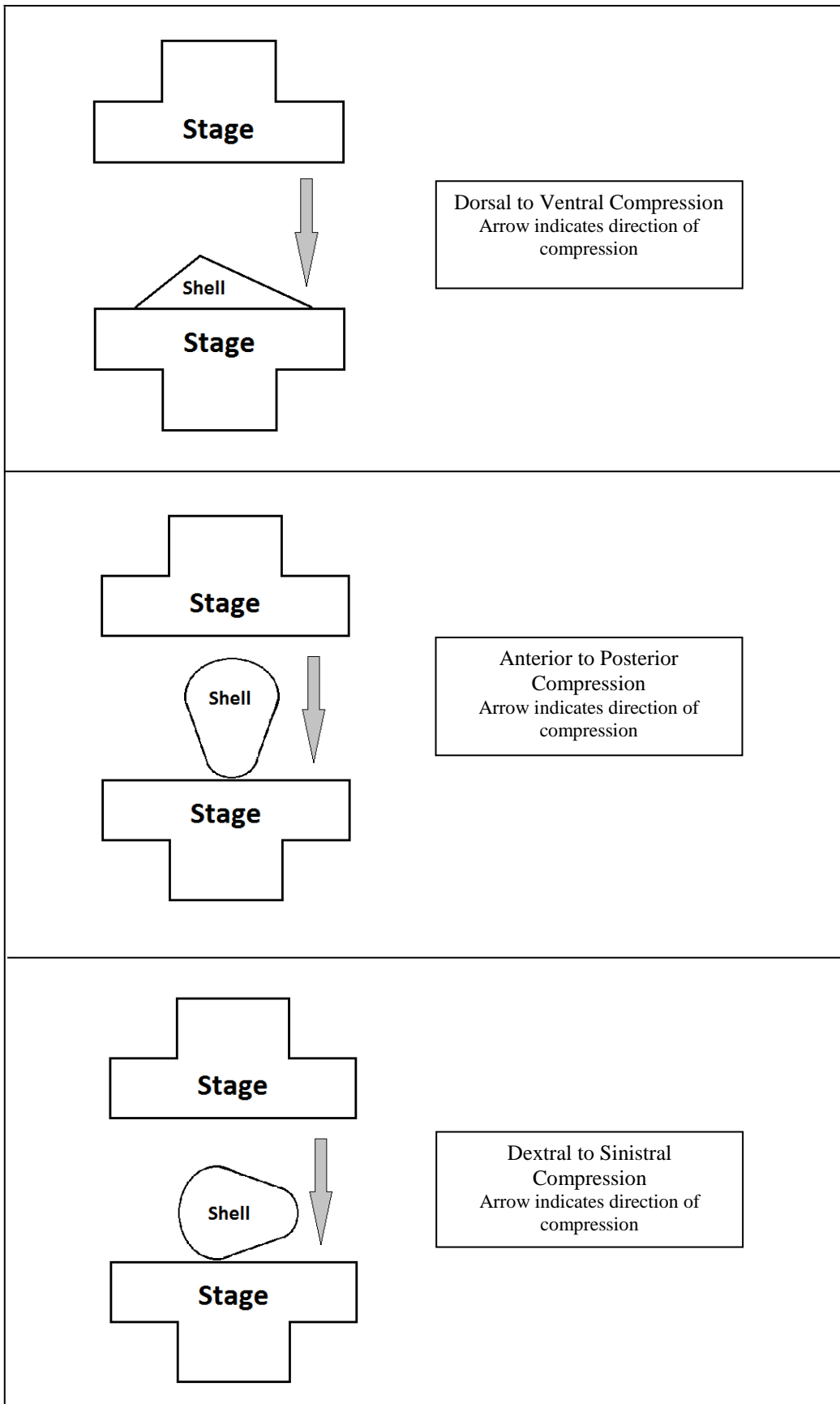
4.4 - CONTROLLED FRACTURE EXPERIMENTS

4.4.1 – INSTRON EXPERIMENTATION

At the heart of this research project is wear patterns and fragmentation in limpet shells. With this in mind it is necessary to identify a base-line of reference for shell fracture. Controlled fracture experiments were conducted with an INSTRON static-testing machine, care of the Materials Engineering Department of the University of Wollongong. Designed to apply and measure force and moment of fracture of an object, an INSTRON static-testing machine, in this project's case, places compressive force on the shell in the form of two flat level stages that come together. Compression automatically stops at the moment of structural failure. By orientating the shell on the stage in various directions, fracture can be forced that is solely the result of this compressive force. The shell samples are placed at the following prior to compression and diagrammed below;

1. Dorsal to Ventral compression
2. Anterior to Posterior compression
3. Dextral to Sinistral compression

Fig. 4.5 : Diagram describing INSTRON controlled fracture experiments and shell and stage orientations



This form of experimentation is useful as all of the fracture patterns generated in the compression process can be identified with certainty to one of the three directions tested. As well as the fractures generated, the software attached to the INSTRON machine provides information of the force applied to the shell in Newtons before catastrophic failure.

4.4.2 - USE-WEAR EXPERIMENTATION

At the very core of this study is the hypothesized evidence of use-traces on shell artefacts within the Golo Cave assemblage (Szabó et al. 2007; Szabó in press). Since no current standardised criteria for identifying worked shell exists, one will begin to be established here. Using materials considered relevant to a Southeast Asian context, and temporally appropriate to that of the chronological placement of the earliest Golo Cave deposits, six different materials were chosen for experimentation; yam (*Dioscorea alata*), taro (*Colocasia esculenta*), bamboo (*Bambusa* sp.), coconut (*Cocos nucifera*), pork flesh and bone (family Suidae), and haematite. These different substances all have distinct textures, as outlined in the table below, and are hypothesized here to affect shell differently throughout the experimentation process. Pork flesh is not necessarily relevant to a Golo Cave context as pigs were not present until the Neolithic or post-neolithic of Gebe Island (Flannery, 1995; Flannery, 1998). It was selected based on the fact that no other substance has a series of textures quite like flesh, from the musculature of the flesh itself, the hard, regular form of the bone and the elastic and tough skin. This would provide a useful contrast in potential wear patterns for later comparison with archaeological specimens outside of Golo Cave. Presumably, also, the earliest inhabitants of Golo Cave were processing and eating non-aquatic fauna, and pig stands in as a proxy for these presently unknown prey species.

TEXTURE	SUBSTANCE
Soft and fibrous	Yam, Taro
Hard and fibrous	Bamboo, wet and dry
Soft and not fibrous	Coconut, Pork skin
Hard and not fibrous	Haematite, Pork bone
Muscular	Pork flesh

*Table 4.3 :
Description of
textures of
substrates being
used in use-
wear
experiments*

4.4.1a - Taro

The taro plant (*Colocasia esculenta*) is a tropical aroid in the Family: Araceae that is generally harvested for its edible corm (ASPCA, 2010). It is a staple food within Oceanic cultures and is believed to be one of the earliest cultivated plants (Jackson et al, 2006). In its raw state, the corm is toxic due to the presence of calcium oxalate crystals in the skin and flesh which are an irritant and can cause severe reactions upon consumption. The cooking process removes the toxic components rendering it safe to eat. Taro is generally boiled or baked when cooked and the entire plant is known to be edible, including leaves and stem (ASPCA, 2010).

It has been suggested that *C. esculenta* may have had a natural range that included the Solomon Islands as well as New Guinea and Southeast Asia (Spriggs, 1997). Residue analysis of stone tool artefacts have led to the theory that cultivation of the large corm variety and targeted collection was conducted to some extent by humans (Spriggs, 1997).

Aim

- To determine the suitability of five species of limpet shells as a tool for food processing, specifically with regards to the peeling of small and large corm taro (*Colocasia esculenta*), as well as analyzing the wear patterns and fragmentation associated with the peeling of the taro.

Method

- Study specimens

The specimens used include five species of limpet; *Cellana tramoserica*, *Cellana solida*, *Patella peronii*, *Patella flexuosa* and *Siphonaria diemenensis*. These mollusc species were utilized in the peeling of small corm and large corm taro (*Colocasia esculenta*).

Six individual specimens of each of the five species of shell were selected based on the overall quality of the shell in regards to erosion, existing fractures and evidence of

bioerosion and adhesions. This was done through taphonomic assessments of each individual shell specimen and will allow maximum comparability of results.

- Experimental design

Preparation of the taro was relatively simple. Cutting the ends of the specimen ensured that the shell samples were exposed only to the flesh of the tuber. The taro specimens were washed and dried with the outer skin still remaining on the fruit.

The shells were held with the thumb located on the ventral surface at the apex and the index finger wrapping over the anterior dorsal surface around the apex. The shell's anterior edge was the exposed to the flesh of the taro corm.

The experiment was then broken up into two separate parts based on the direction of the scraping action; towards the body of the holder, and away from the body of the holder. Each of these directions is then broken



Fig. 4.6 : Depiction of taro use-wear experiment

up into the number of strokes the shell contacted the taro; 20, 40 and 100 strokes for each species of shell.

The shells used in the experiments were then catalogued, individually bagged, and then organized according to species. Following this, each shell sample was then photographed under a low-power light-microscope, and then selected samples were viewed under a scanning electron microscope (SEM).

These images were then analysed and the patterns observed were interpreted following the principles of fractography (Hull, 1999) as well as any other visible signs of alteration.

4.4.1b - Coconut

The coconut (*Cocos nucifera*) is synonymous with the tropical environment. A member of the Arecaceae family, it is the only accepted species in the genus *Cocos* (Mellars, 2006). The coconut itself is made up of three distinct parts; exocarp, mesocarp and endocarp. The exocarp makes up the outer section of the coconut, also called the husk. The mesocarp is the brown shell, which is the hardest part of the coconut. The white flesh inside is called the endocarp, which is the edible part. While in contemporary western cultures only the flesh is utilized, in a traditional context nearly every part of the coconut, including the tree itself has been utilized by native cultures (Spriggs, 1997).

Aim

- To determine the suitability of the five species of limpet shells as a tool for food preparation, specifically with regards to the coconut (*Cocos nucifera*), as well as analyzing the wear patterns and fragmentation that is associated with the scraping, scooping and cutting of coconut flesh.

Method

- Study specimens

The specimens being studied are five species of limpets; *Cellana tramoserica*, *Cellana solida*, *Patella peronii*, *Patella flexuosa* and *Siphonaria diemenensis*. These mollusc species were utilized in the scraping, scooping and cutting of coconut flesh.

Nine individual specimens of the five species of shell were selected based on the overall quality of the shell in regards to erosion, existing fractures and evidence of bioerosion and adhesions with the most pristine specimens being selected. This was done through taphonomic assessments of each individual shell specimen prior to experimentation. By selecting the specimens with the least taphonomic alteration, maximum comparability of results can be achieved.

- Experimental Design

Three coconuts were obtained for experimentation. Preparation of the coconut involved breaking into mesocarp by first using a saw to create a groove and structural weak point, and hitting the mesocarp against the corner of a wall, splitting the coconut into two halves. Once access to the endocarp was achieved, the coconut water was drained and any debris removed.

The experiment was then broken up into three separate parts; scraping towards the body of the holder, away from the body of the holder and the cutting of the coconut meat based on three different methods in which coconut flesh can be separated from the mesocarp. By using three separate directions, the edge of the shell was also exposed to three different directions of force and wear separately, as well as the flow of removed material and how it contacts and potentially affects the shell surface. Each of these actions was then broken down further into the number of strokes the shell contacted the coconut; 20, 40 and 100 strokes for each species of shell.

The shells were held with the thumb located on the ventral surface at the apex and the index finger wrapping over the anterior dorsal surface around the apex. The shell's anterior edge was the exposed to the meat of the coconut .

The shells used in the experiments were then catalogued, individually bagged, and then organized under species. Following this, each shell sample was then photographed under a low-power light-microscope, and selected samples were then imaged under scanning electron



Fig. 4.7 : Depiction of coconut use-wear experiment

microscope (SEM). The patterns observed were interpreted following the principles of fractography (Hull, 1999) as well as any other visible signs of alteration.

4.4.1c - Bamboo

Bamboo is one of the most prevalent plant taxa of the Southeast Asian region and represents a major part of Asian and Southeast Asian culture. It is used for many different purposes such as building, storage, tools and as a food resource (West and Louys, 2007). The large scale utilisation of this resource is easily explained by the ease in which it is incorporated into specific purposes and its extensive abundance.

Bamboo plays a rather large role in regional archaeological theorizing, and especially in the subject matter of this research project. The 'Bamboo Theory' is at the forefront of explanations of the replacement of stone as a raw material in artefact production (Mellars, 2006). This theory however, cannot be proven or disproved based on the perishable nature of the material and its inability to be preserved in the archaeological record. In addition to numerous historical and ethnographic references, recent studies have concluded that bamboo is indeed suitable for use as a raw material for artefact production (West and Louys 2007). Chemical and structural analysis of bamboo reveal it as being comprised of up 70% silica, and when split cleanly can have a very sharp edge (West and Louys, 2007). Experimentation using bamboo as a tool conducted by West and Louys (2007) have yielded surprising results of bamboo knives being more than adequate for defleshing animal bones and cutting through flesh. While not as effective as lithic tools in retaining a sharp edge, the bamboo knives had a longer cutting surface and are arguably easier to produce.

Aim

- To determine the suitability of five species of limpet shells as a tool the removal of cellulose material in bamboo allowing access to fibrous material inside the plant's stem, as well as analysing the wear patterns and fragmentation that is associated with this process on the shells.

Method

- Study specimens

The specimens being studied are five species of limpets; *Cellana tramoserica*, *Cellana solida*, *Patella peronii*, *Patella flexuosa* and *Siphonaria diemenensis*. These mollusc species were utilized in the rubbing of the surface of bamboo.

Twelve individual specimens of the five species of shell were selected based on the overall quality of the shell in regards to erosion, existing fractures and evidence of bioerosion and adhesions with the most pristine specimens being selected. This was done through taphonomic assessments of each individual shell specimen prior to experimentation. By selecting the specimens with the least taphonomic alteration, maximum comparability of results was ensured.

- Experimental design

One four metre long length of bamboo (cf. *Bambusa vulgaris*) was obtained, and cut into a series of smaller lengths at least one segment (culm-node to culm-node) long. Preparation of the bamboo involved splitting the culm lengthways to create two halves. Not only did this double the number of lengths, but it also allowed access to the inner culm pith of the bamboo plant. This would provide another to be experimented upon in contrast to the green outer layer. Depending on desired final use, the bamboo can be soaked to soften the culm prior to modification and use. Given this possibility, half of the bamboo samples were soaked in water for several days in an attempt to best utilise the potential methods used by cultures at the time and replicate possible actions.

The actual experimentation was conducted using a rubbing action more than a cutting, scooping, scraping or peeling action used in previous experiments. This means that the shell edge was in constant contact with the bamboo surface with a backward and forward motion constituting one stroke. As mentioned previously, the bamboo lengths

were split allowing access to the inner structure of the plant, which were utilised in experimentation in the same way as the green outer layer. This experiment was then further broken down into three sections based on the number of strokes per shell specimen; 20, 40 and 100 strokes for each species.

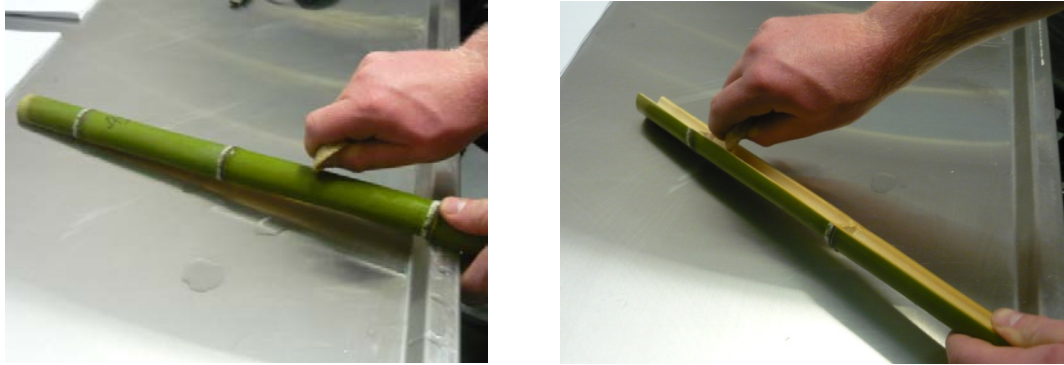


Fig. 4.8 : Depiction of bamboo (interior and exterior) use-wear experiment

The shells were held with the thumb located on the ventral surface at the apex and the index finger wrapping over the anterior dorsal surface around the apex. The shell's anterior edge was the exposed to the inner and outer surface of bamboo

The shells used in the experiments were then catalogued, individually bagged, and then organized under species. Following this, each shell sample was then photographed under a low-power light-microscope, and then selected samples were viewed under a scanning electron microscope (SEM).

These images were then analysed using low-powered light microscopy followed by scanning electron microscopy and the patterns observed were interpreted following the principles of fractography (Hull, 1999) as well as any other visible signs of alteration.

4.4.1d - Haematite

Haemetite is the mineral form of iron (III) oxide. Ranging in colour from blacks and greys to reds, this mineral has played a major role in prehistoric cultures all over the world. While the mineral in its raw form was rarely used, when ground and added to clay it forms a coloured material that has been extensively used as a decorative medium throughout the world and history (e.g. Mellars, 2006; Szabó et al., 2007; Henshilwood and Marean, 2003). Ochre is significant in an archaeological context as it represents one of the very first example of



Fig. 4.9 : Picture of hematite block, cut in half prior to experimentation

‘modern human behaviour’ and the use of arbitrary symbols in Blombos Cave where an engraved piece of ochre was found (Henshilwood et al., 2002). Ochre has since been used more and more in symbolic acts such as a medium for rock art and body paint (Henshilwood and Marean, 2003), decoration of symbolic pieces and in burial rituals (Szabó et al., 2007 and Einwögerer et al., 2006).

Aim

- To determine the suitability of shell as a raw material for the reduction of haematite into a powder suitable for ochre production, as well as analysing the wear/fragmentation patterns associated with this task on shells.

Method

- Study Specimens

The specimens being studied are five species of limpets; *Cellana tramoserica*, *Cellana solida*, *Patella peronii*, *Patella flexuosa* and *Siphonaria diemenensis*. These mollusc species were utilized in the scraping of the surface of a haematite node.

Three individual specimens of the five species of shell were selected based on the overall quality of the shell in regards to erosion, existing fractures and evidence of bioerosion and adhesions with the most pristine specimens being selected. This was done through taphonomic assessments of each individual shell specimen prior to experimentation. By selecting the specimens with the least taphonomic alteration, maximum comparability of results was ensured.

- Experimental Design

A node of raw haematite was made available from the School of Earth and Environmental Sciences geology bulk specimen collection, University of Wollongong. Preparation of the haematite sample involved cutting the rough shaped rock with a diamond saw leaving a smooth face. Like the bamboo experiment, a rubbing action was used as opposed to specific cutting, scooping or scraping. The experiment was then broken down into three sections for each shell dependent on the number of strokes the shell was used; 20, 40 and 100 with one stroke constituting a forward and backwards motion with the shell edge in constant contact with the substrate.

The shells were held with the thumb located on the ventral surface at the apex and the index finger wrapping over the anterior dorsal surface around the apex. The shell's anterior edge was the exposed to the surface of the haematite.

The shells used in the experiments were then catalogued, individually bagged, and then organized under species. Following this, each shell sample was then photographed under a low-power light-microscope, and selected samples were then viewed under a scanning electron microscope (SEM).

These images were then analysed using low-powered light microscopy followed by scanning electron microscopy and the patterns observed were interpreted following the principles of fractography (Hull, 1999) as well as any other visible signs of alteration.

4.4.1e Yam

Yam is the common name for species in the genus *Dioscorea* (family Dioscoreaceae). This herbaceous vine forms a staple for many cultures both present and past. While the sweet potato is commonly associated with yams, they are not related at the family level (Christensen, 2002). *Dioscorea* species were traditionally thought to have been introduced from Southeast Asia into Sahul. It has also been suggested that New Guinea was a secondary dispersal route for *D. esculenta* and *D. alata* (Fullagar et al., 2006). Throughout history, yams have been a staple in the diet of many hunter gatherer cultures, and this remains true today (Bellwood, 1997), and agricultural practices such as clearing patches of forest floor encouraging yam vine growth have been noted.

Aim

-To determine the suitability of five species of limpet shells as a tool for food processing, specifically the removal of the outer skin of yam (*Dioscorea esculenta*) allowing access to the flesh inside, as well as analysing wear patterns associated with this task on the shells.

Method

- Study Specimens

The specimens being studied are five species of limpets; *Cellana tramoserica*, *Cellana solida*, *Patella peronii*, *Patella flexuosa* and *Siphonaria diemenensis*. These mollusc species were utilized in the peeling of the yam.

Three specimens of each of the target species were selected based on the overall quality of the shell in regards to erosion, existing fractures and evidence of bioerosion and adhesions. This was done through taphonomic assessments of each individual shell specimen with samples selected based on minimal taphonomic alteration to ensure maximum comparability of results.

- Experimental Design

Purple yam specimens were obtained from a Pacific Island food store in Sydney. Preparation of the yam involved cutting the end of each specimen creating a uniform face for the shell to move against. The experiment was then broken down into three sections for each shell dependent on the number of strokes the shell was used; 20, 40 and 100 with one stroke constituting a single motion either towards or away from the body with the shell edge in constant contact with the substrate.

The shells were held with the thumb located on the ventral surface at the apex and the index finger wrapping over the anterior dorsal surface around the apex. The shell's anterior edge was the exposed to the surface of the yam.



Fig. 4.10 : *Depiction of yam use-wear experiment*

The shells used in the experiments were then catalogued, individually bagged, and then organized under species. Following this, each shell sample was then photographed under a low-power light-microscope, and then selected samples were viewed under a scanning electron microscope (SEM).

These images were then analysed using low-powered light microscopy followed by scanning electron microscopy and the patterns observed were interpreted following the principles of fractography (Hull, 1999) as well as any other visible signs of alteration.

4.4.1f – Pork

Pork (Family: Suidae) is recognized as not relevant to a Golo Cave context. Mammals were not introduced to the area until well after the cultures inhabiting the cave had moved away (Flannery, 1995). It was included in the scientific analysis because of the range of textures that are apparent in the leg structure; being bone, flesh and skin. Shell material will be tested against these materials and the wear patterns that occur recorded.

Aim

- To determine the suitability of five species of limpet shells as a tool for food processing, specifically with regards to the slicing of animal skin, the cutting of flesh and the scraping of bone, as well as analysing the wear patterns and fragmentation associated with this processing. .

Method

- Study specimens

The specimens used include five species of limpet; *Cellana tramoserica*, *Cellana solida*, *Patella peronii*, *Patella flexuosa* and *Siphonaria diemenensis*. These mollusc species were utilized in various actions associated with the processing of pork.

Nine individual specimens of the five species of shell were selected based on the overall quality of the shell in regards to erosion, existing fractures and evidence of bioerosion and adhesions. This was done through taphonomic assessments of each individual shell specimen and allowed maximum comparability of results.

- Experimental design

A whole pork leg was obtained that had large amounts of flesh, skin and bone which allowed experimentation on a large number of textures that fall under the category of pork.

The shells were held with the thumb located on the ventral surface at the apex and the index finger wrapping over the anterior dorsal surface around the apex. The shell's anterior edge was the exposed to a part of the pork leg that was being tested; either flesh, bone or skin.

The experiment was then broken up into two separate parts based on the direction of the scraping action; towards the body of the holder, and away from the body of the holder. Each of these directions was then broken up into the number of strokes the shell contacted the pork; 20, 40 and 100 strokes for each species of shell. The direction in which the shells were moved is dependent on the material being tested. Both flesh and



Fig. 4.11 : Depiction of pork (skin, flesh and bone) use-wear experiments

skin involved cutting actions whereas for bone a rubbing action was utilised. This was to represent cutting into and through flesh and skin, and defleshing bone. For the cutting action, one stroke constituted one motion towards the body with the shell contacting the skin for the dur-

ation of the stroke. This is the same for flesh.

One stroke in rubbing pork bone constitutes a forward and backwards motion with the shell in contact with the bone for the duration of the stroke.

The shells used in the experiments were then catalogued, individually bagged, and then organized under species. Following this, each shell sample was then photographed under a low-power light-microscope, and then selected samples were viewed under a scanning electron microscope (SEM).

These images were then analysed and the patterns observed are interpreted following the principles of fractography (Hull, 1999) as well as any other visible signs of alteration.

4.5 – LOW AND HIGH POWERED MICROSCOPY

Following the experimentation, each shell that was used was analysed under a low-powered stereoscopic light microscope with magnification capabilities of up to 45 times. This allowed observation of the dorsal and ventral shell surface, with any form of chipping or fragmentation that had occurred during the course of the experiments being noted. Using the taphonomic assessments conducted previously in conjunction with the light microscope, modifications that occurred in the process of experimental working could be isolated with a high degree of certainty. Samples from the Golo Cave assemblage were also analysed under a low-power light microscope.

After the low-powered visual analysis of the shell samples, a selection of the experimental shell sample, as well as *Patella flexuosa* samples from the Golo Cave assemblage, were selected for

scanning electron microscopy (SEM), once again care of the University of Wollongong's Faculty of Engineering. Due to restraints on booking times and limitations in funds, not every specimen could be viewed with SEM. By first analysing samples under a low-powered microscope, those that showed the most distinct fragmentation, fracture or other evidence of use were selected for SEM analysis. SEM allowed the most detailed view of the results of the experimentation process, including micro-abrasion, micro-chipping and striations as well as seeing in high resolution the effect of force on the microstructure of shells. SEM analysis also allowed the identification of the microstructure of *S. diemenensis* which was hitherto unreported.

Chapter 5

Results

5.1 - ACCESSION DATA

Specimens collected were sorted by species and each given a unique accession code and stored separately. This was done for ease of recognition and recollection when needed for experimentation or reference, and for general organization. A total of 353 individual shell specimens were collected spread over five species excluding the Golo Cave samples.

The diagram depicts the differentiation among species based on length, width and elevation of apex from the margin. This supports the notion that species are different in their morphology and using this data it can be said with confidence that the sample species are well represented and cover a broad morphological range. Points positioned closer to each other have similar shell morphologies

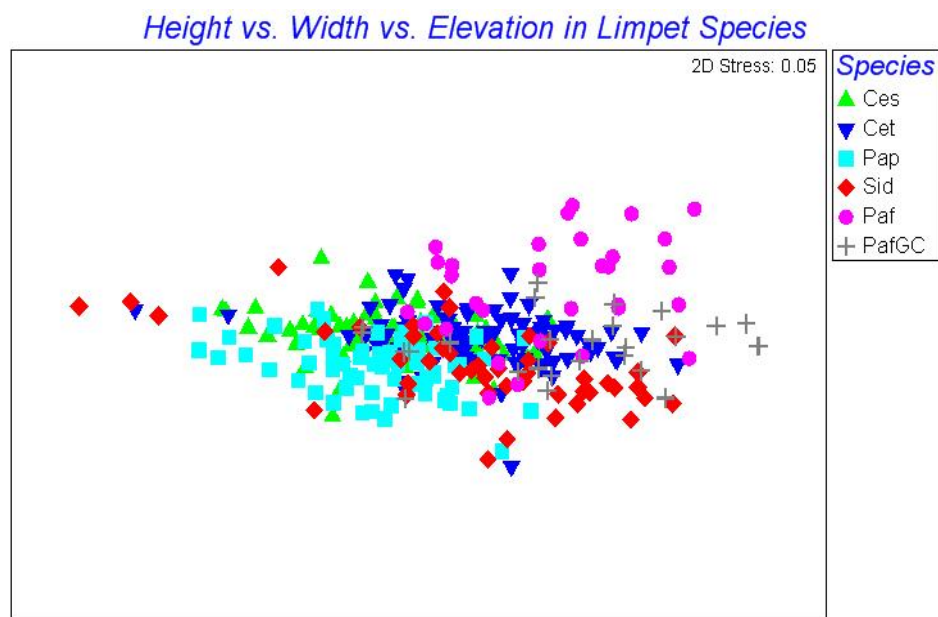


Fig. 5.1 : Diagram above shows scatter plot of limpet specimens graphed where height, width and shell elevation are variables. As can be seen species cluster for the most part in species similar groups. ANOSIM analysis indicates a large significance between species (Significance level of sample statistic 0.1%).

5.2 – XRD Analysis

As mentioned in a previous chapter, molluscan shell is made of calcium carbonate in the mineral form of calcite and aragonite. The ratio of these two minerals that come together to create the overall composition of the shell is not a uniform value between genera. The ratio is influenced by a number of factors, in particular, whether the animal is a tropical or temperate species (Vermeij, 1993). In limpets, tropical species have a higher proportion of aragonite versus calcite, and the reverse is true for temperate species. By utilising x-ray diffraction (XRD) analysis, the ratios of calcite and aragonite can be identified (Watabe, 1988).

As well as this, it has been known for calcium carbonate crystals, regardless of form to recrystallise. This may happen at times of extreme heat or pressure and is also associated with burial in the archaeological record. Recrystallisation will alter the ratios of aragonite to calcite and as such affect the way the shell would react to certain forces. Conducting XRD analysis is a way of recognising whether shell has undergone recrystallisation.

The tables and graphs on the following page present the ratios of calcite and aragonite present in each of the target species of this research project. *S. diemenensis* is a temperate species yet is comprised of 97% aragonite. It is important to note, as mentioned previously, *S. diemenensis* is not a true limpet, so some characteristics may not apply.

Table 5.1		<i>C. tramoserica</i>	
Comment:	Cet016		
Results:	Contrast Corrected Weight %		
Chi square	2.23		
#	ID	Phase	Weight%
1	10	Calcite 1	77.2
2	97	Aragonite	22.8

Table 5.2		<i>C. solida</i>	
Comment:	Ces016		
Results:	Contrast Corrected Weight %		
Chi square	2.16		
#	ID	Phase	Weight%
1	10	Calcite 1	58.2
2	97	Aragonite	41.8

Table 5.3		<i>P. peronii</i>	
Comment:	Pap049		
Results:	Contrast Corrected Weight %		
Chi square	2.12		
#	ID	Phase	Weight%
1	10	Calcite 1	31.9
2	97	Aragonite	68.1

Table 5.4		<i>P. flexuosa</i>	
Comment:	Paf006		
Results:	Contrast Corrected Weight %		
Chi square	2.66		
#	ID	Phase	Weight%
1	10	Calcite 1	26.5
2	97	Aragonite	73.5

Table 5.5		<i>S. diemenensis</i>	
Comment:	Sid019		
Results:	Contrast Corrected Weight %		
Chi square	2.46		
#	ID	Phase	Weight%
1	10	Calcite 1	2.1
2	97	Aragonite	97.9

Table 5.6		<i>P. flexuosa (Golo Cave sample)</i>	
Comment:	PafGCxxx		
Results:	Contrast Corrected Weight %		
Chi square	2.48		
#	ID	Phase	Weight%
1	10	Calcite 1	40
2	97	Aragonite	60

Table 5.1-5.6 : Results of XRD analysis of the 5 target species and Golo Cave archaeological specimen

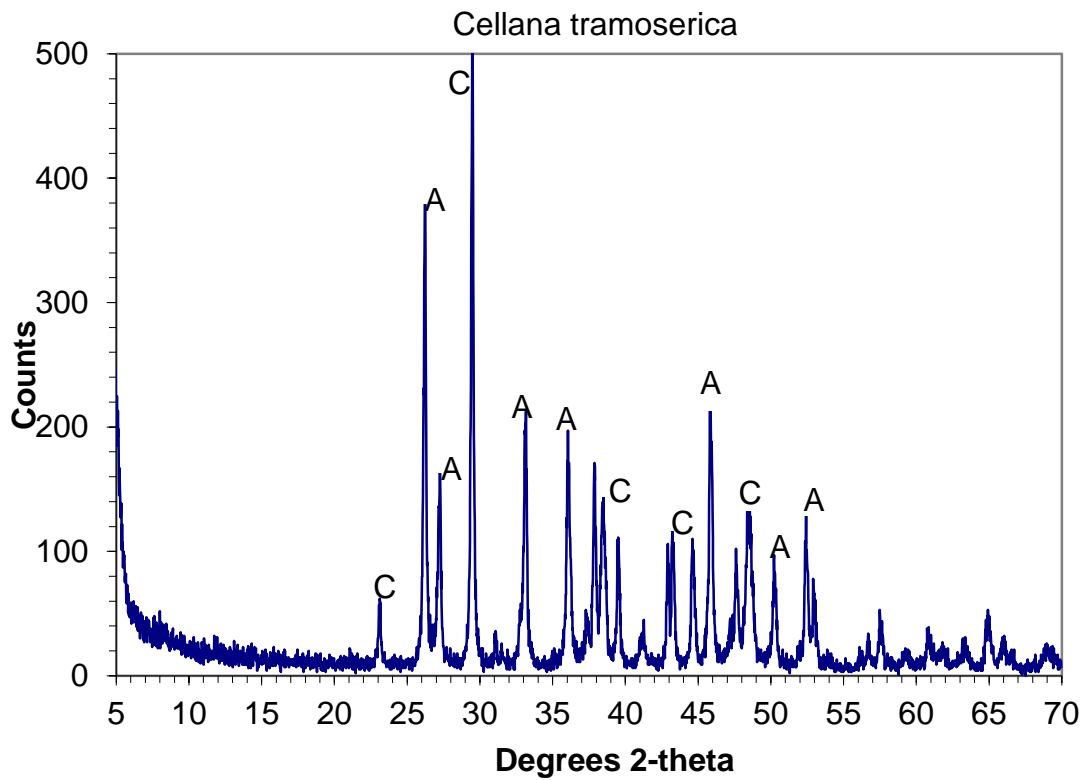


Fig. 5.2 : Graph of XRD results of C. tramoserica with aragonite and calcite crystals labeled

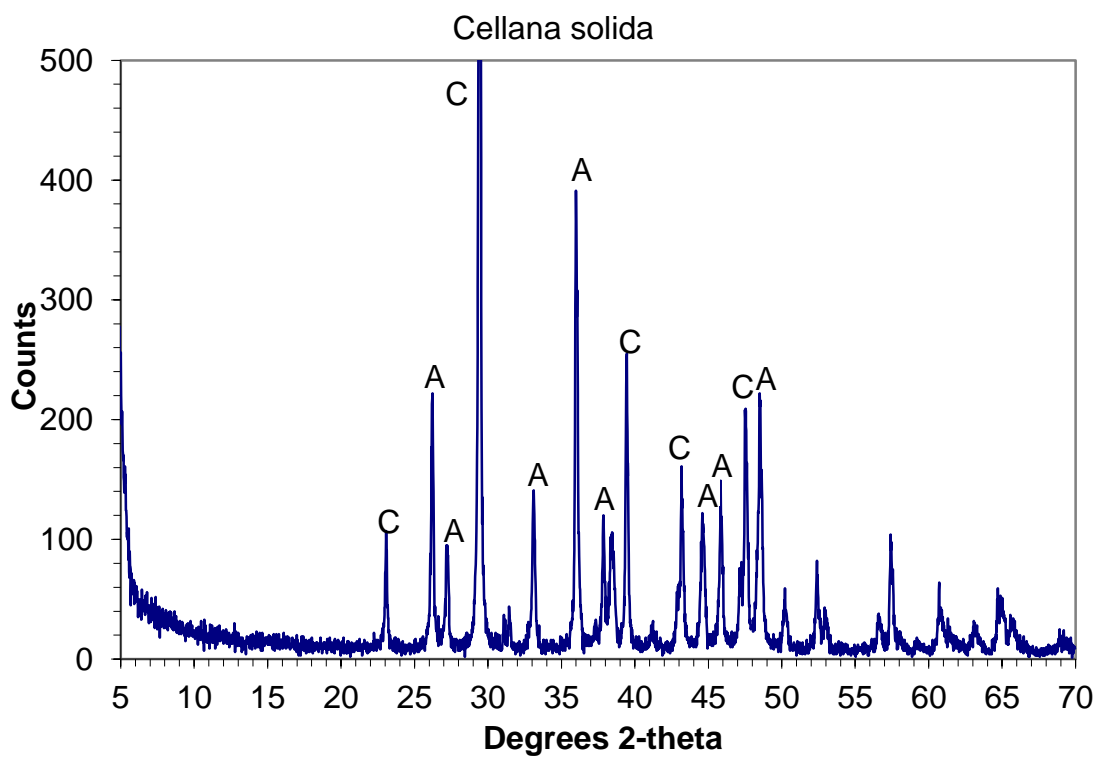


Fig. 5.3 : Graph of XRD results of C. solida with aragonite and calcite crystals labeled

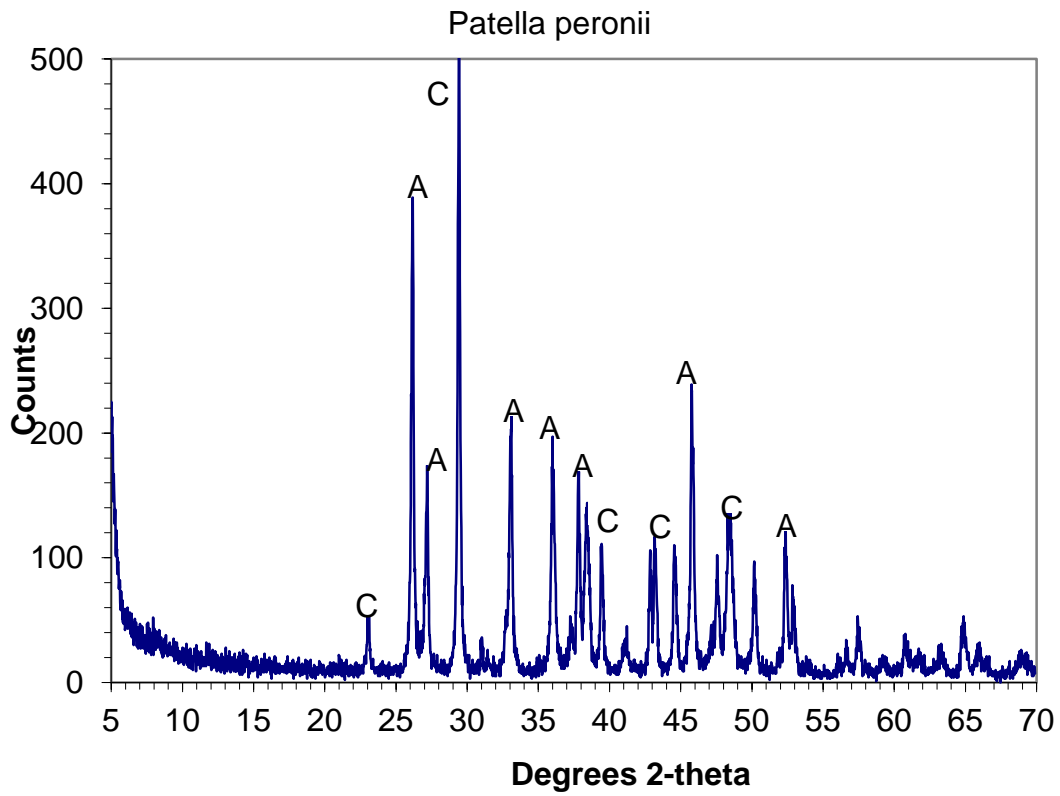


Fig. 5.4 : Graph of XRD results of P. peronii with aragonite and calcite crystals labeled

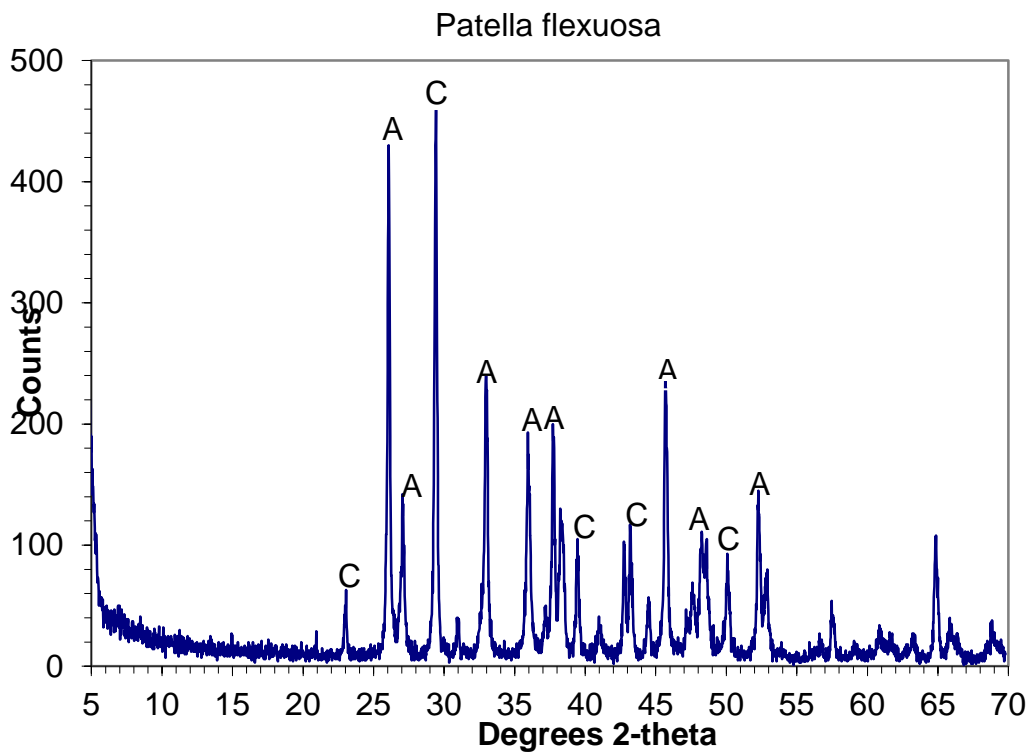


Fig. 5.5 : Graph of XRD results of P. flexuosa with aragonite and calcite crystals labeled

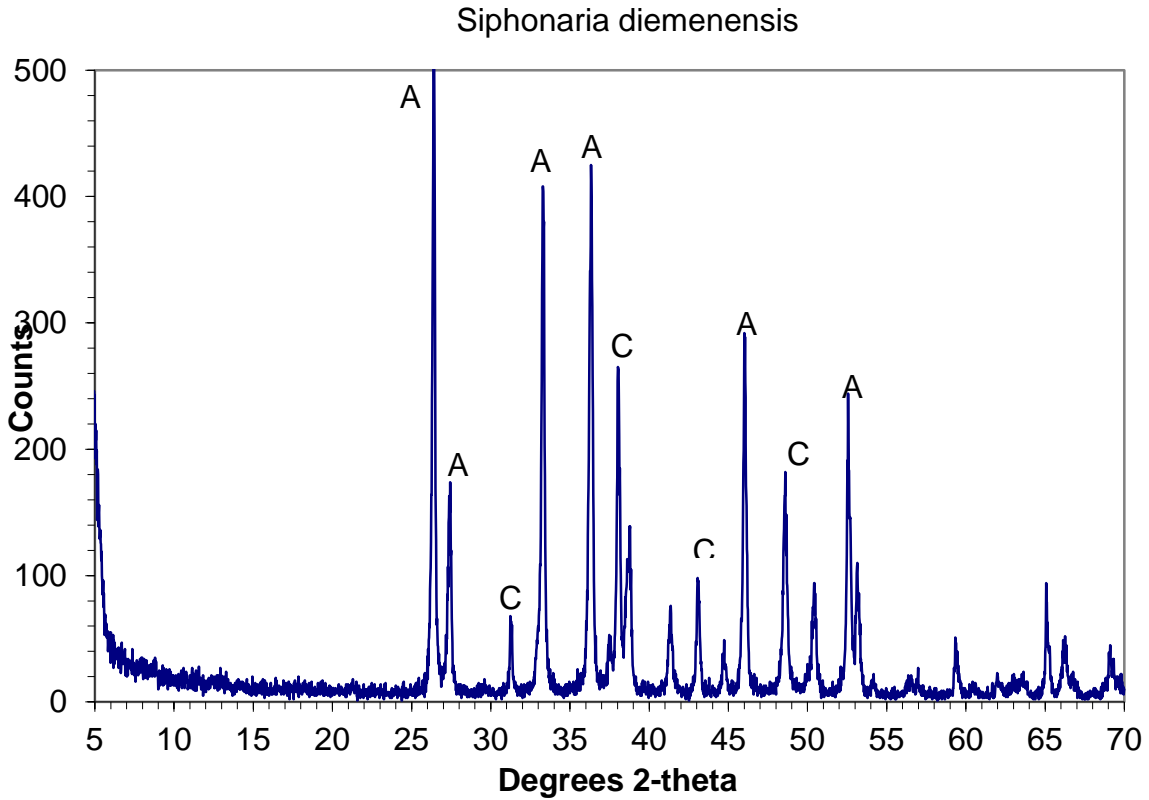


Fig. 5.6 : Graph of XRD results of S. diemenensis with aragonite and calcite crystals labeled

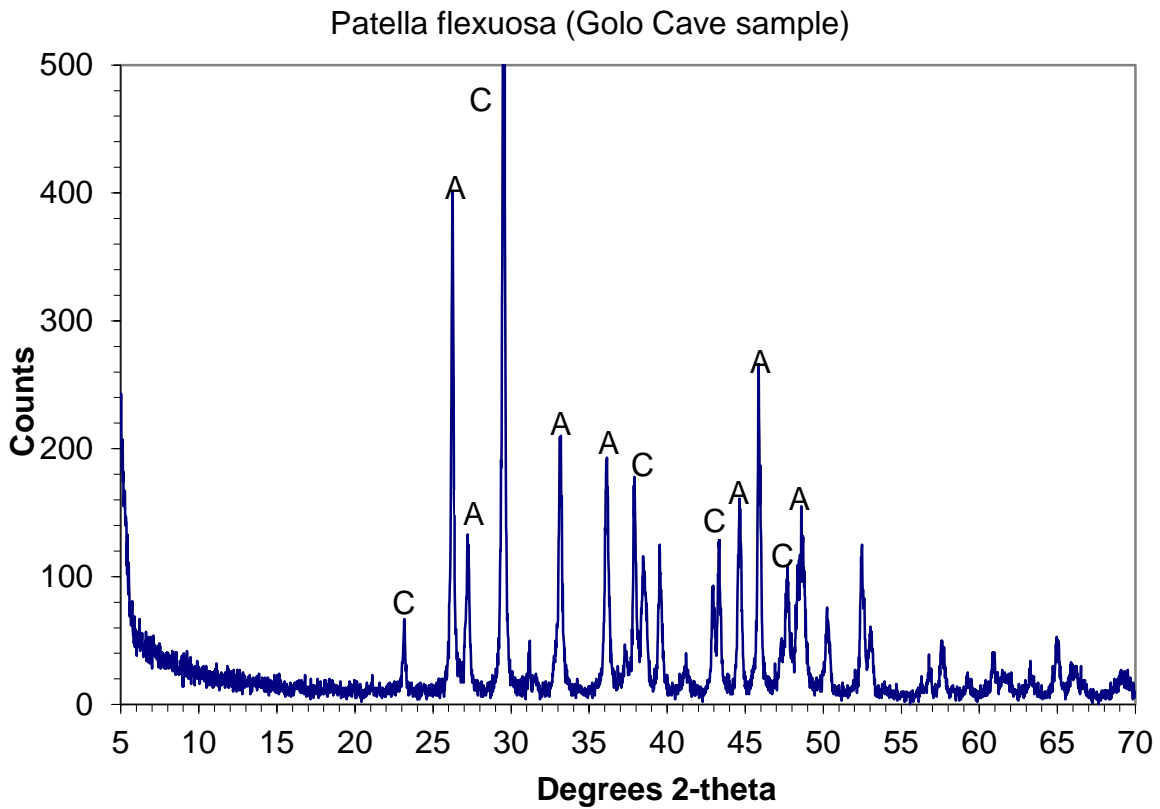


Fig. 5.7 : Graph of XRD results of P. flexuosa (Golo Cave specimen) with aragonite and calcite crystals labeled

The series of tables on page 68 are the results from the XRD analysis of the 6 shell samples. The column labeled 'Weight%' describes the proportion of calcite to aragonite in the tested sample as a percentage by weight.

The graphs on the previous pages (Fig. 5.2 to Fig. 5.7) are a graphical representation of the data presented in the tables related to the XRD analysis conducted where each peak represents either aragonite or calcite in the sample. Peaks labeled with 'A' are aragonite and peaks labeled 'C' are calcite. It is worth noting that the values for contemporary *P. flexuosa* specimens and the *P. flexuosa* specimens from the Golo Cave assemblage are nearly identical. This implies that the archaeological specimens from Golo Cave have not undergone recrystallisation and are thus suitable for direct comparison with the contemporary specimens.

5.3 – INSTRON Results

INSTRON experimentation was utilised for a number of reasons; first and foremost is creating a baseline of fracture patterns in controlled conditions. An INSTRON machine will continually apply increasing amounts of force to an object until the point that structural integrity fails, resulting in fracture and fragmentation. Natural taphonomic processes are complex and a large number of factors are in play at any one time. By applying force in a controlled setting, such as experimentation with an INSTRON machine, fracture patterns relating to a specific amount or direction of strain will yield reduction patterns relating to that force alone.

The diagrams represented below are graphical representations of such an event. Where the line tracking the amount of force being applied returns to the zero level, a point of structural failure has been observed. Five of the target specimens were each subject to such a test with three of each species experiencing a different direction of force, as described in Chapter 3. After the point of structural failure has been attained, the specimens are then analysed in an attempt to interpret the reduction patterns observed.

Cellana tramoserica

Cet091 – Dorsal to ventral compression

Specimen 1 to 1

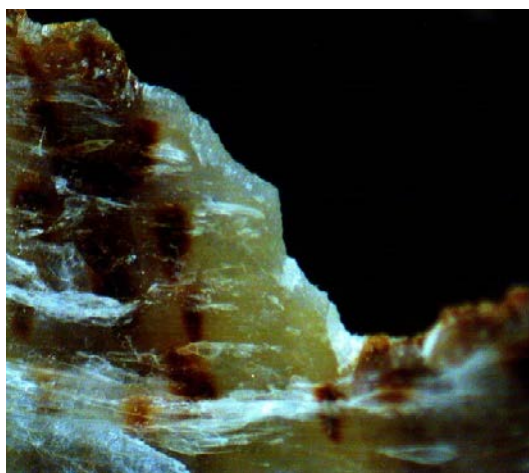
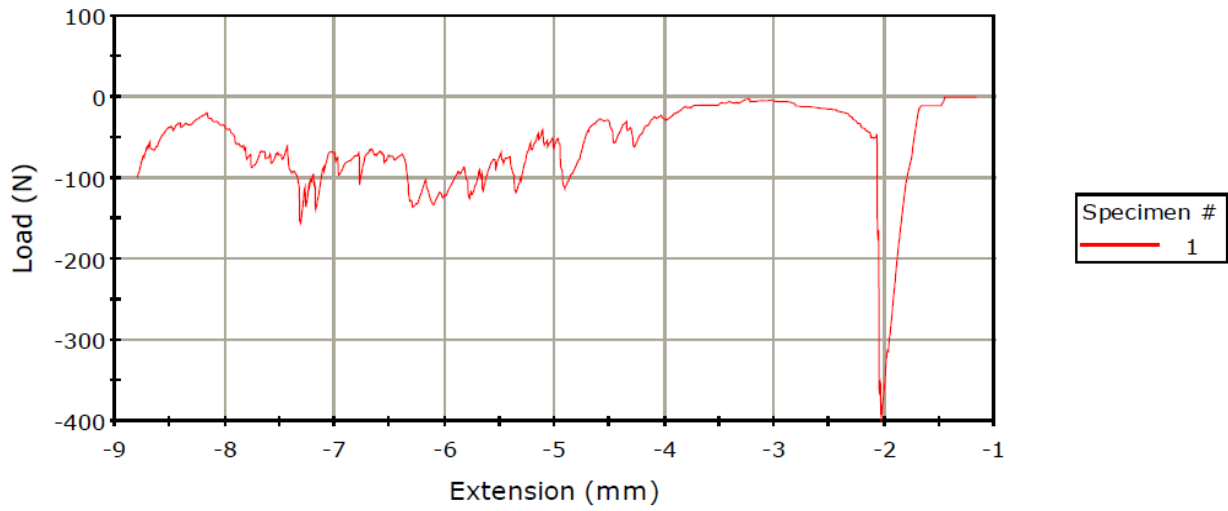


Fig. 5.8 : Results of INSTRON controlled fracture experiment of *C. tramoserica* with pictured breakage patterns

Cet092 – Anterior to posterior compression

Specimen 1 to 2

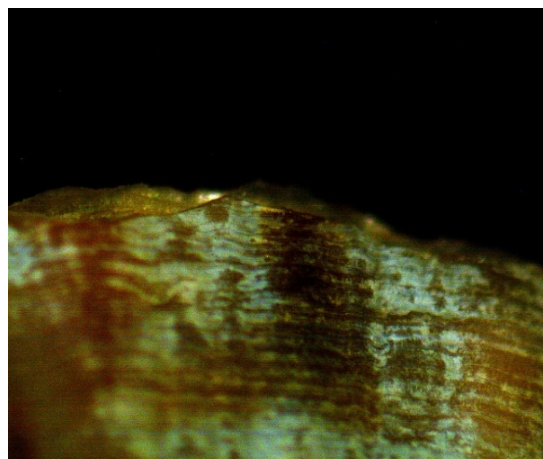
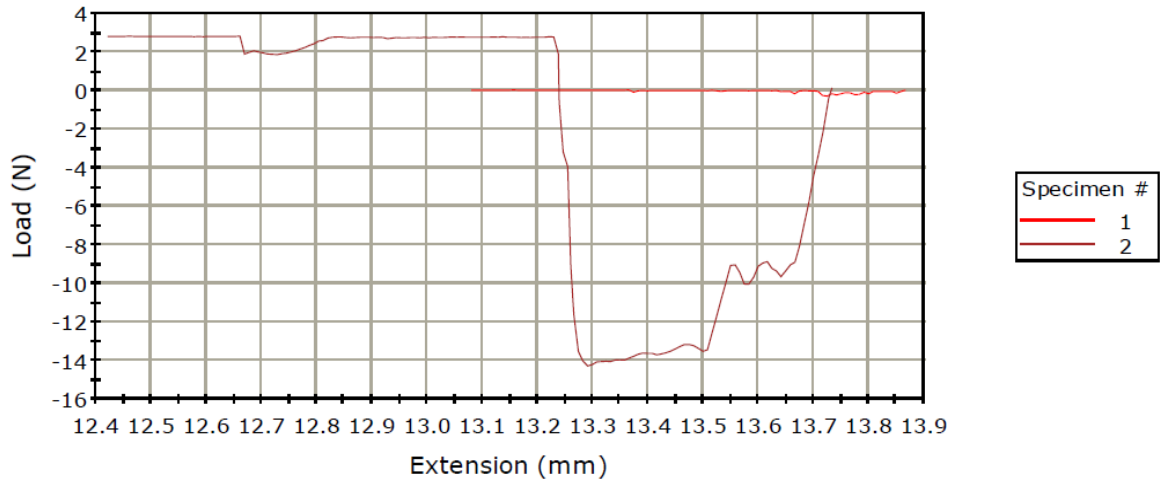


Fig. 5.9 : Results of INSTRON controlled fracture experiment of C. tramoserica with pictured breakage patterns

Cet066 – Dextral to sinistral compression

Specimen 1 to 1

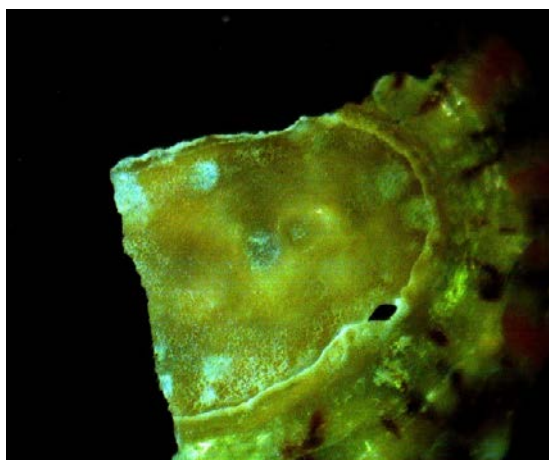
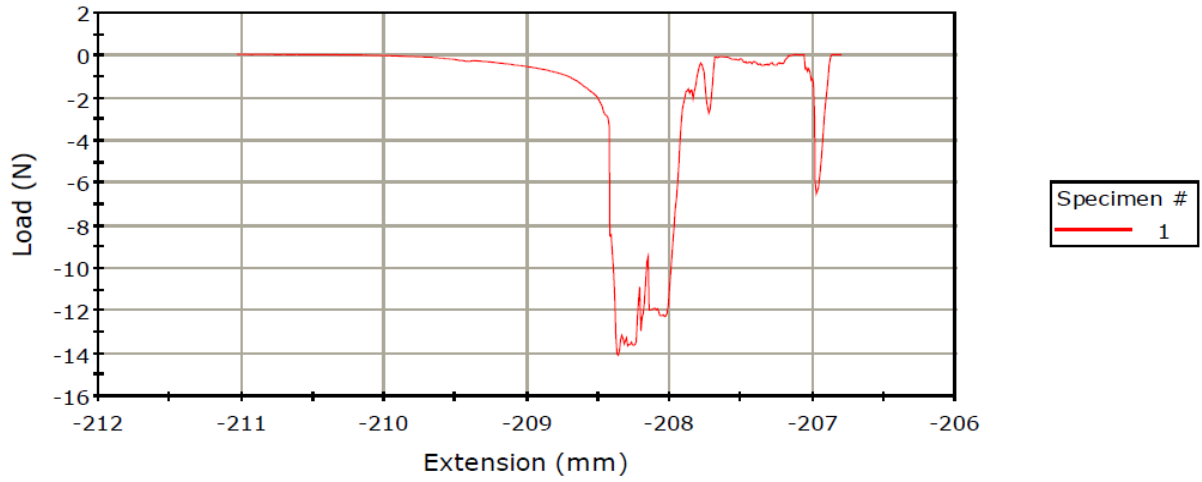


Fig. 5.10 : Results of INSTRON controlled fracture experiment of *C. tramoserica* with pictured breakage patterns

C. tramoserica showed a diverse range of fracture patterns during the INSTRON stage of experimentation. Damage was nearly total in all cases except for Cet092 which only fragmented slightly at the shell posterior, causing it to slip off of the stage and end testing. Large amounts of shatter was recorded, especially Cet091 in which most of the nacreous apex material fragmented into small pieces, as seen in the picture above. The irregular complex crossed lamellar portion of the apex remained intact, though was still removed from the rest of the shell.

Interestingly, seen in Cet066, bioerosion does not influence the direction of fracture. A hole penetrating the shell surface, as seen above does not appear to be a zone of weakness, and hence the crack does not travel this path which goes against traditional understanding as outlined by Zuschin (2003) and others. Multilayer cracking at shell margin as well as different cracking directions is also apparent. Different directions of cracking as well as multilayer cracking were also seen in Cet091 and Cet092 respectively.

Cellana solida

Ces006 – Dorsal to ventral compression

Specimen 1 to 1

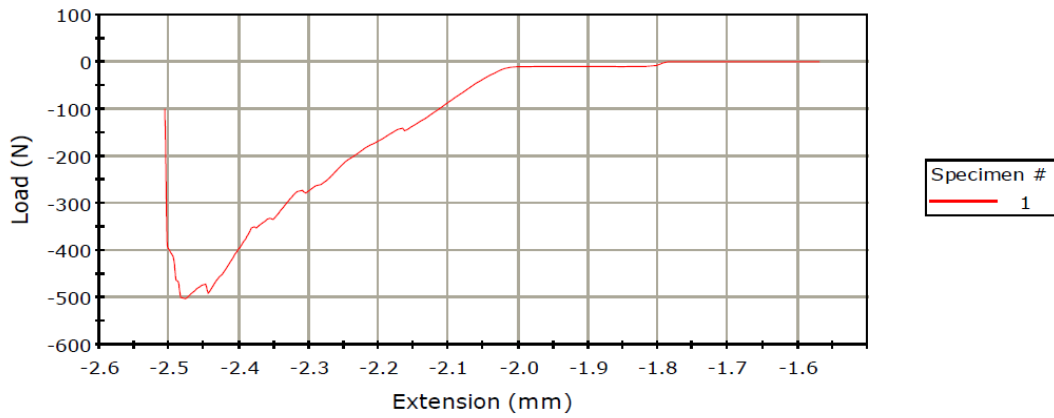


Fig. 5.11 : Results of INSTRON controlled fracture experiment of *C. solida* with pictured breakage patterns

Ces020 – Anterior to posterior compression

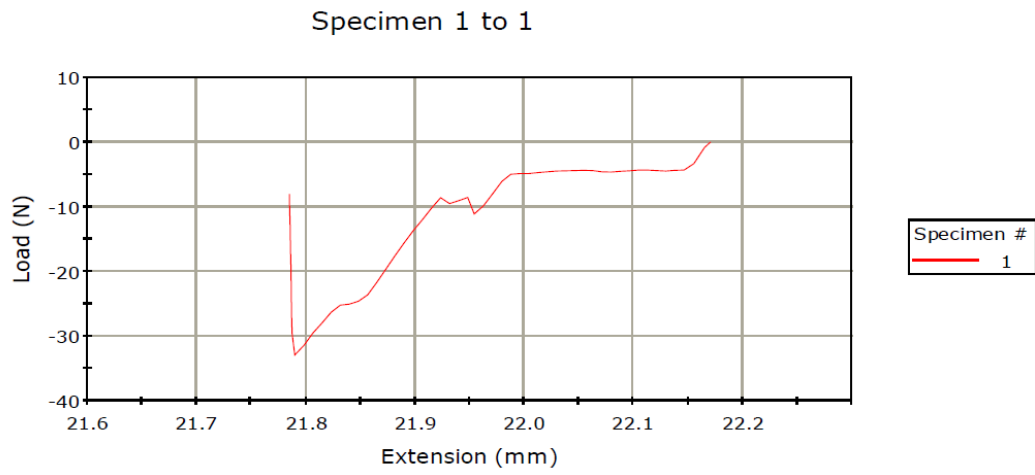


Fig. 5.12 : Results of INSTRON controlled fracture experiment of C. solida with pictured breakage patterns

Ces051 – Dextral to sinistral compression

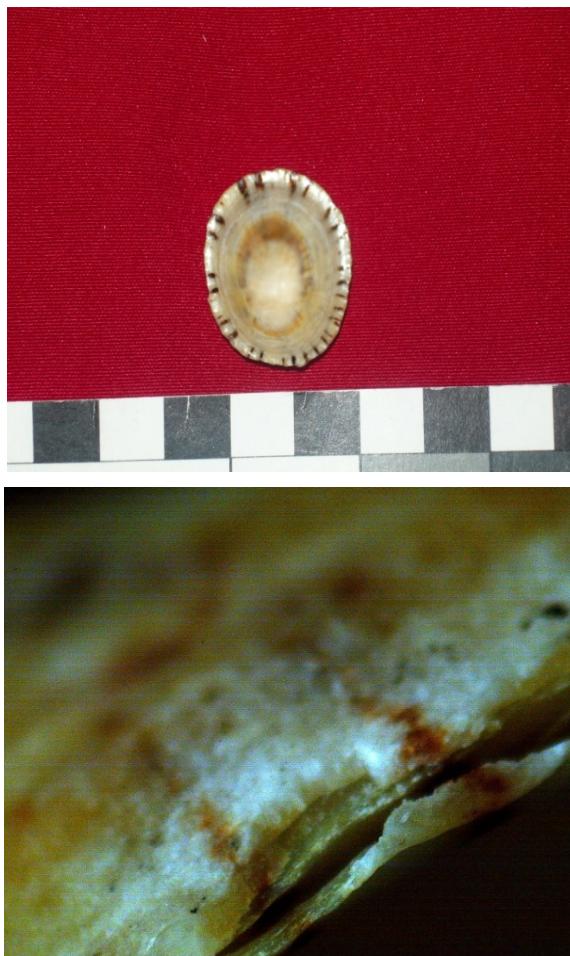
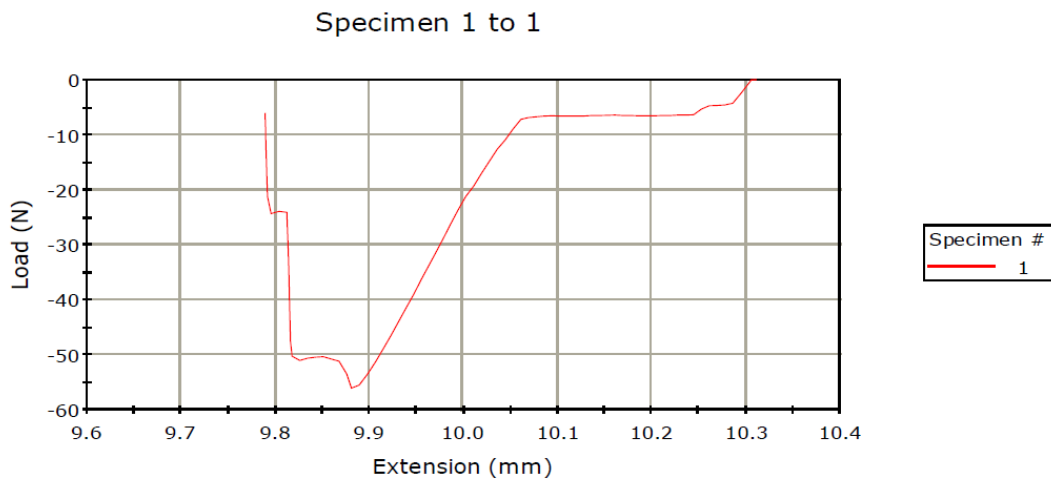


Fig. 5.13 : Results of INSTRON controlled fracture experiment of *C. solida* with pictured breakage patterns

Reduction in *C. solida* samples that were used in INSTRON experimentation exhibited little fragmentation, and minor fracture. The majority of the reduction in the INSTRON samples came in the form of edge damage with one large crack in Ces006 running in a radial direction from the shell margin to the apex with the shell remaining whole. Differential fracture can also be seen in this example. Round fracturing of the shell margin, seen in Ces020 is also an example of minor damage seen. Compression along the medial margin has forced bending/shearing fracture on Ces051. Here the nacreous ventral layer has separated and has almost chipped off. What seems to be becoming a trend in fracture patterns with shell bearing a nacreous interior, a separation between the nacreous and overlying prismatic layer is once again apparent,

Patella peronii

Pap075 – Dorsal to ventral compression

Specimen 1 to 1

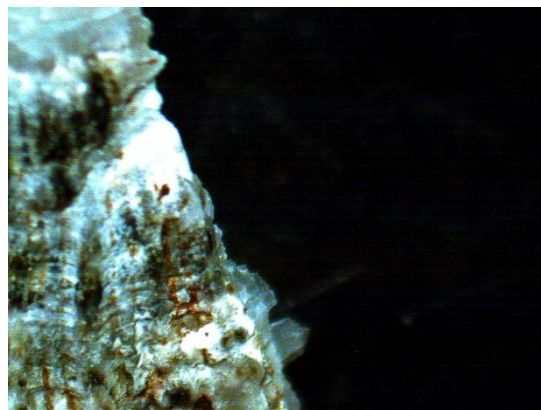
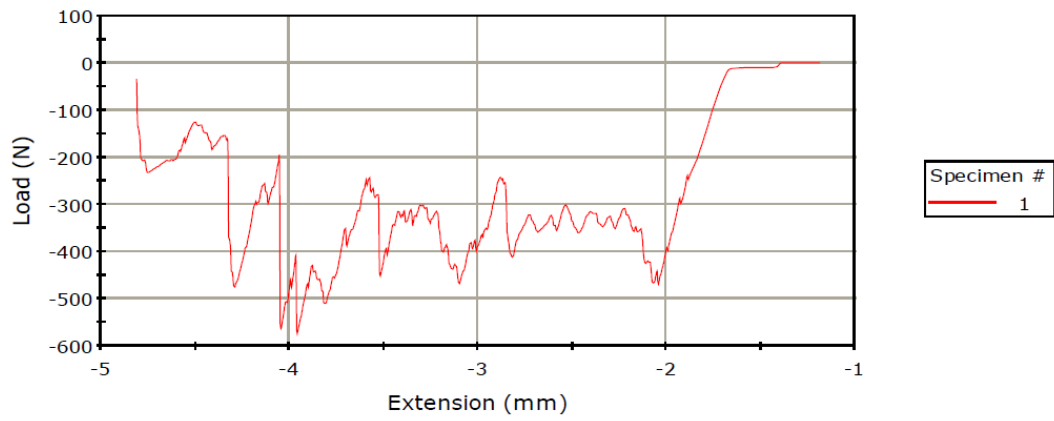


Fig. 5.14 : Results of INSTRON controlled fracture experiment of P. peronii with pictured breakage patterns

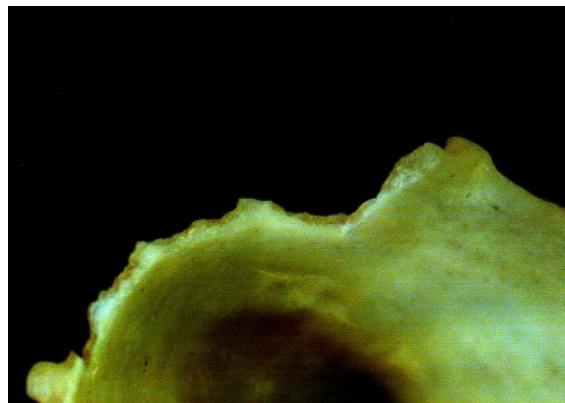
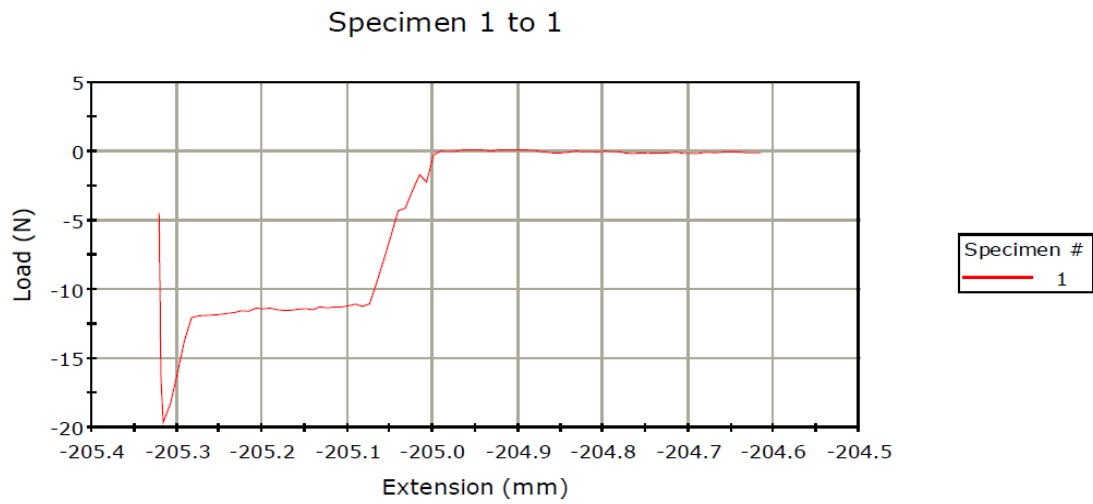


Fig. 5.15 : Results of INSTRON controlled fracture experiment of P. peronii with pictured breakage patterns

The 'Dorsal-Ventral' compression test caused complete destruction of the apex of Pap075. The apex fractured concentrically while one crack travelled radially, splitting between the layers. Fragmentation of Pap073 consisted of a fracture running parallel to the shell margin in a concentric fashion, suddenly terminating in a radial direction back to the shell edge. This caused dislodgement of a large portion of the anterior edge. Concentric fracture is also seen in Pap073, though the edge of these cracks is rougher than that of Pap075.

Pap074 was used in the INSTRON experiment, but was later identified as a different species. This means that the results for the anterior-posterior compression experiment are not relevant to this study anymore and therefore incomparable. This experiment will be repeated at a later time to complete the study.

Patella flexuosa

Paf029 – Dorsal to ventral compression

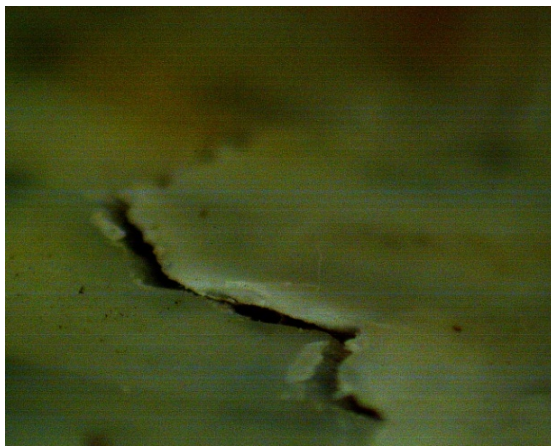
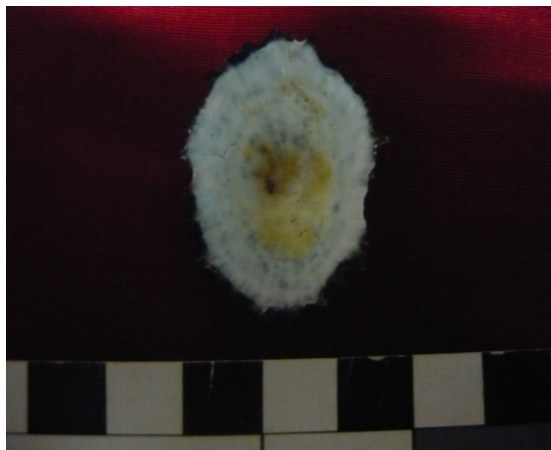
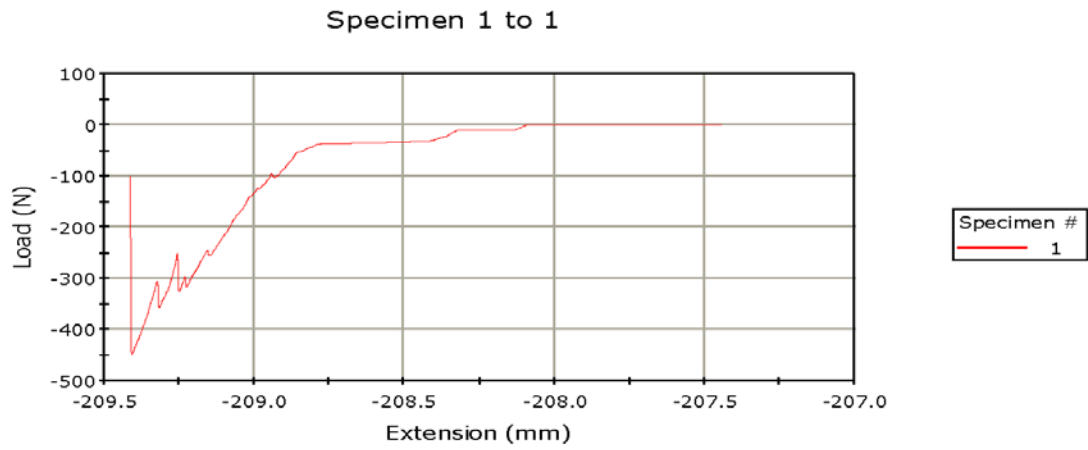


Fig. 5.16 : Results of INSTRON controlled fracture experiment of P. flexuosa with pictured breakage patterns

Paf030 – Anterior to posterior compression

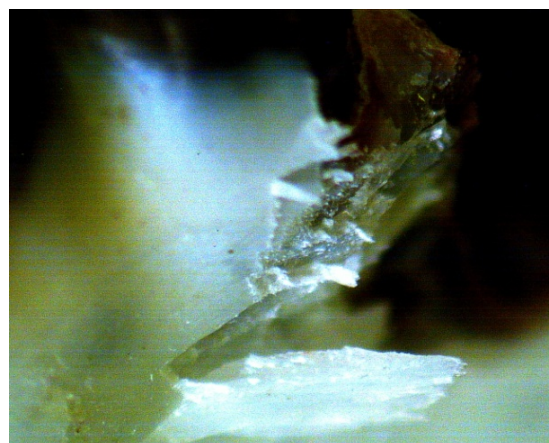
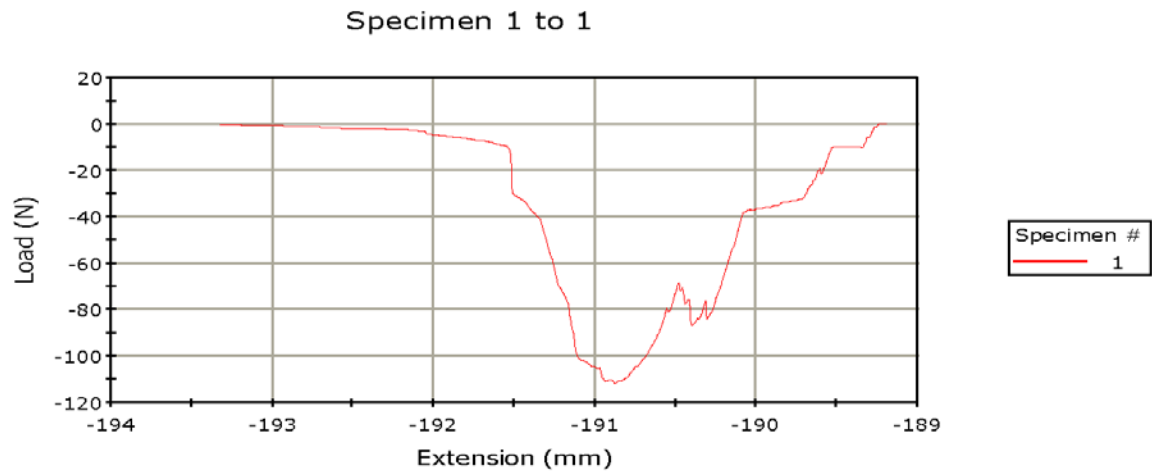


Fig. 5.17 : Results of INSTRON controlled fracture experiment of P. flexuosa with pictured breakage patterns

Paf031 – Dextral to sinistral compression

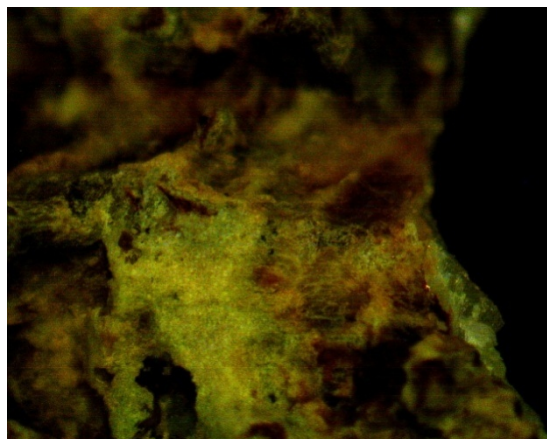
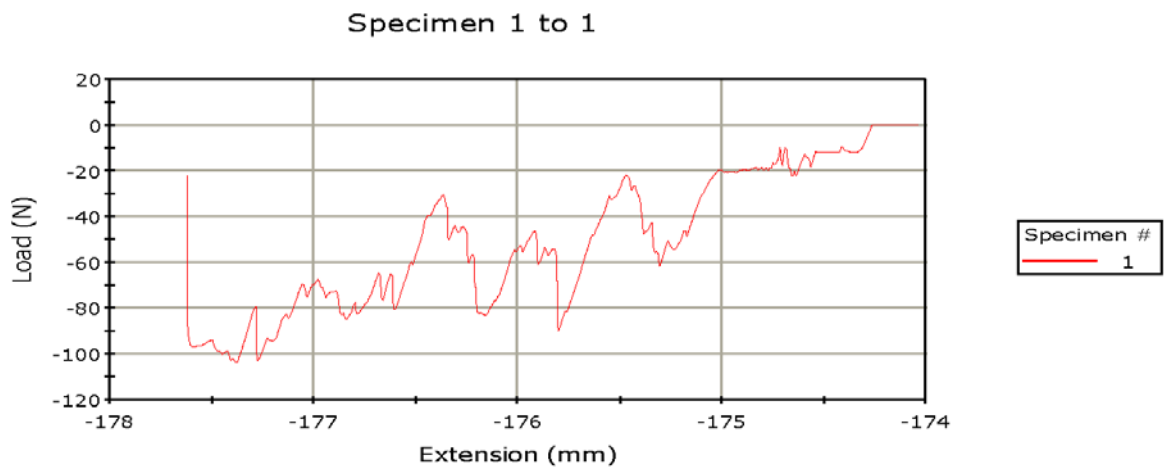


Fig. 5.18 : Results of INSTRON controlled fracture experiment of *P. flexuosa* with pictured breakage patterns

Fracture in *P. flexuosa* was varied on a macro scale. Paf029 suffered only edge chipping on its margin in the 'Dorsal-Ventral' compression experiment. As well as this, a radial crack originating from the apex towards the shell margin is clear. Paf030 was tested using 'Anterior-Posterior' compression, and all the damage that occurred was minor chipping at the posterior edge. No other cracks or damage are visible. In contrast, Paf031 in 'Dextral – Sinistral' compression suffered complete destruction. Each fragment displays both concentric and radial fracture and little shell shatter or debris outside of the five large pieces is apparent.

On a micro scale, fracture is characterised by rough and sharp breaks, as well as shearing in between layers. The organic content of the shell structure also plays a part in its fracture patterns. Seen in where cracks and fractures clearly form in planes of weakness designated by a higher organic content (Watabe, 1988). Seen in Paf030, breakage along growth lines parallel to the shell margin, as well as differential breakage between the rib and furrows of the dorsal surface is also apparent. The crossed lamellar microstructure of *P. flexuosa* is clearly visible in Paf031.

Siphonaria diemenensis

Sid 050 – Dorsal to ventral compression

Specimen 1 to 1

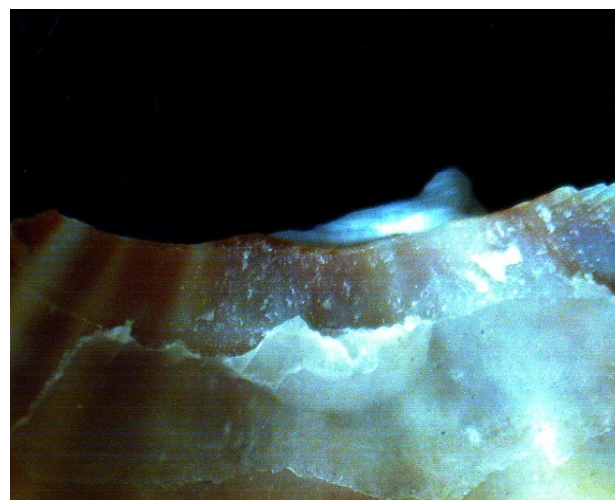
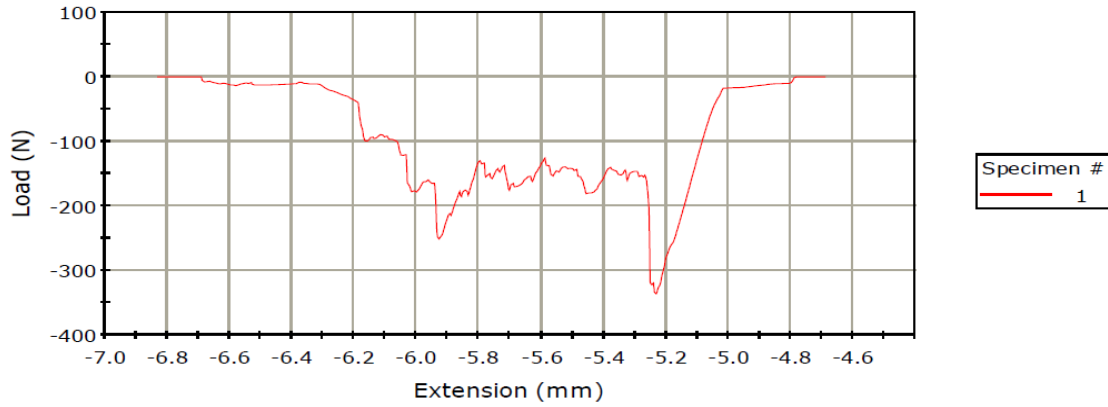


Fig. 5.19 : Results of INSTRON controlled fracture experiment of S. diemenensis with pictured breakage patterns

Sid051 – Anterior to posterior compression

Specimen 1 to 1

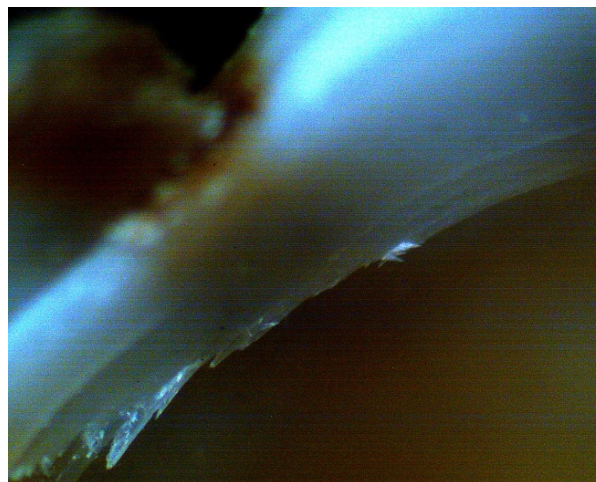
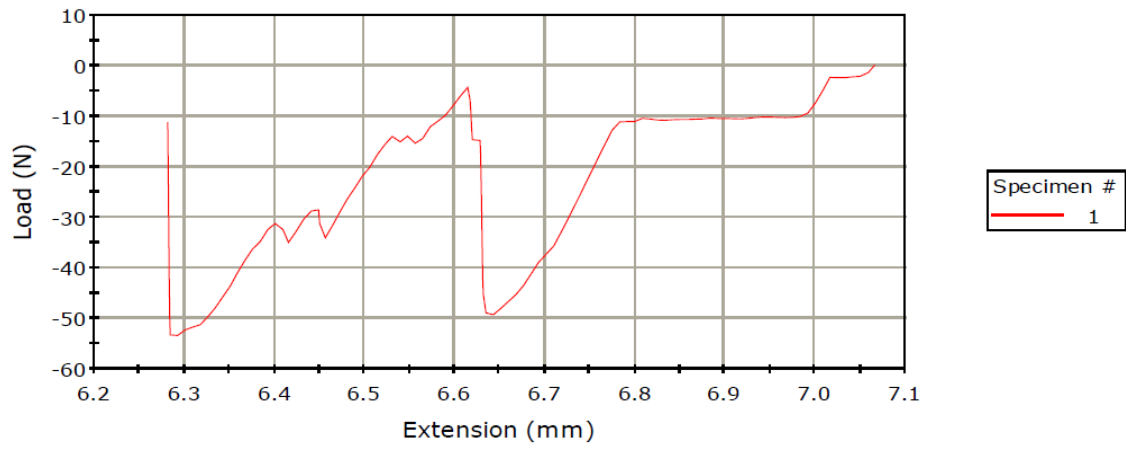


Fig. 5.20 : Results of INSTRON controlled fracture experiment of *S. diemenensis* with pictured breakage patterns

Sid052 – Dextral to sinistral compression
Specimen 1 to 1

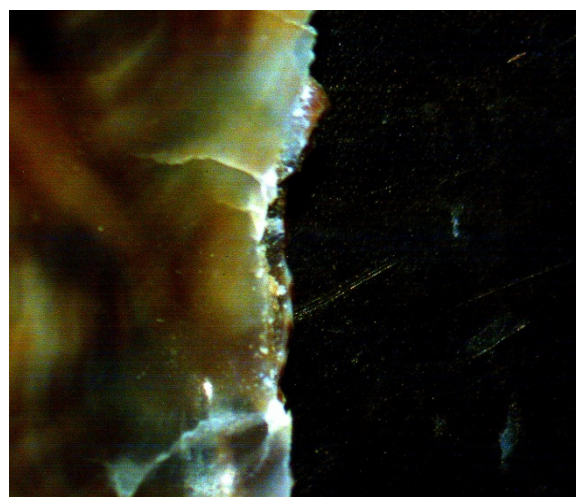
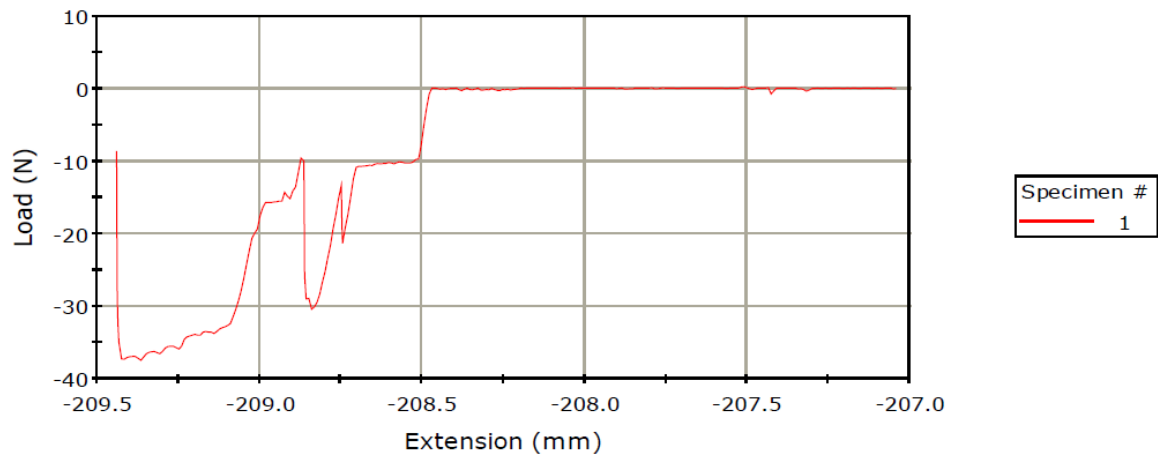


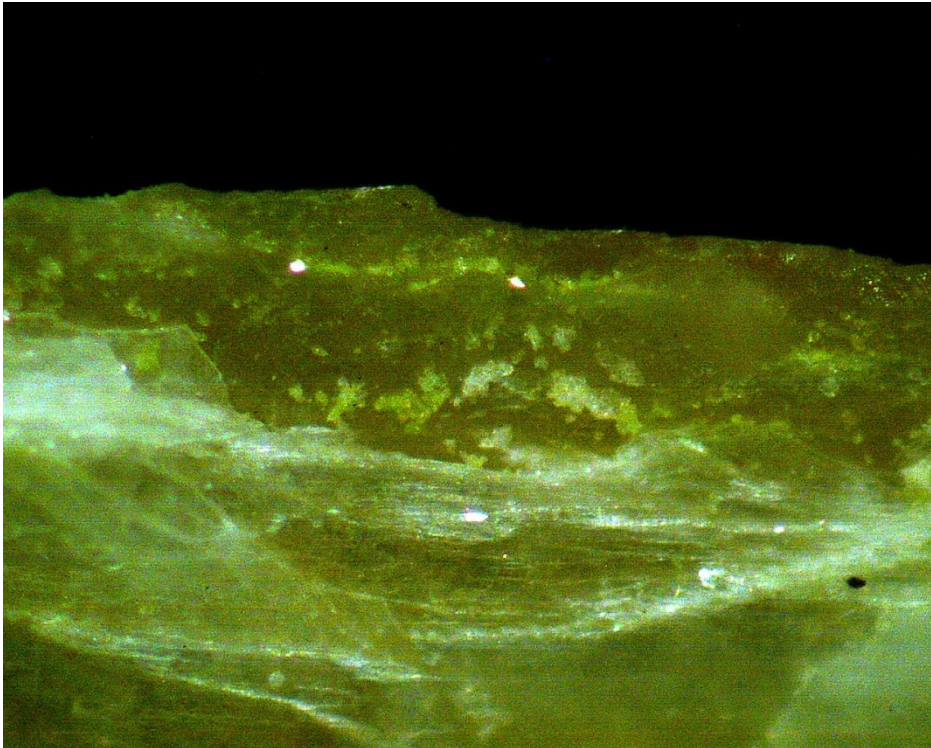
Fig. 5.21 : Results of INSTRON controlled fracture experiment of *S. diemenensis* with pictured breakage patterns

A diverse range of fracture patterns occur in the fracture patterns of *S. Diemenensis*, however the trend leans more towards radial breakage than concentric breaks with seemingly less structural integrity at the apex. Sid050 is characterised by a series of fragments that have been removed from the main structure with a combination of a radial crack changing to a concentric direction then returning to a radial orientation towards the shell margin. Sid051 has fractured via two radial cracks joining at the apex. Sid052 exhibits minor edge chipping towards its posterior.

Sid050 exhibits differential fracture as well as shearing between layers seen in Concentric fracture patterns as well as tearing structures are seen in Sid051 and in respectively. Branching cracks are also apparent in Sid052.

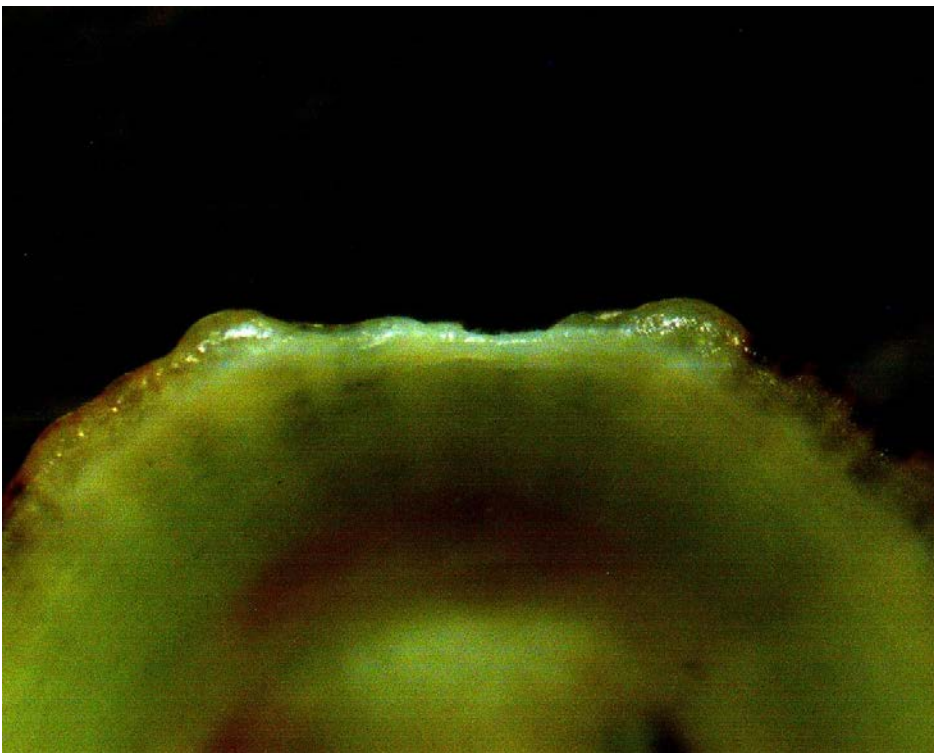
5.4 - EXPERIMENTAL WORKING RESULTS

Fig. 5.22 : Ces022 – Soaked Bamboo (30x Magnification)



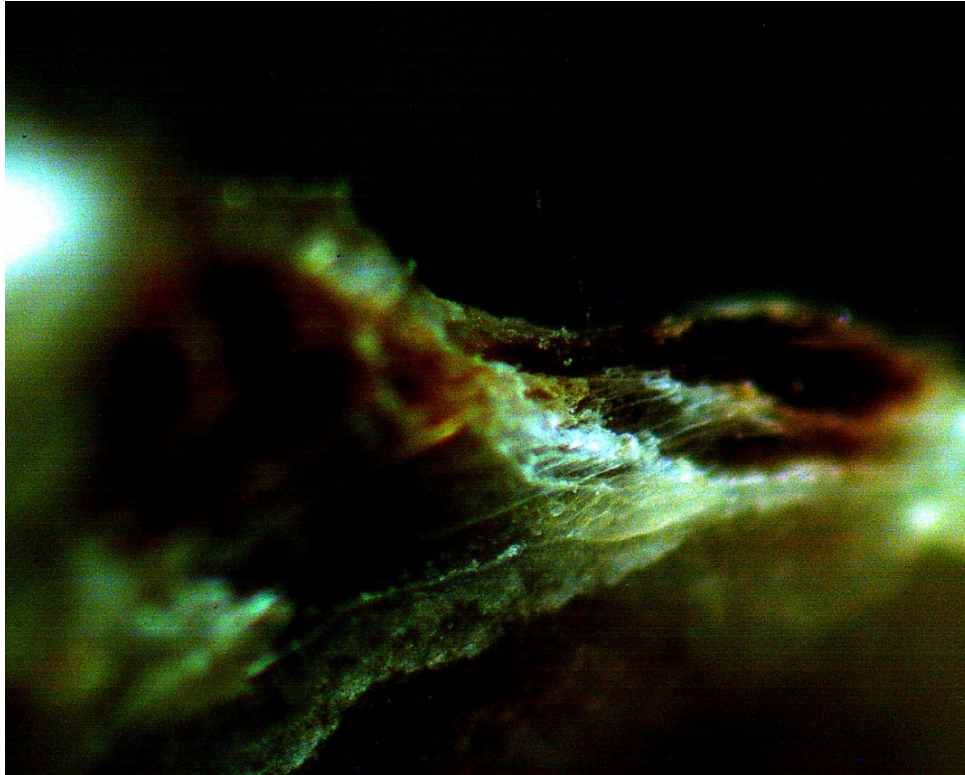
Edge chipping
and concentric
cracks running
along ventral
layer.

Fig. 5.23 : Pap071 – Soaked Bamboo (7x Magnification)



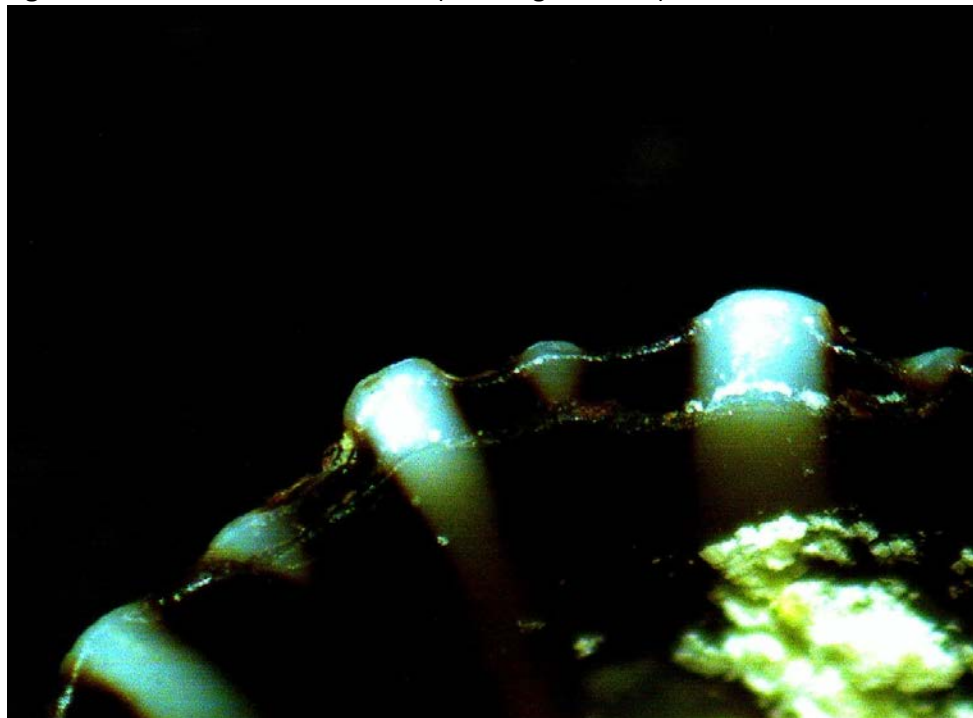
Rounded facet
across shell
margin as well
as incipient
cracking parallel
to margin

Fig. 5.24 : Cet038 – Soaked Bamboo (30x Magnification)



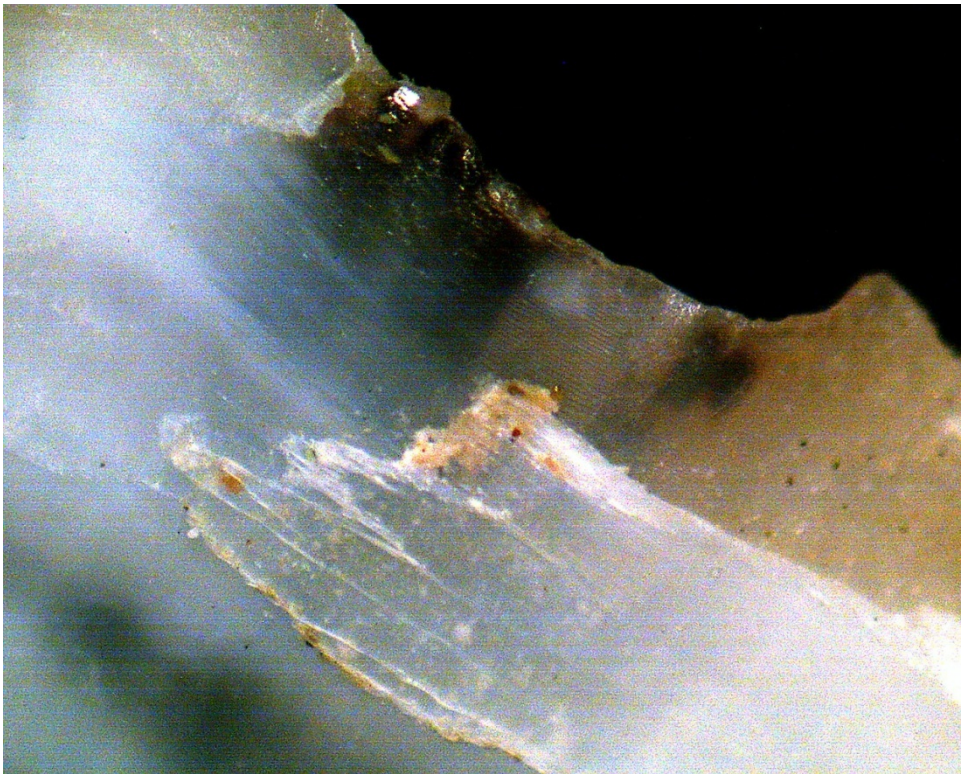
Crack seemingly following furrow of shell as well as differential breakage between layering

Fig. 5.25 : Sid048 – Soaked Bamboo (12x Magnification)



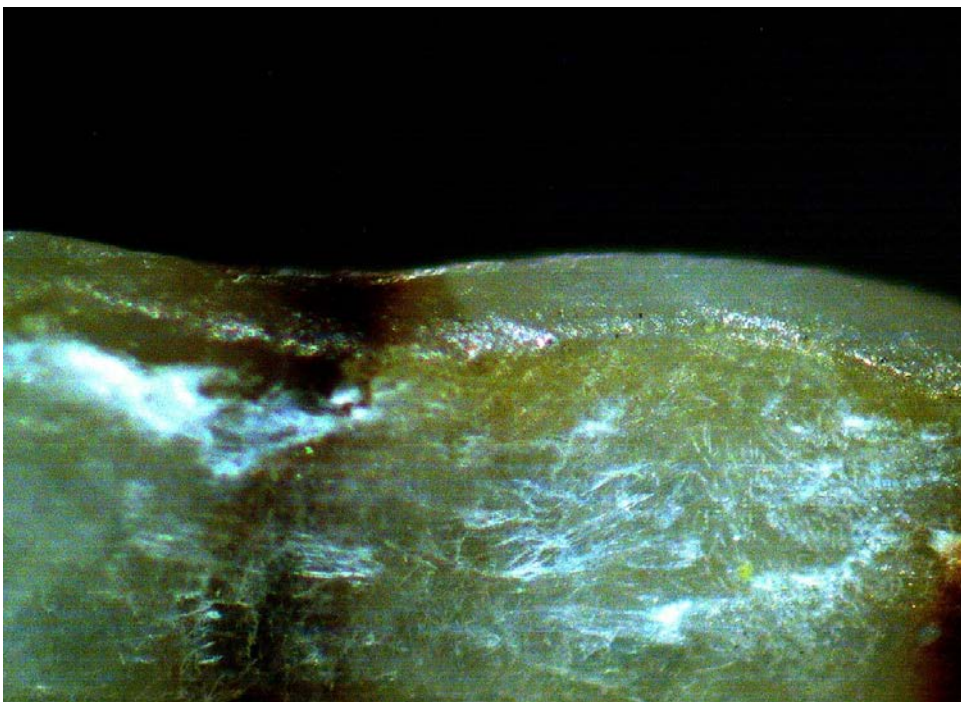
Edge wear and rounding, especially on edges of ribs.

Fig. 5.26 : Paf021 – Dry Bamboo (15x Magnification)



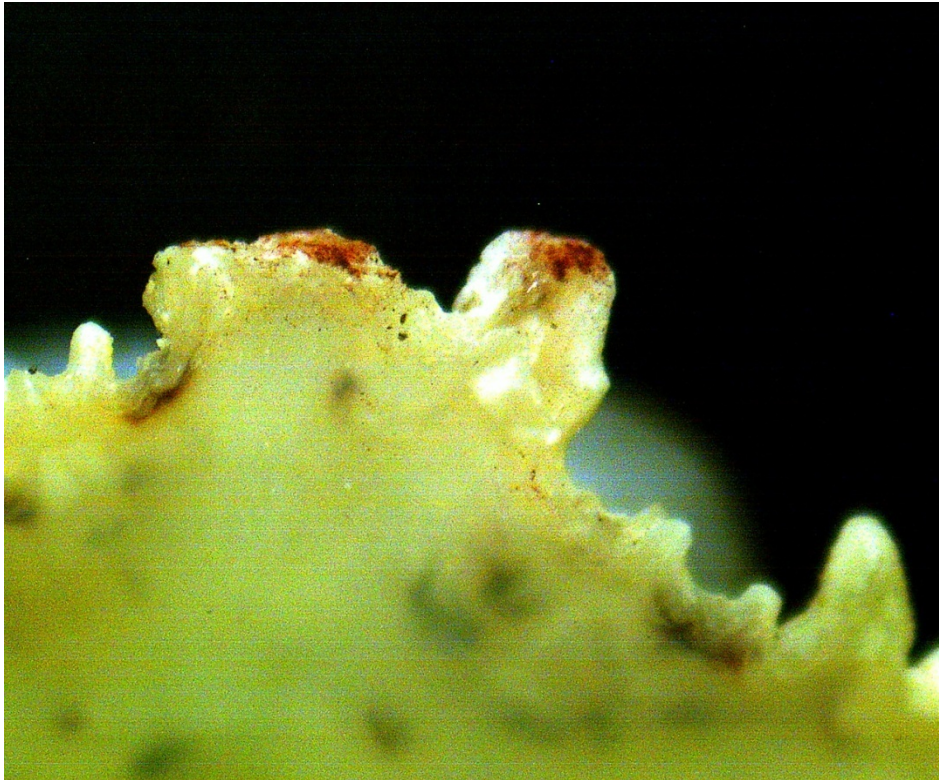
Differential breakage in minor edge chipping and cracks running parallel to shell edge

Fig. 5.27 : Cet087 – Dry Bamboo (20x Magnification)



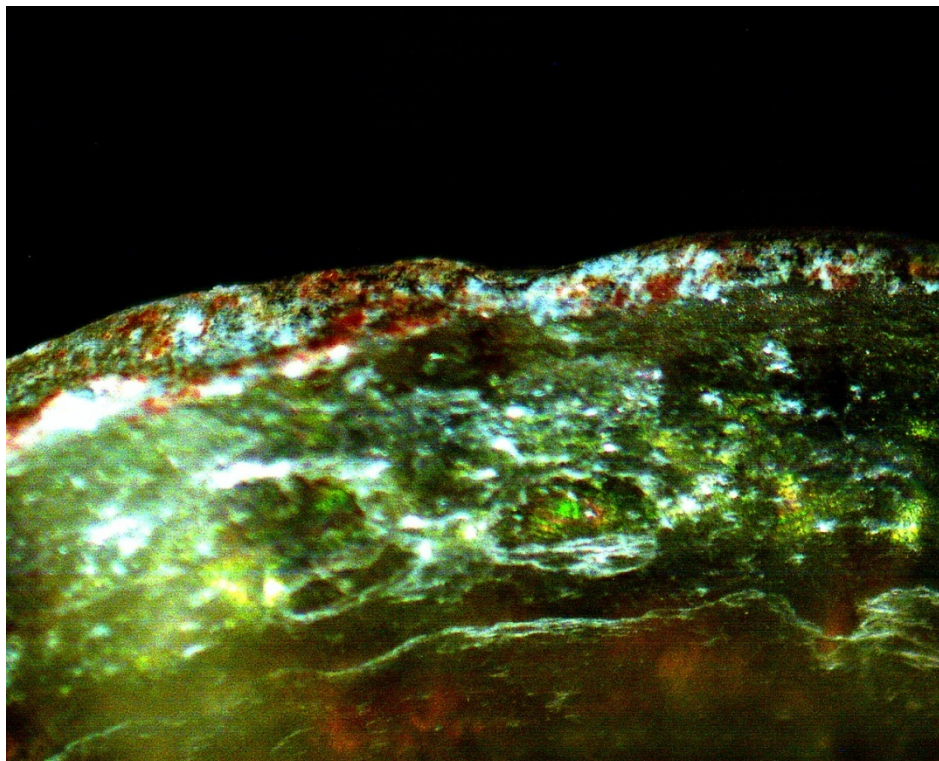
Heavy edge rounding with intense, untidy fractures

Fig. 5.28 : Paf026 – Haematite (20x Magnification)



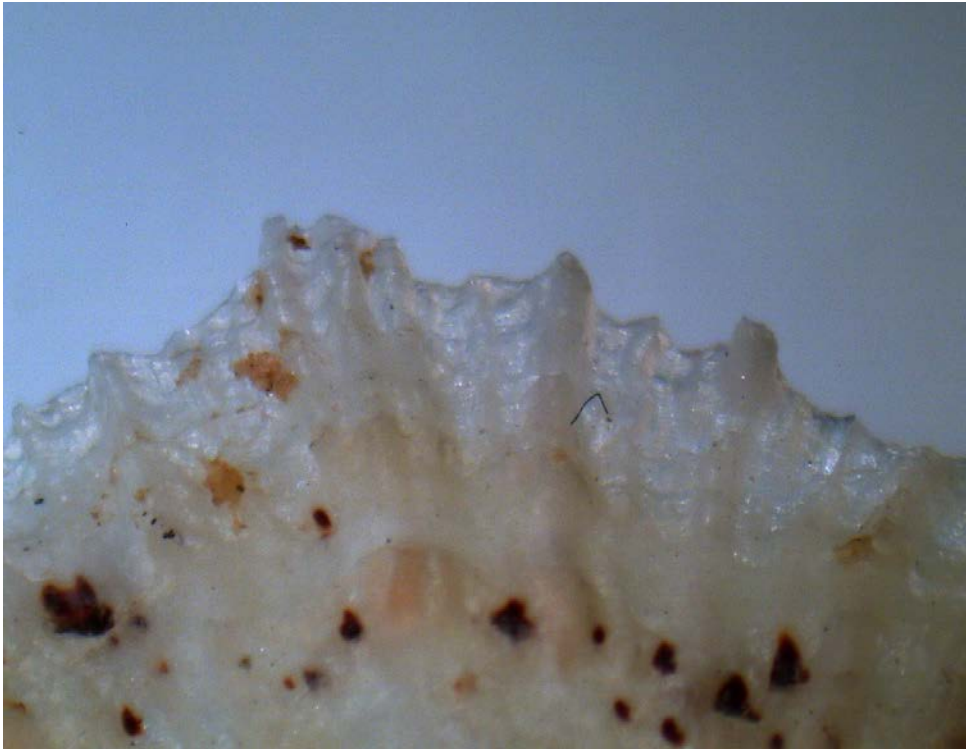
Very little damage though obvious residue left on rib

Fig. 5.29 : Cet088 – Haematite (15x Magnification)



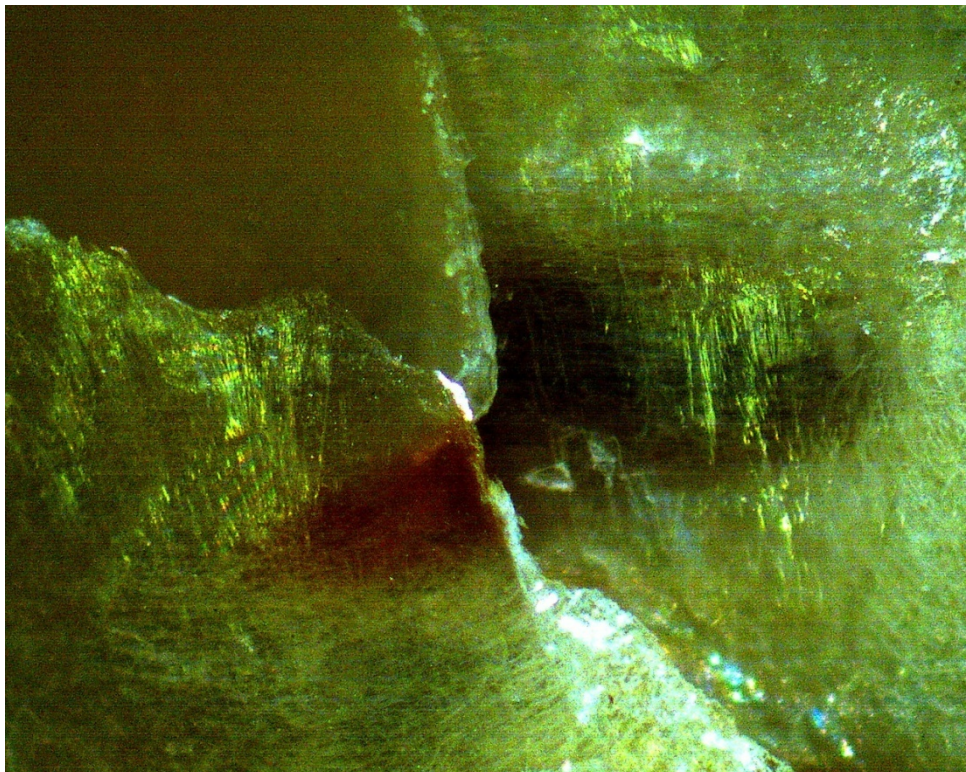
Edge wear as well as differential cracking

Fig. 5.30 : Paf003 – Taro (7x Magnification)



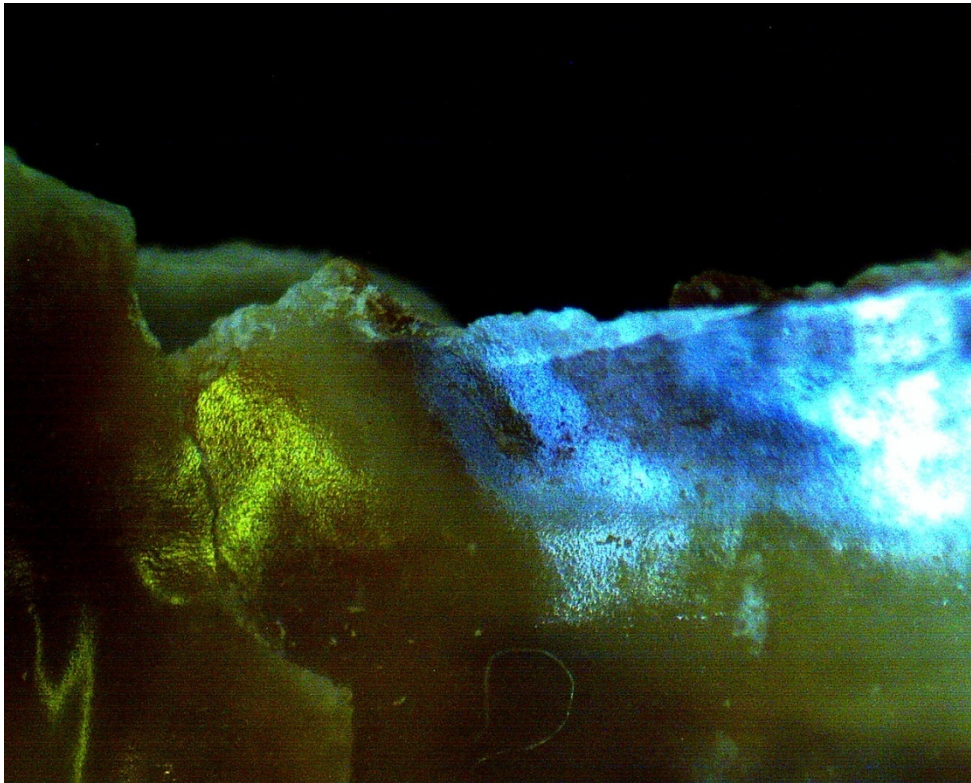
Edge chipping and removal of periostracum from furrows while ridges remain relatively untouched

Fig. 5.31 : Cet043 – Taro (30x Magnification)



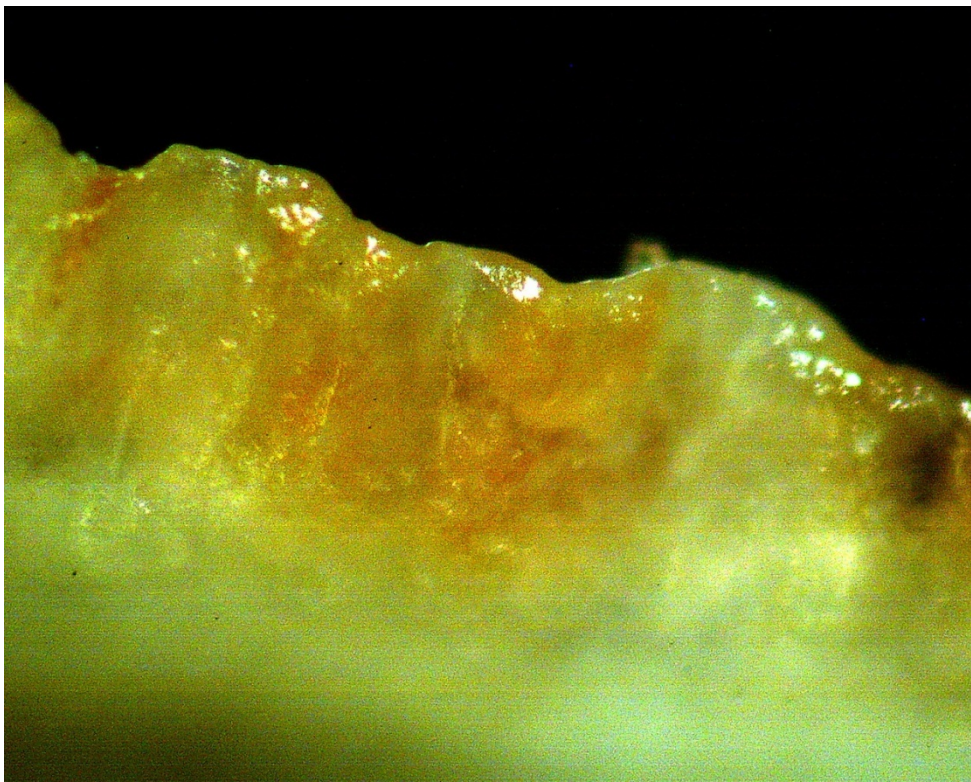
Differential breakage patterns between shell's structural layering

Fig. 5.32 : Sid002 - Taro (15x Magnification)



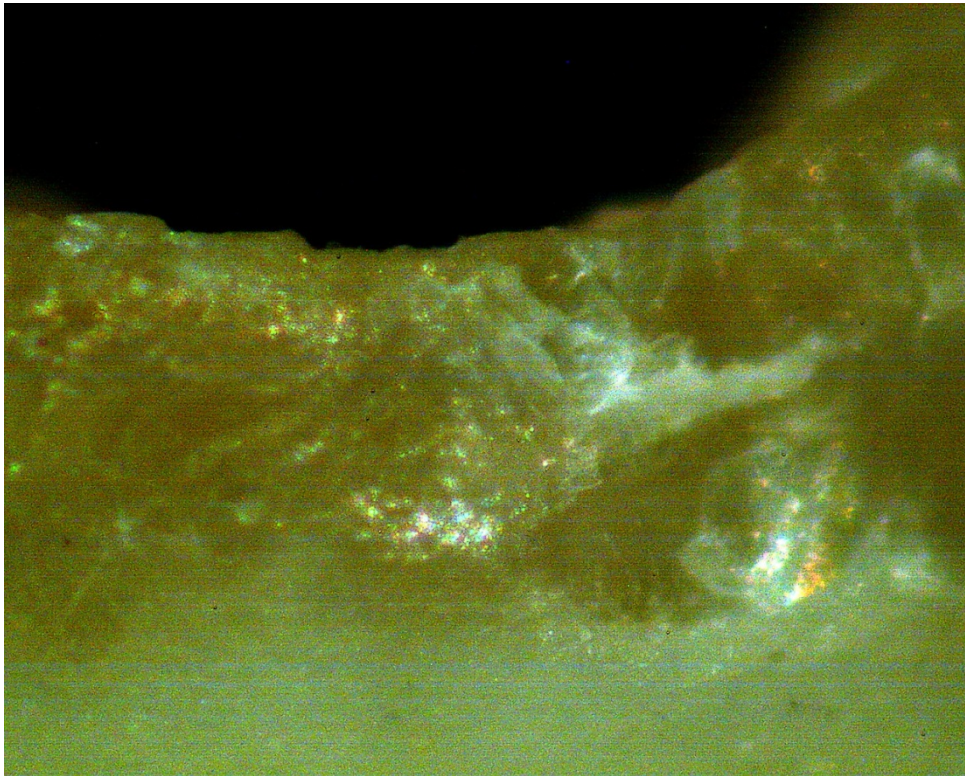
Differential
breakage
patterns
between
shell's
structural
layering

Fig. 5.33 : Pap010 – Taro (22x Magnification)



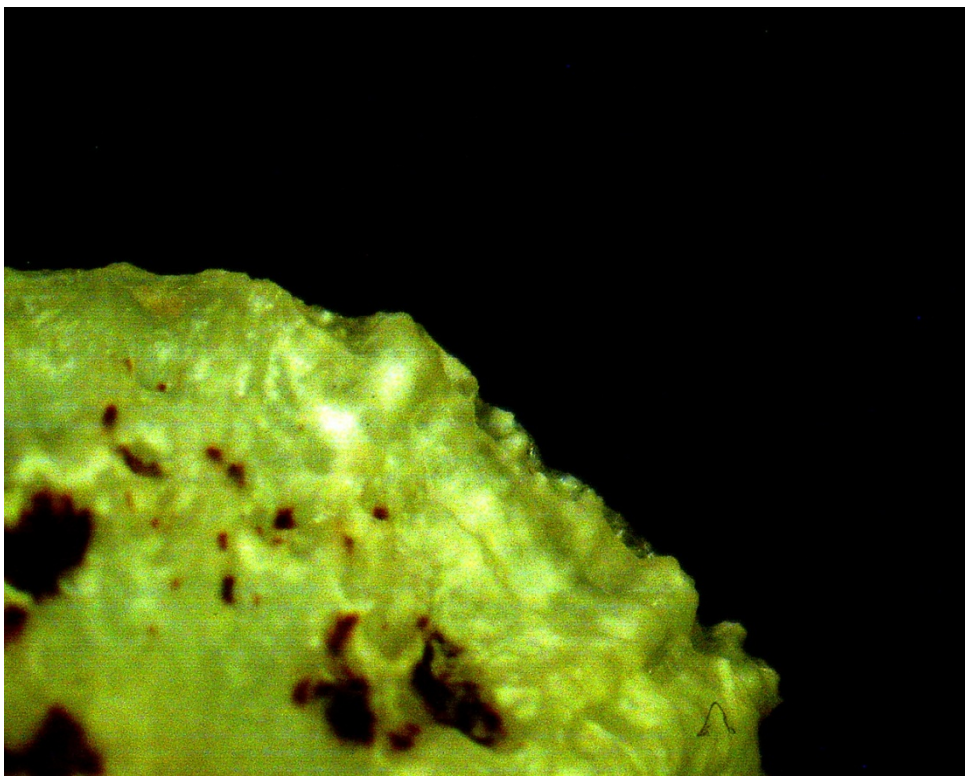
Radial
scratches
and incipient
cracking

Fig. 5.34 : Pap059 – Pork (45x Magnification)



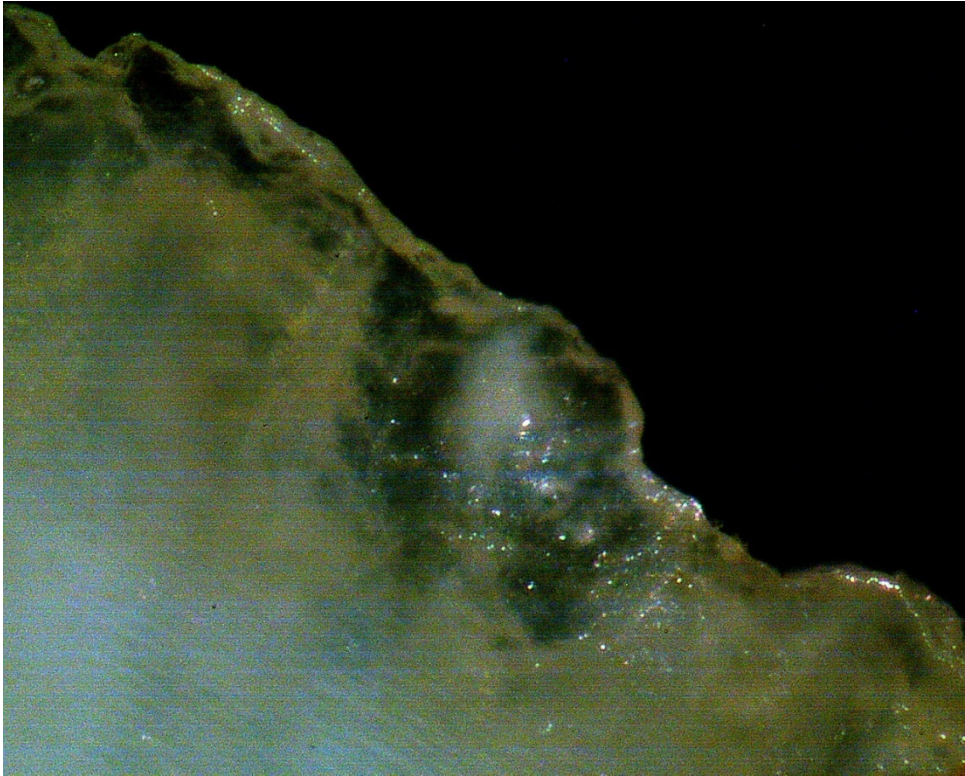
Fracturing
with no
particular
orientation

Fig. 5.35 : Paf016 – Pork (7x Magnification)



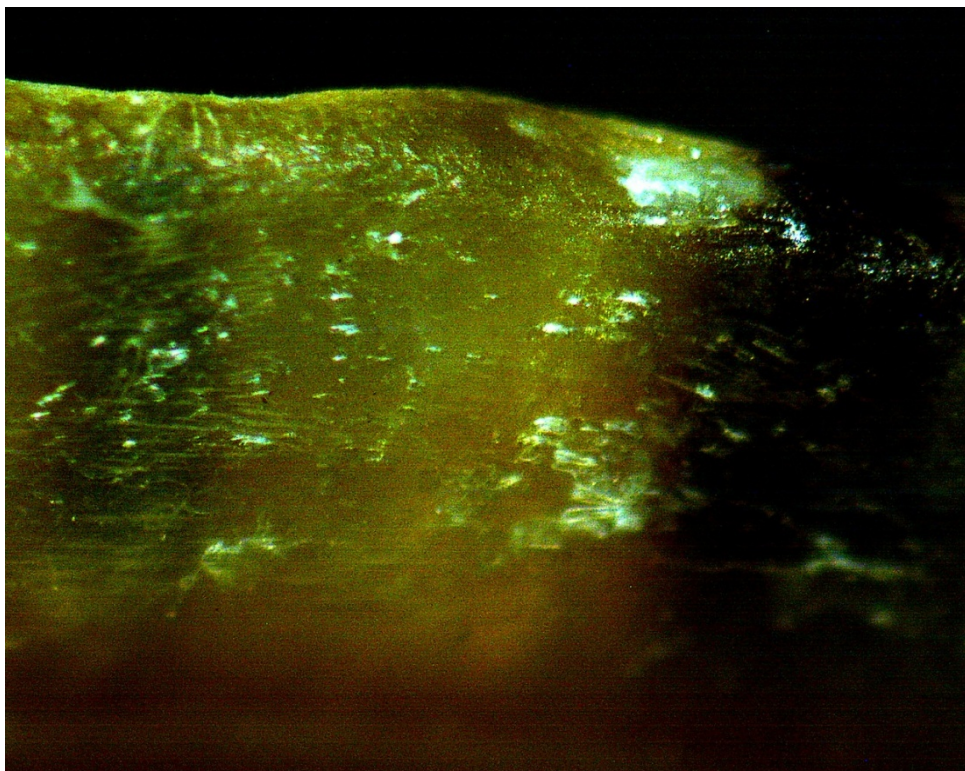
Differential
chipping of
shell edge

Fig. 5.36 : Paf014 – Pork (45x Magnification)



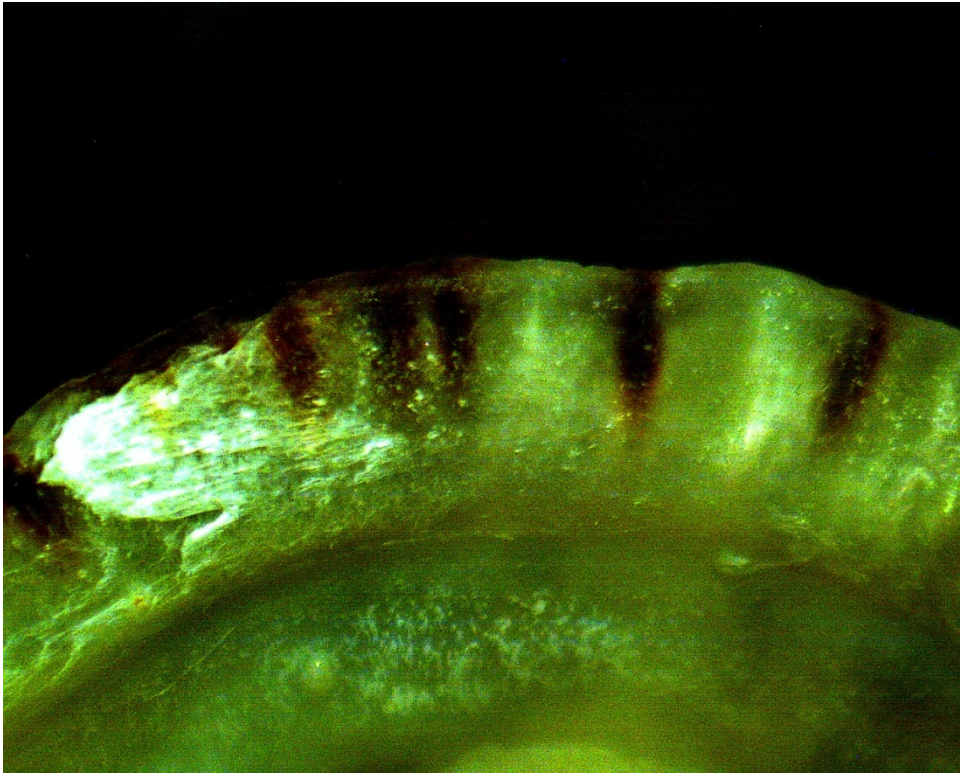
Edge
rounding
and
chipping
along
edge

Fig. 5.37 : Ces029 – Pork (20x Magnification)



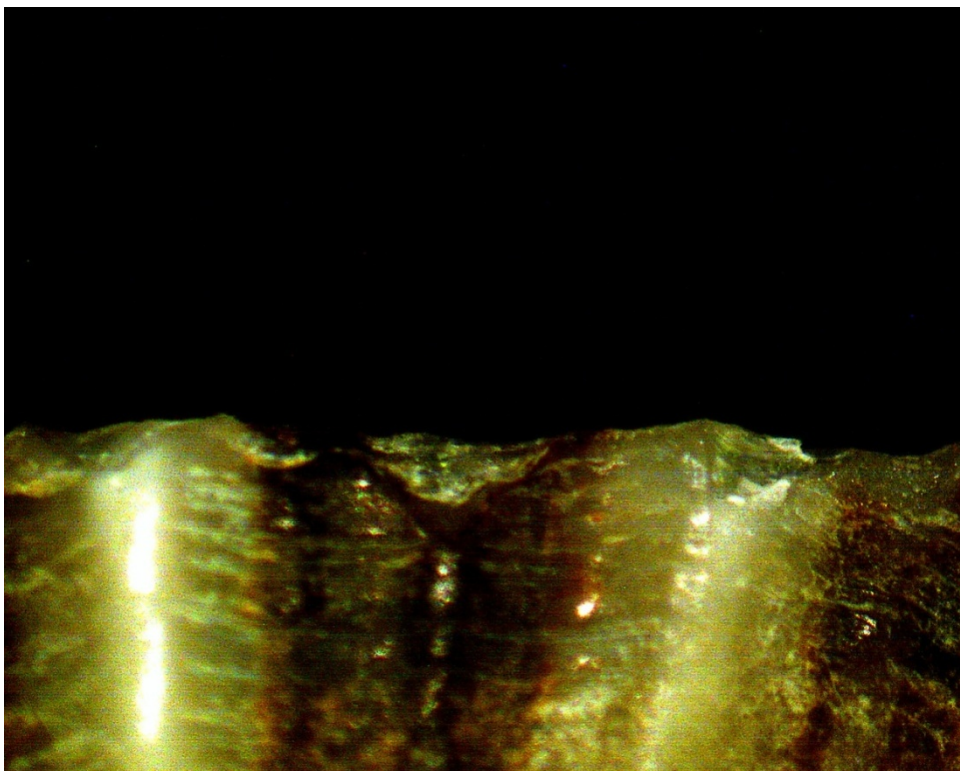
River
cracks
(Hull,
1999)
running
parallel to
shell
margin

Fig. 5.38 : Ces078 – Pork (7x Magnification)



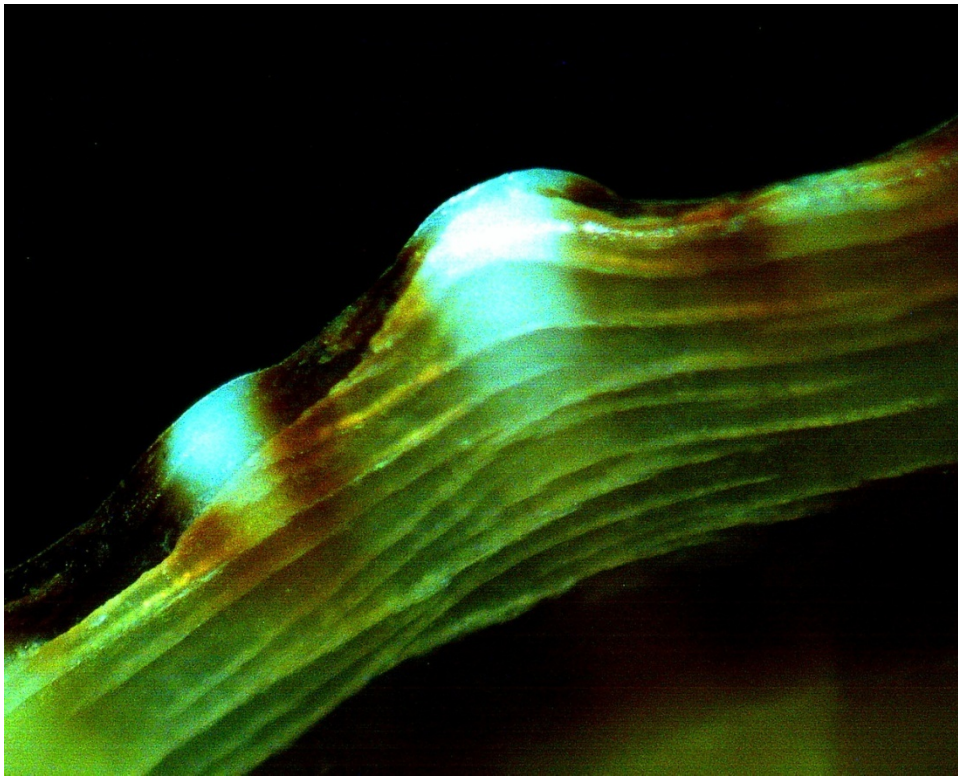
Differential
breakage
between
layers of shell

Fig. 5.39 : Cet040 – Pork (15x Magnification)



Cup shaped
chips across
dorsal edge

Fig. 5.40 : Sid042 – Yam (15x Magnification)



Heavy
concentric
cracks
around shell
margin

5.5 – Scanning Electron Microscopy (SEM)

While light powered microscopy is useful in the analysis of fracture and wears patterns, scanning electron microscopy (SEM) is the best way to view high resolution images and micro traces. As the core of this research project is wear patterns and comparing different structures on a number of scales, SEM was a logical addition to the experimentation process. Imaging specimens that have previously been used in the experimental stages of the research project using SEM, a magnification of up to 330 times was achieved giving great detail in imaging micro features and identification of features invisible to the naked eye.

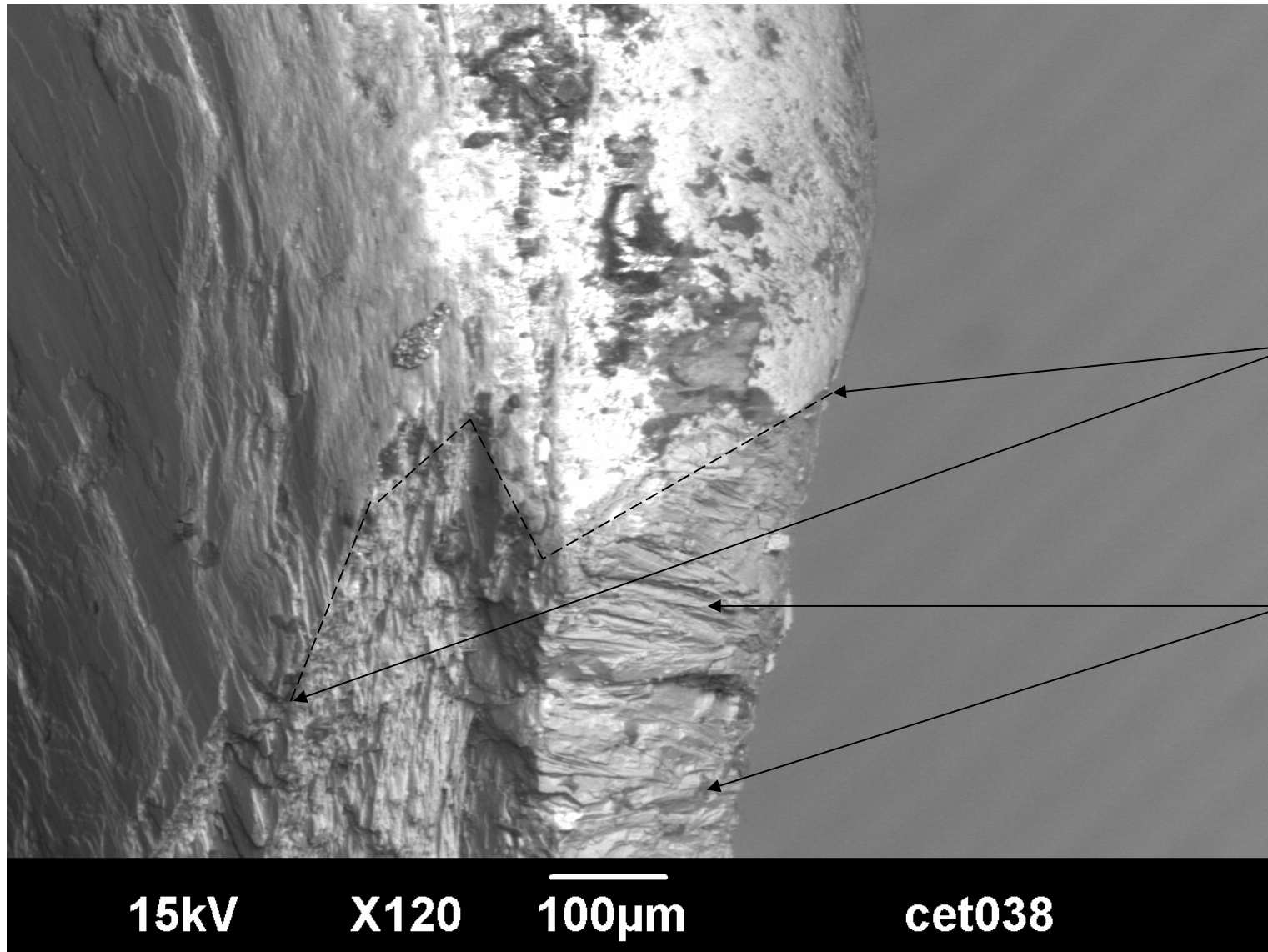


Fig. 5.41
SEM; Cet038 – Soaked
bamboo use-wear
experiment (120x)

Boundary between
worked and not
worked edge. (Worked
below, un- worked
above)

Scoring/Striations

15kV

X120

100 μ m

cet038

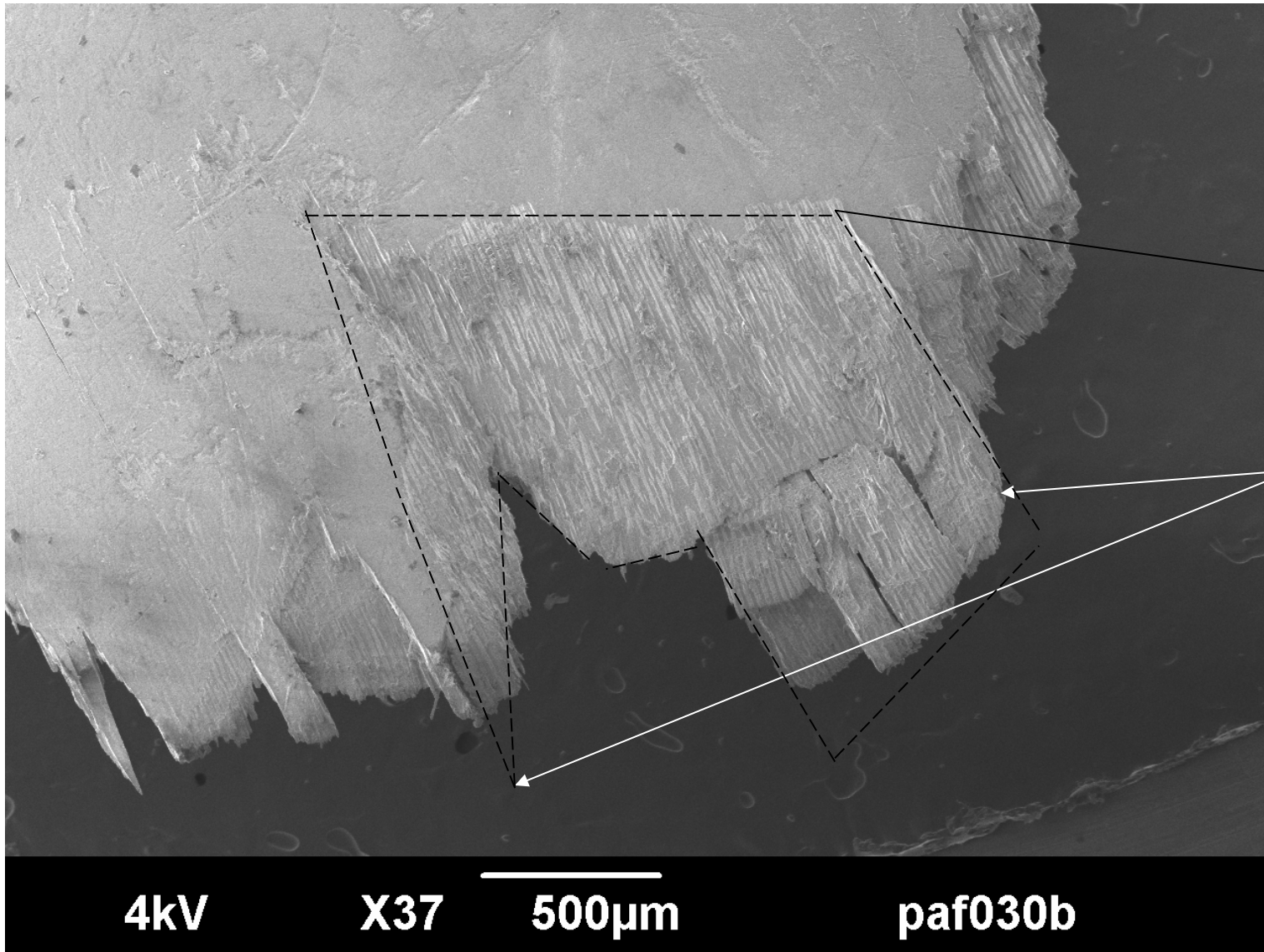


Fig. 5.42
SEM; Paf030 – INSTRON
experiment; Anterior-
Posterior orientation
(37x)

Sheared surface.
Topmost layer removed
showing pristine
crystallographic
structure underneath.

Tearing of the edge

4kV

X37

500µm

paf030b

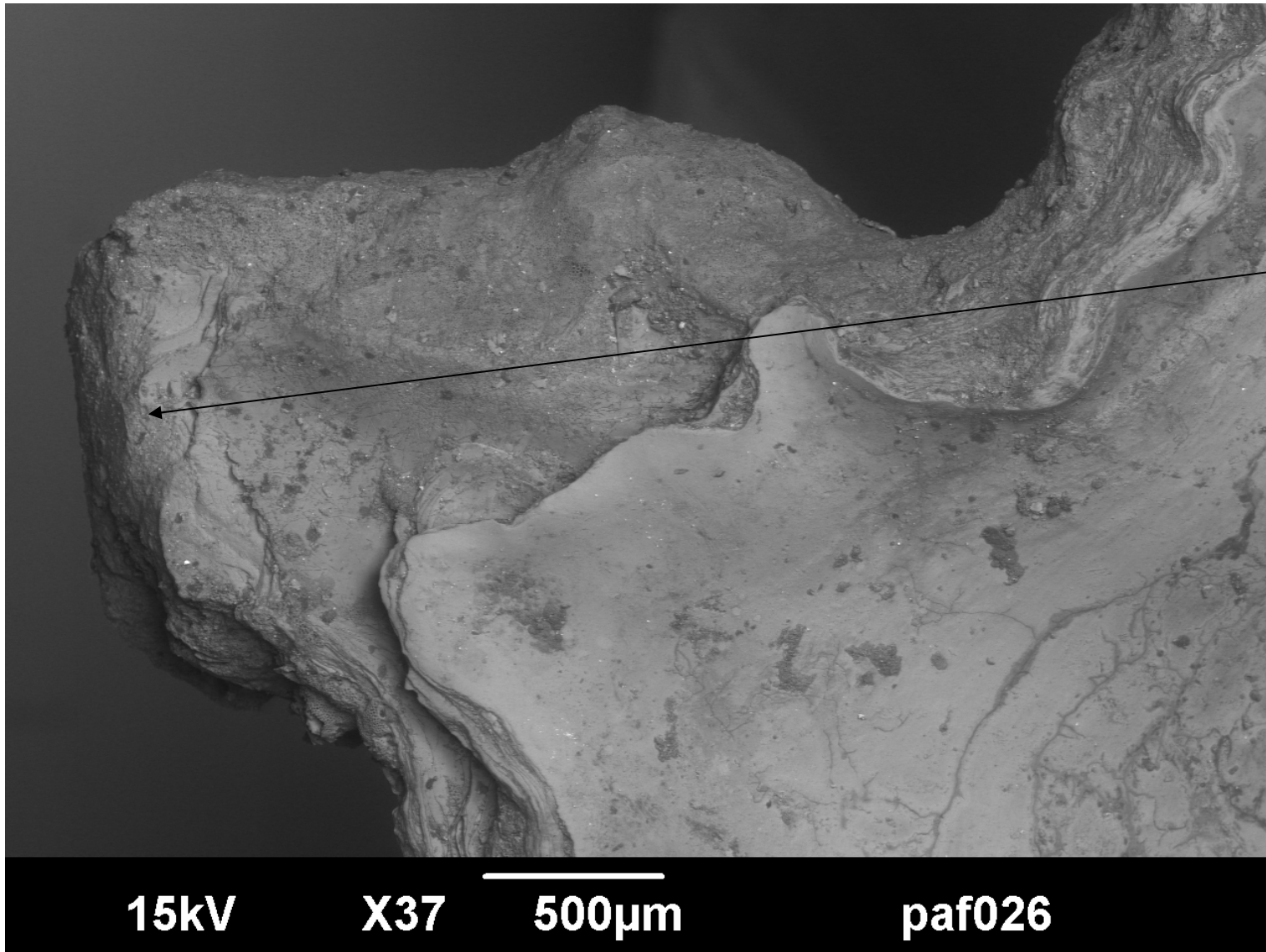


Fig. 5.43 :
SEM; Paf026 –
Hematite use-wear
experiment (37x)

This is the sample of *P. flexuosa* being rubbed against hematite. Note the distinct lack of edge damage besides very minor examples

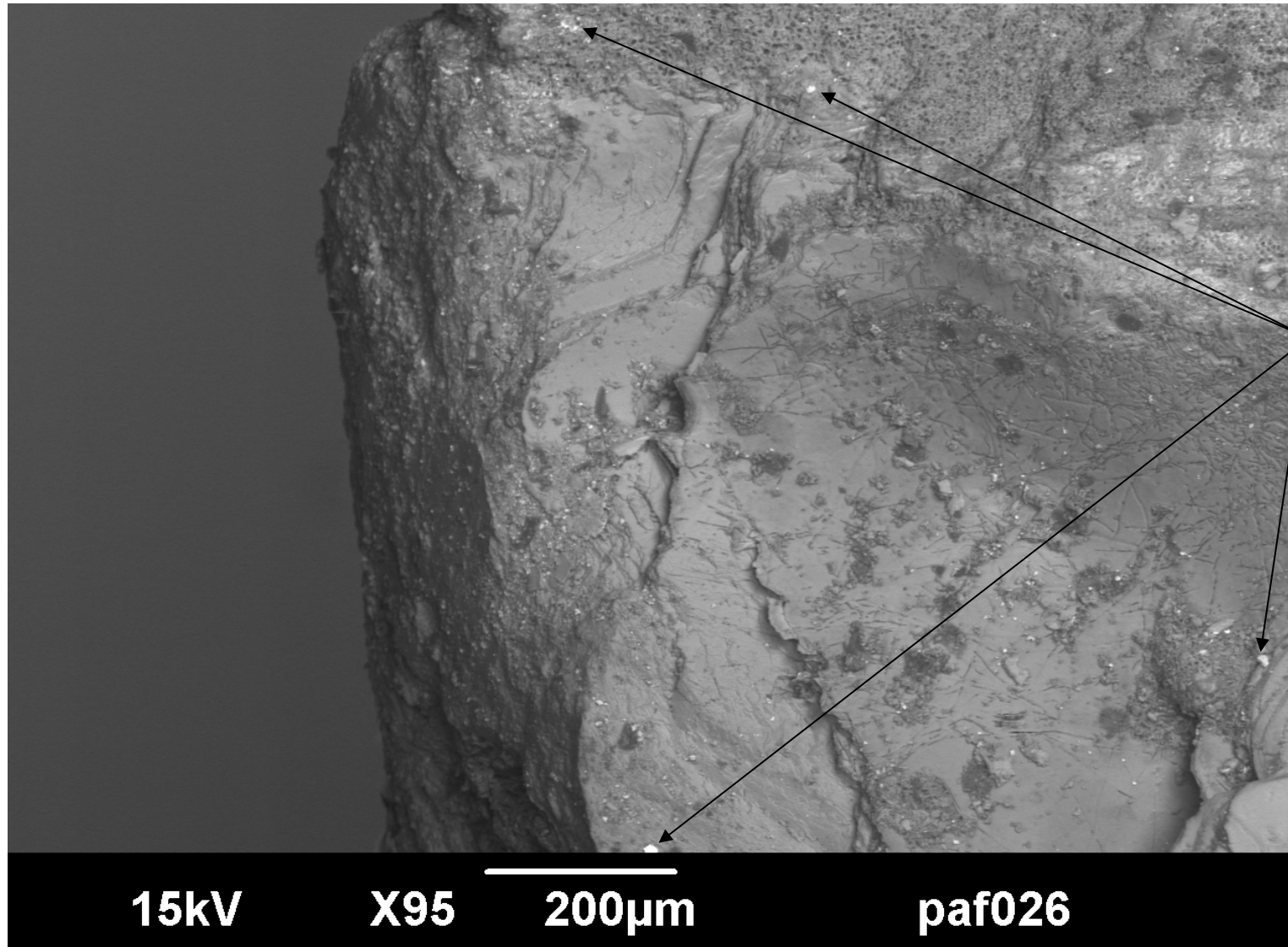


Fig. 5.44 :
SEM; Paf026 –
Hematite use-wear
experiment (95x

Residual particles
(white spots) from the
hematite experiment
mentioned on the
previous page

15kV

X95

200µm

paf026

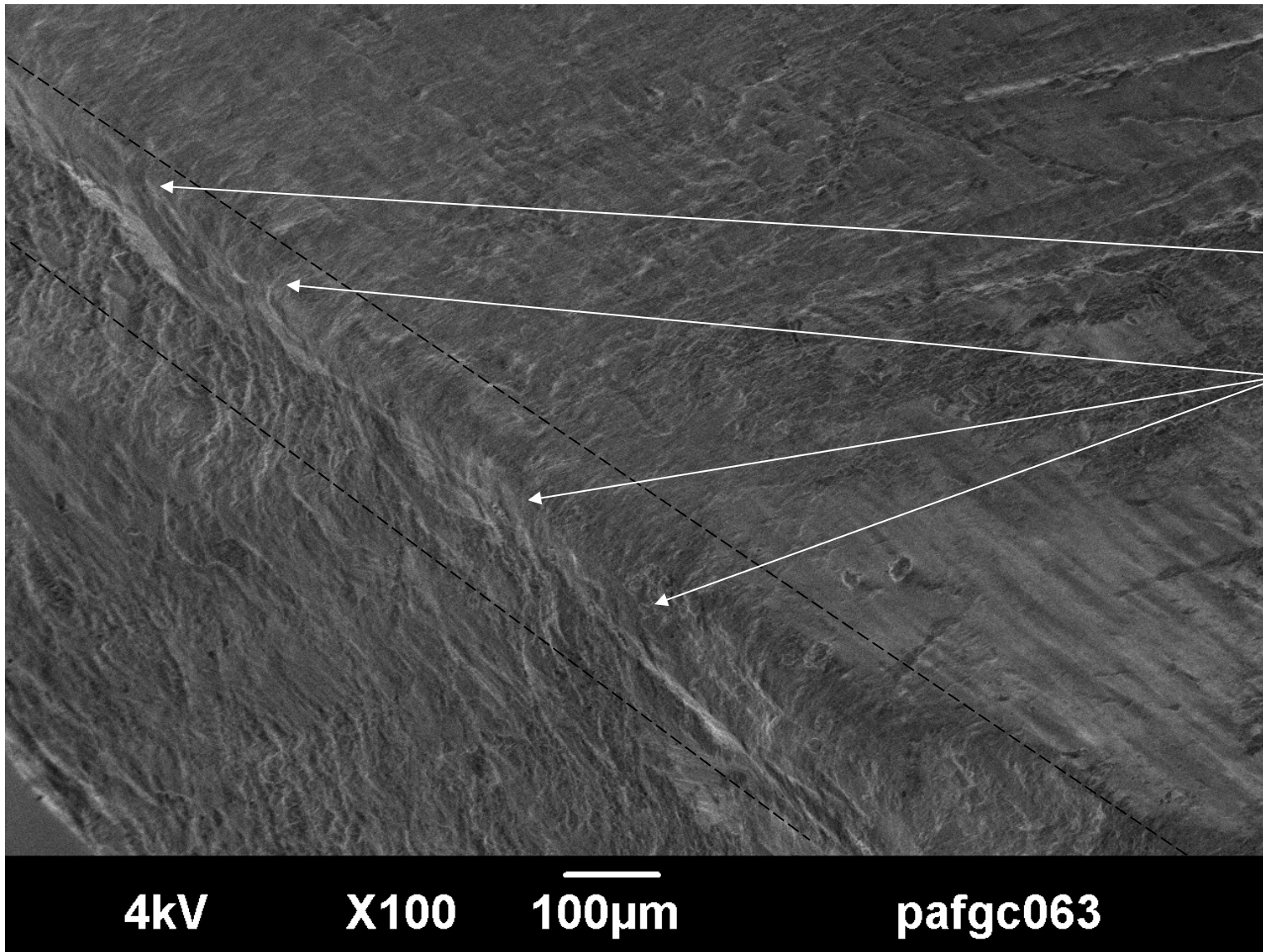


Fig. 5.45 :
SEM; PafGC063 – Golo
Cave archaeological
specimen (100x)

Very straight and
regular edge.

Grooves perpendicular
to edge may indicate
working

4kV

X100

100µm

pafgc063

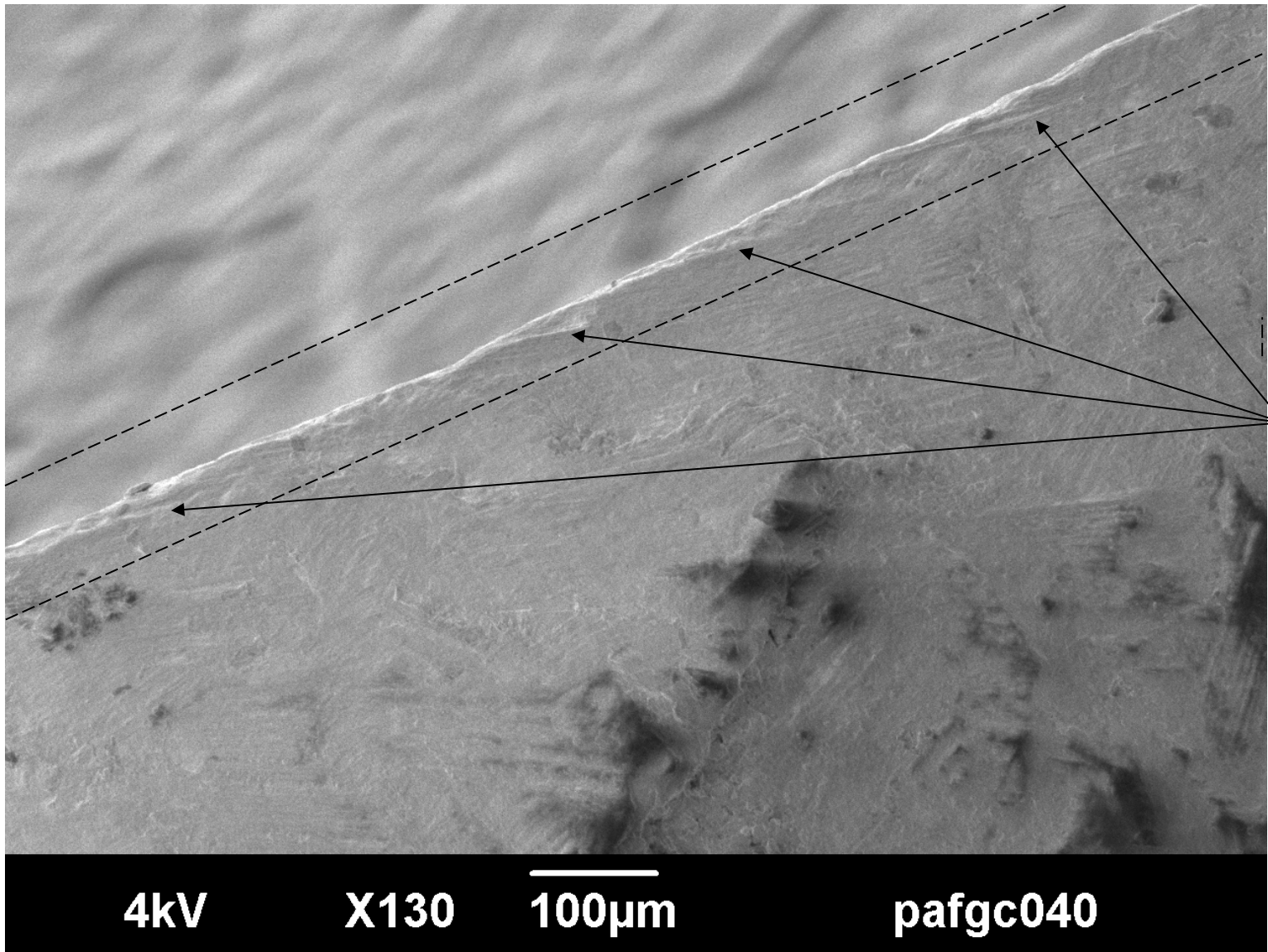


Fig. 5.46 :
SEM; PafGC040 – Golo
Cave archaeological
specimen (130x)

Very straight and
regular edge.

Pressure induced cracks
with a regular
orientation along edge

4kV

X130

100µm

pafgc040

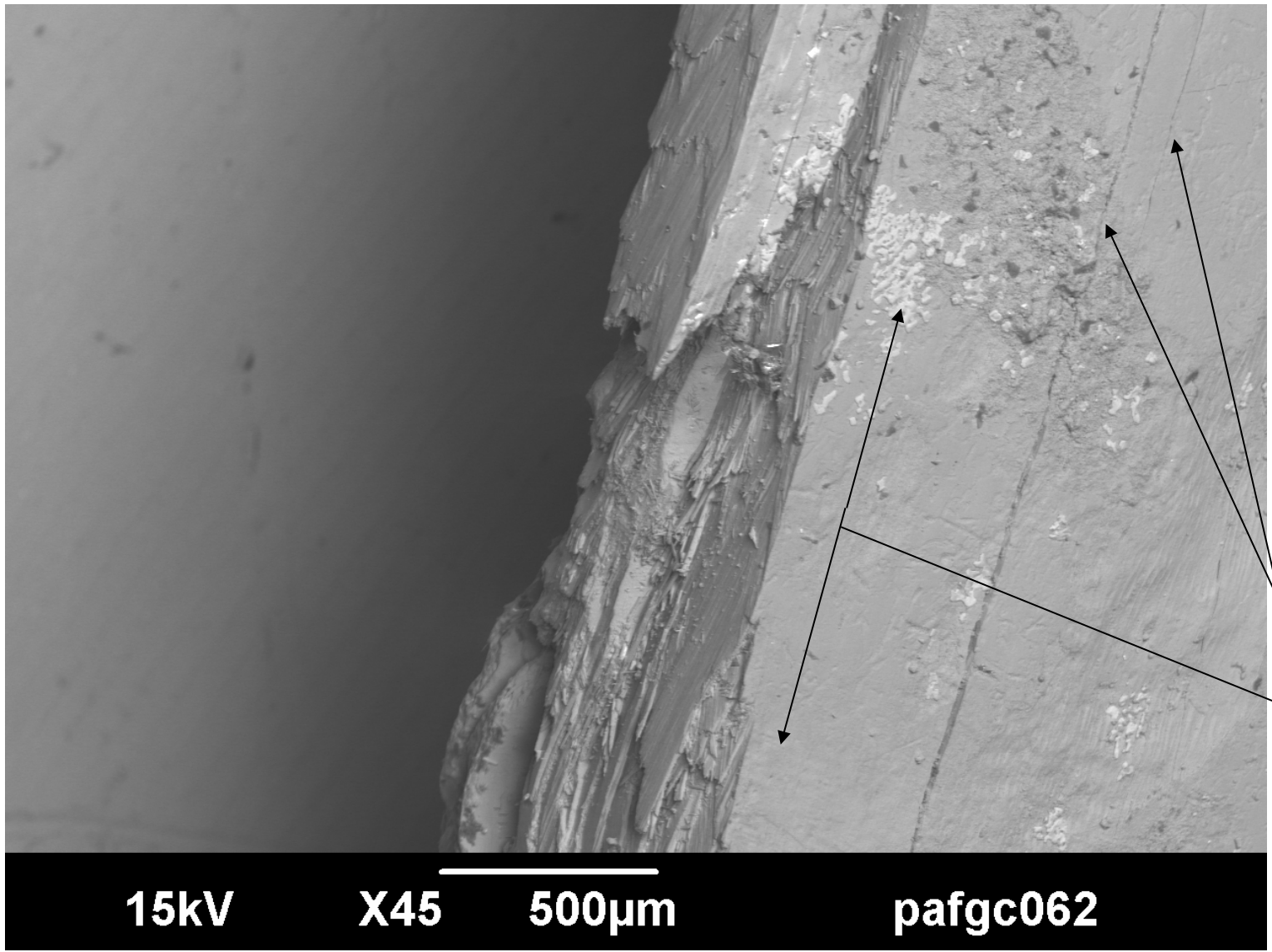


Fig. 5.47 :
SEM; PafGC062 – Golo
Cave archaeological
specimen (45x)

Image of natural
fracture patterns. All
fragmentation has
occurred along planes of
weaknesses naturally
generated with crystal
growth as can be seen
through shearing
through cleavage
planes.

Fracture running
parallel to others

All fractures running in
the same direction

15kV

X45

500µm

pafgc062

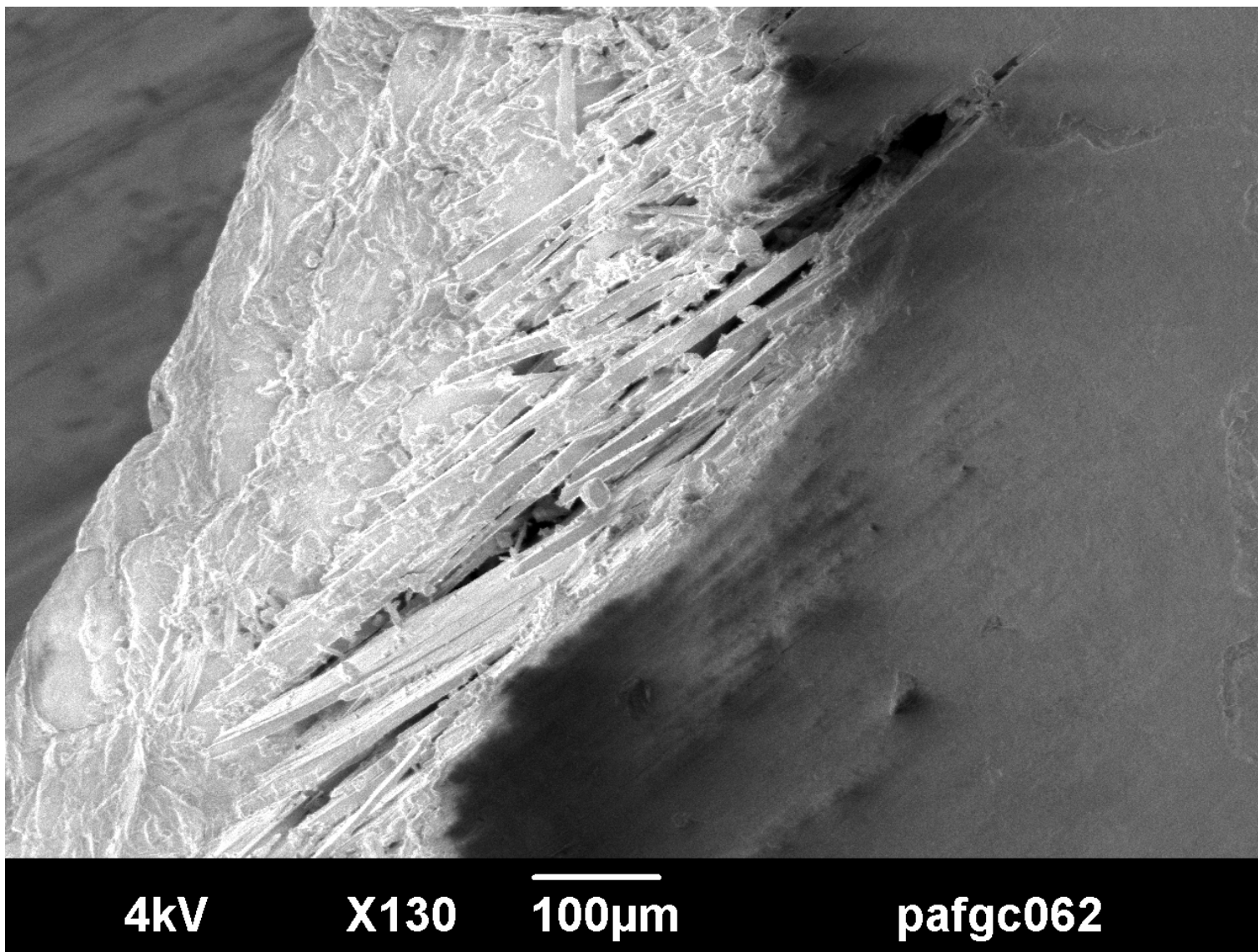


Fig. 5.48 :
SEM; PafGC062 – Golo
Cave archaeological
specimen (130x)

Tearing of microstructure indicates that the organic content of the shell was still good, which implies that this shell was fragmented when it was either alive, or not long after its death.

Preservation of this feature is also very good in regards to it being one of the Golo Cave archaeological specimens. This quality of preservation means that the archaeological specimens are directly comparable to the contemporary specimens in this study.

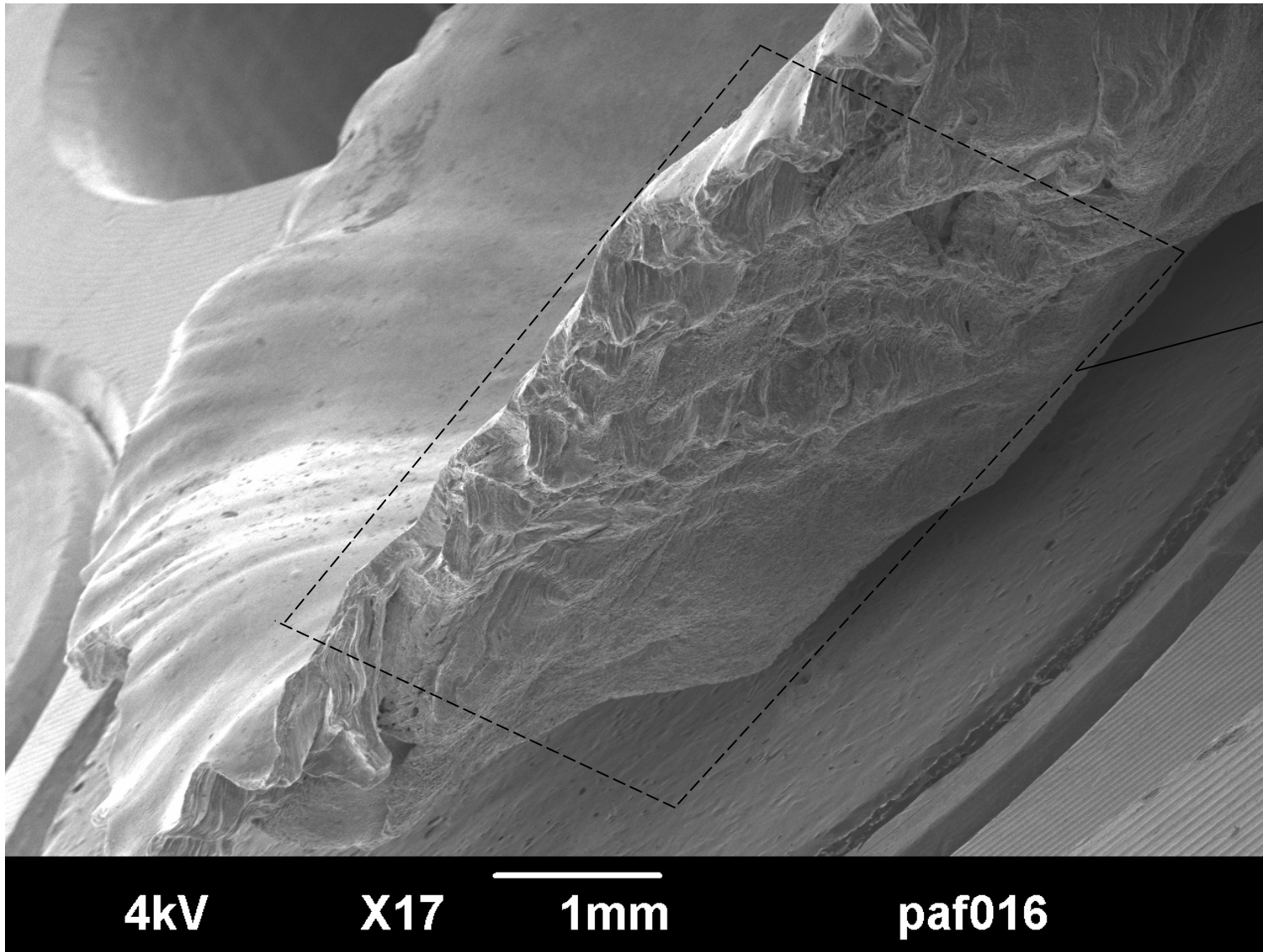


Fig. 5.49 :
SEM; Paf016 – Pork
use-wear experiment
(17x)

Very irregular
chipping/crushing of
edge.
Possible reflection on
the difference in
texture in bone
between macro and
micro structure.

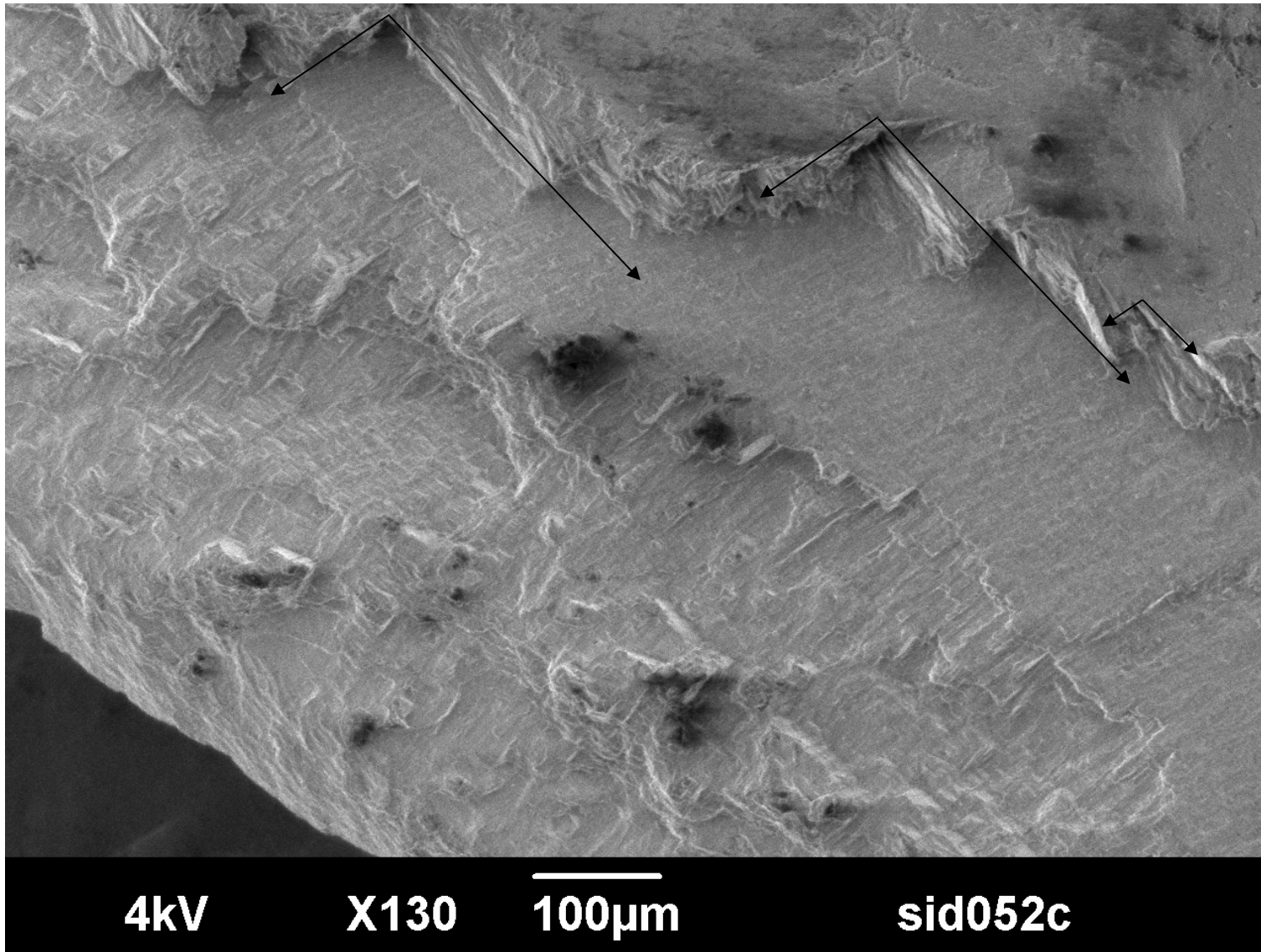


Fig. 5.50 :
SEM; Sid052 – INSTRON
experiment; Dextral-
Sinistral orientation
(130x)

Microstructure of
S. diemenensis.
Notice third order
lamellae of one layer
overlying another at
perpendicular angles,
with this pattern
repeating itself along
the fractured edge. This
indicates a crossed
lamellar microstructure.

What can be discerned from the SEM analysis is the sheer variety of micro features that are apparent in the sample assemblage of this research project. Specifically referring to the Golo Cave samples, tearing features (PafGC062) and natural fracture edges (PafGC062) were identified as well as edge wear that does not resemble any natural taphonomic processes (PafGC040). This clear distinction between natural and potentially culturally modified edge wear and fracture that does not resemble any form of taphonomic effect on shell builds a strong argument for an alternate source of such wear patterns, and at the forefront of this argument is shell utilised as a raw material for use as a tool.

5.6 – Results in Summary

What can be discerned from the results of this chapter is the range of diversity in fracture and reduction patterns in the limpet species through the experimentation process. Through controlled fracture experiments using INSTRON machinery and software, and use-wear experiments, a broad range of results were achieved relating to archaeological situations; with INSTRON experimentation serving as a proxy for taphonomic compaction and the use-wear experiments representing expedient usage of a by-product of food procurement. This now creates a basic reference point to compare the results of the experimentation process and determine if indeed a significant difference between taphonomic and cultural modification exists in the samples from Golo Cave, Indonesia.

Reduction patterns observed from the INSTRON experimentation is dominated by catastrophic failure events resulting in fragmentation of large pieces of the shell. This was particularly apparent in ‘Dorsal-Ventral’ compression where force was constantly applied until catastrophic failure resulted in the release of energy, as opposed to ‘Sinistral-Dextral’ compression where relatively minor chipping occurred on the shell margin causing the shell to slip off the stage. This was a limiting factor in this stage of experimentation as compression is stopped when the machine’s software detects a sharp drop in resistance, which can be catastrophic failure, or merely chipping of the shell margin.

What can be inferred from the INSTRON experiment results is that fracture occurs along existing planes of weakness. These planes occur as existing features in the crystallised structure, interaction between adjacent microstructures or morphological features in the shell itself such as the muscle scar being thinner than the surrounding shell or taphonomic features weakening the shell’s structure. These fracture patterns are seen in the shell

specimens bearing nacreous layers (*C. tramoserica* and *C. solida*) where the inner nacreous layer fragments almost entirely and separating from the prismatic outer layer. The orientation of the individual calcium carbonate crystals is very different between these two microstructures, causing a natural weak point at their contact. This is best represented by Cet091 where the nacreous interior fragments into nearly a powder, and Cet051 where the nacreous interior layer remains intact, but peels away from the prismatic outer layer.

The other shell specimens still show this pattern of fracturing happening along planes of weakness, predominantly along the concentric growth lines around the apex, best seen in Pap075, Cet091, Pap073 and Paf031. This concentric fracture does also turn into radial fracture towards the shell margin forming a removed shell fragment. The results of the INSTRON experimentation on *S. diemenensis* led to a greater degree of radial fracture than all four other species. This is explained by the radial ribs of *S. diemenensis* shell being more prominent than the others, making natural channels for cracks to run down leading to detaching of a fragment. This is seen in the 'Dorsal-Ventral' and 'Dextral-Sinistral' compression of *S. diemenensis*.

Microscopically, these patterns are also reflected in the SEM picture of Sid052 (Fig. 5.50), where the microstructure of *S. diemenensis* becomes apparent. What is seen is the fracturing of the crossed-lamellar microstructure along planes of crystal growth. As well as this, the notable separation between the different orders of lamellar layers; another plane of weakness is apparent. Paf030, while appearing quite ragged and rough, does have some uniformity in its fracture patterns, with the orientation of cracks and separation of crystals along consistent axes.

These patterns are in contrast to those seen in the use-wear experiments. While total catastrophic failure was less common than the INSTRON experimentation, fracture and fragmentation was definitely observed. What the experimental working shows is localised damage to the shell and a number of breakage patterns observed on the one specimen.

Interestingly, the material the shell was being used on does not necessarily yield predictable results. For example, the rubbing experiment of bamboo with *P. flexuosa* (Paf021) created more fragmentation when compared with the hematite experiment and shell of the same species Paf026. This result highlights the fact that not all materials react as we expect. While a more substantial explanation may exist for this occurrence, it was not followed into in this study.

Chapter 6

Discussion and Conclusion

In the previous chapter, a combination of light microscopy and SEM was used to recognise and identify examples of fracture and modification. Using these imaging techniques, detailed high resolution images were obtained detailing the fracture and wear patterns created during the experimentation process. Coming out of the results of this research project is the observation of the large amount of variation in fracture and modification features and structures in shell. This variation ranged in structural features observed to the amount and intensity of fracture and modification in the shell samples.

Within the Golo Cave assemblage with specific regards to *P. flexuosa*, variation exists on both a macro and micro scale. Firstly and most obviously was the variation in complete and fragmented samples. Within the fragmented assemblage differentiation could be made over shell samples that had been broken taphonomically and those that had been culturally modified. As seen in the SEM pictures, a broad range of microtraces became apparent, such as the very regular and fine line of pafgc040 that in all probability was modified by man to the rough, naturally fractured surface seen in pafgc062. All of these microtraces tell of different causing forces and as much can be learned by identifying what it is not than what it is.

While the focus in this research project is on modified shells, equal attention was paid to those that did not exhibit signs of modification. The action of a number of taphonomic processes was apparent throughout the assemblage such as compaction-breakage, bioerosion and burning as well as what is now contested to be definitive cultural modification.

Using the data gathered from the experimental work and light microscope and SEM analysis, there is definitely a strong argument that a portion of the *P. flexuosa* specimens from the Golo Cave assemblage are culturally modified, and all the various elements of this project contributed valuable aspects to their interpretation. The XRD analysis demonstrated that the archaeological *P. flexuosa* sample was not recrystallised, with the aragonite to calcite ratio in the shell of archaeological *P. flexuosa* is near identical to that of contemporary specimens.

Thus, despite being over 32,000 years old (Szabó et al., 2007), the modern and archaeological shells are chemically and structurally comparable. There is also clear evidence on the archaeological *P. flexuosa* specimens being collected and used either live, or shortly after death. The loss of the organic fraction of the shell microstructure begins shortly after the death of the animal. The SEM picture of the archaeological *P. flexuosa* specimen (PafGC062) shows a distinct tearing fracture that only occurs when a relatively high organic content of the shell is present. Were it to have been an 'old shell' or one that has gone through stages of chemical degradation like bleaching from the sun reducing the organic content organic content, then the fracture pattern would have been more likely to resemble standard multi-directional cross-lamellar fracturing uninfluenced by the presence of organic matter.

Of particular note is the fact that some of the SEM pictures shell that had very straight, regular edges; specifically PafGC040 and PafGC063. Naturally occurring fractured edges, like the ones seen in PafGC062 follow existing planes of weakness that orientate themselves in the same direction as the shell's microstructure (Currey, 1980). This tendency was clearly shown in the results of the INSTRON experiments. However, with the archaeological specimens PafGC040 and PafGC063, the edge is incredibly regular and flat, with minimal undulation, chipping or serration. Instead, a well-rounded edge that crosses the lamellae of the *P. flexuosa* shell's crossed-lamellar layers can be seen. Such damage is not within the limits of the natural fracture tendencies of the shell.

The morphology of edge modification results from a combination of two major factors; the properties of the material being worked and the material properties of the tool with which the working is being undertaken. While extensive study has been done related to shell, its structural abilities and limitations, and particularly on shell microstructure (Currey, 1980; Watabe, 1988; Chateigner et al., 2000; Bruet et al., 2005 Kobayashi and Samata, 2006 and others) the vast majority of these studies have been set in an engineering context. Very little study in this field has been

applied to the field of archaeology, but presents a valuable baseline for the recognition of natural fracture tendencies.

As discussed in Chapter 2, lithic artefacts have been pivotal in discussions of human behavioural evolution on a global scale (Clark, 1971; Foley and Lahr, 2003). So in the context of Southeast Asia, the general simplicity of the region's lithic artefacts lead to a label of cultural and technological simplicity. Once again, as discussed in Chapter 2, there are arguments against that claim (White, 1977; Brumm and Moore 2005), and one is the replacement of stone as the primary medium of artefact production with other materials – most notably bamboo (Mellars, 2006). Szabó et al. (2007) raised the possibility of shell as a largely unrecognised alternative raw material in the region, but there is debate as to whether shells are an effective raw material for tools (Semenov, 1964).

Now speaking from experience, and based on the experiments conducted within this research project, it is apparent that shell is more than suitable for some applications, but is entirely ineffective in others. In the experimental working, the shells were largely able to effectively complete the allotted task, but resulting traces of these actions on the shell itself were variable. For example, the peeling of the soft and fibrous taro had a small effect on the shell, namely the removal of the periostracum layer and some minor edge chipping especially on highly ornamented shell like *P. flexuosa*. Despite this, large corm taro could be peeled quickly and effectively. Equally, with the scraping haematite experiment, *P. flexuosa* shell was more than capable of removing significant amounts of material from the rock itself with minimal damage to the shell margins, as seen in Chapter 5 and in the SEM analysis of the same chapter. That experiment alone should be enough in demonstrating how underestimated shell as a raw material really is. Shells also seem to excel at peeling materials, such as yam and taro. Conversely, shell failed to do any real damage to the bamboo, both inside and out and proved largely ineffective in butchering the leg of pork.

With regards to acquisition of shell, the use of limpet scrapers in the Golo Cave setting seems to represent casual artefact use. *P. flexuosa* was one of the dominant species in the midden, suggesting

its primary subsistence function. No *P. flexuosa* showed signs of shaping or working to create a specific shape prior to use, and thus it has been inferred that *P. flexuosa* shell specimens were used in their raw state and probably in passing (Szabó et al., 2007). This is in contrast to *Turbo mamoratus* opercula which, based on their ecology, one would have to go well out of one's way to acquire these specimens (Szabó et al. 2007). It is therefore reasoned that *P. flexuosa* specimens are sourced from midden material in an act that resembles recycling. In saying this however, there is some form of systematic approach in the selection of *P. flexuosa* for use as a tool. In the Golo Cave assemblage, no other species of limpet exhibit the same wear patterns seen in *P. flexuosa*. It can thus be concluded that *P. flexuosa* specimens are selectively chosen based on a then established understanding of varying levels of effectiveness that specific species have at specific jobs.

Throughout the experimentation process, I demonstrated that it is possible to peel yam and taro with a limpet shell. I also demonstrated that it was possible to extract a substantial amount of powdered haematite using the anterior edge of a limpet shell. As well as this, it was also demonstrated that heavier use does not necessarily lead to greater degrees of modification. Twenty strokes against bamboo and a faceted edge was developing, whereas the same number of strokes against the haematite left a chipped edge only visible with SEM. This then prompts questioning about the extent and nature of working that meant that the archaeological specimens of *P. flexuosa* developed such a flat and clearly modified edge. The surprisingly minimal degree of modification to the shell seen in much of the experimental work suggests that the Golo specimens isolated were heavily worked indeed.

These various observations lead to a number of important conclusions. Firstly, the presence of the modified *P. flexuosa* in the Golo Cave deposits expands the repertoire of shell artefact use at the site. Secondly, the experimental work has demonstrated that unmodified *P. flexuosa* shells are a highly suitable tool for some tasks and not others. Thirdly, the surprisingly minimal amount of modification on most of the experimental specimens suggests that shell tool use may be very easy to

overlook where present. Fourthly, an understanding of the precise nature of the microstructure of the shell and the shell's reaction to different forces has been shown to be critical in pinpointing and interpreting working. It is hoped that this pilot study will form the basis of a new method of investigating and interpreting shell use and modification.

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Appendix

Appendix 1: Written taphonomic assessment sheet

Accession number:

Species:

Location and date collected:

Length (Anterior to posterior):

Width (Left to right):

Elevation:

Location of apex:

Taphonomic notes

- Chipping/Fragmentation

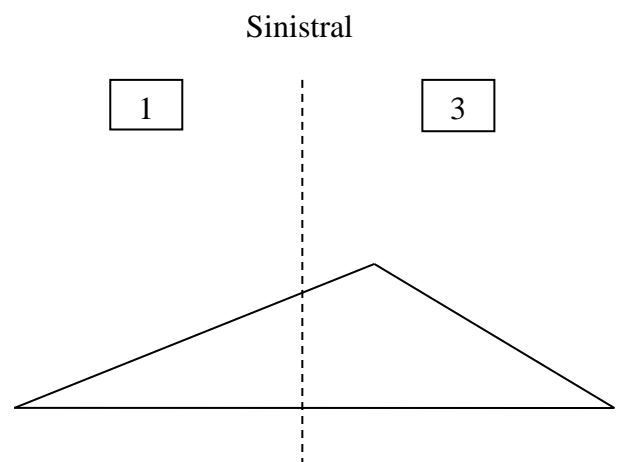
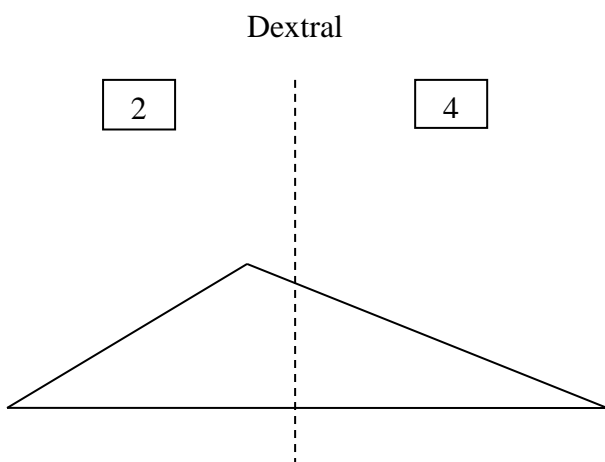
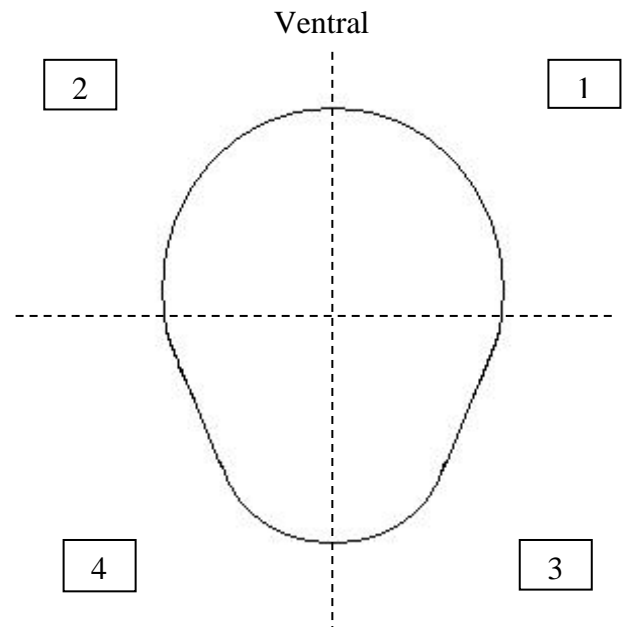
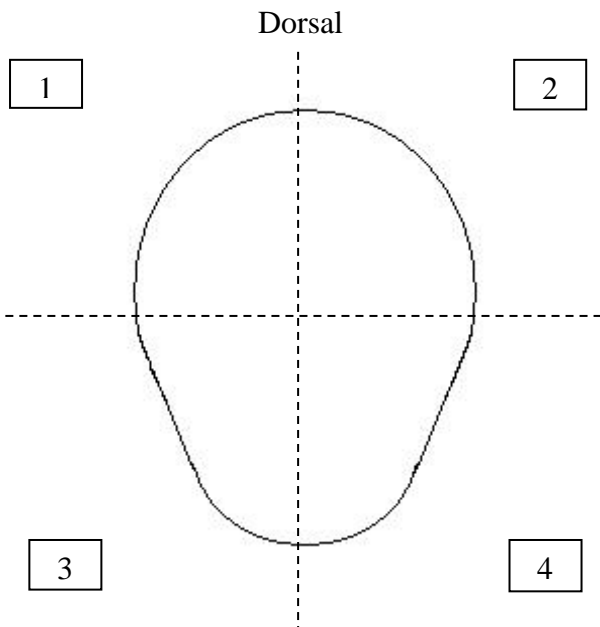
- Erosion

- Adhesions

- Other comments

Appendix 2: Diagrammatic taphonomic assessment sheet used with Appendix 1

Accession number:



Appendix 3: Example of completed written taphonomic assessment

Accession number: Cet 087
Species: Cellana tramoserica
Location and date collected: Headlands Beach 25/7

Length (Anterior to posterior): 39.2
Width (Left to right): 32.3
Elevation: 13.9
Location of apex: 15.4

Taphonomic notes

- Chipping/Fragmentation

- Erosion
 - erosion of apex thought confined to small area
 - erosion of confined areas towards anterior

- Adhesions
 - Calcareous adhesions ^{on} ventral surface

- Other comments
 - Ventral surface milky and very dull

Appendix 4: Example of completed diagrammatic taphonomic assessment attached to written assessment on previous page.

Accession number: *Cet 087*

