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Shell as a Raw Material: Mechanical Properties and Working Techniques in the Tropical Indo-West Pacific

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ABSTRACT: Considering the temporal depth and geographical breadth of shell-working within the archaeological record, the lack of literature addressing identification and analytical protocols is somewhat surprising. As a starting point, this paper investigates the microstructural and physical properties of three major taxa selected for artefact production in the tropical Indo-Pacific region. Against this baseline information, the technological choices of ancient Pacific shell-workers are assessed, leading to the conclusion that from at least the terminal Pleistocene, shell-workers altered their techniques in accordance with the various structural properties of different types of shell.

KEYWORDS: SHELL ARTEFACTS, SHELL-WORKING, MICROSTRUCTURE, SHELL FRACTURE, *Turbo*, *Trochus, Conus*

RESUMEN: Dada la amplitud temporal y dispersión geográfica que manifiesta el trabajo en conchas por lo que atañe al registro arqueológico, resulta llamativa la ausencia de trabajos que traten sobre la identificación de estos restos y sus protocolos analíticos. A modo de punto de partida, este trabajo investiga las propiedades microestructurales y físicas de tres grandes taxones seleccionados para la producción de utensilios en la región tropical indopacífica. Sobre esta base se evalúan las opciones tecnológicas de los antiguos artesanos de la concha en el Pacífico y se concluye que cuando menos desde el Pleistoceno terminal estos artesanos acoplaron su tecnología de acuerdo con las propiedades estructurales de los diferentes tipos de concha.

PALABRAS CLAVE: UTILLAJE EN CONCHA, TRABAJO EN CONCHA, MICROESTRUCTURA, FRACTURACIÓN DE LA CONCHA, *Turbo*, *Trochus*, *Conus*

INTRODUCTION

In order to understand the working of a particular raw material, there must be some understanding of the material itself. It is only within this context that technological decisions can be fairly understood, and an appreciation of culturally distinctive technological choices can be gained. While stone in particular has received a great deal of attention as a raw material, there is scant archaeological literature discussing the structural and mechanical properties of molluscan shell. Indeed, many studies of shell artefact production have explicitly taken their lead from archaeological understandings of lithic properties and technologies (e.g. Cleghorn, 1977; Smith, 1991). Unfortunately, this has often resulted in an obfuscation of our understanding of shell-working technologies and it is questionable how far conclusions such as the 'crude and uninspired' nature of shell-working (Cleghorn, 1977: 241 for mid-Holocene Philippines) represent fair judgments.

What follows is an attempt to investigate the physical properties of shell as a raw material, and assess technological decisions made by Late Pleistocene - Mid Holocene shell workers in Island Southeast Asia and the western Pacific in relation to these. Three major taxa consistently selected as raw materials are introduced together with a discussion of their microstructural properties. In addition to microstructure, standard and idiosyncratic features of shell growth and repair will also be considered, as these further influence fracture mechanics. Drawn from a study of shell-working practices evidenced at seventeen sites across Island Southeast Asia and the western Pacific (see Figure 1 and Table 1), the relationships between various shell taxa utilised as raw materials and different working techniques are investigated.

SHELLS UTILISED AS RAW MATERIALS FOR ARTIFACT PRODUCTION

The tropical Indo-Pacific is the world's most speciose molluscan biogeographic region with over 10,000 species of mollusc. Despite this diversity, however, only a small number of species are

FIGURE 1

Map showing region showing location of sites under discussion. The boundary between Near and Remote Oceania represents the limits of Pleistocene colonisation, with Remote Oceania first being colonised c. 3300 B.P.

SITE	LOCATION	CHRONOLOGICAL RANGE(S) b.p.*	ASSOCIATED SHELL-WORKING	FORMAL ARTEFACT TYPES	REFERENCES
Golo Cave	Gebe Island, Maluku, eastern Indonesia	c. 32,000 – c. 16,000	*Turbo marmoratus* shell *Turbo marmoratus* opercula *Patella flexuosa* *Nautilus pompilius*	? Scraper? Scraper? ?	Szabó 2005; Szabó *et al.* 2007; Bellwood *et al.* 1998
		c. 7,000	*Tridacna gigas* (sub-fossil) *Hippopus hippopus*	Adze Gouge	
		c. 2,500	*Cassis cornuta* (sub-fossil)	Adze/gouge	
Ille Cave	Northern Palawan, Philippines	c. 5,500 – 7,000	*Trochus niloticus*** *Turbo marmoratus*** *Hippopus hippopus***	? ? ?	Szabó 2005; Szabó *et al.* 2004
		c. 3,500 – 2,000	*Strombus canarium* *Strombus labuanus* *Melo broderipii* *Conus* spp. *Nassarius pullus* *Nassarius globosus* *Nassarius arcularius* *Pyrene scripta* *Pictocolumbella ocellata* *Cypraea annulus* *Spondylus* sp.	Disc bead Perforated spire 'Scoop' Ground/perforated spires, rings Bead Bead Bead Bead Bead Bead Bead	
		c. 2,000 – colonial era	*Tridacna* spp? *Charonia tritonis*	Ground beads and ornaments – various types Trumpet	
Kamuanan Shelter	Talikod Island, Gulf of Davao, southern Philippines	c. 4,500 – 5,500	*Trochus niloticus* *Tectus pyramis* *Turbo marmoratus* shell *Conus* spp. *Tridacna gigas* *Tridacna squamosa* *Tridacna crocea*	? ? ? ? ? ? ?	Szabó 2005; Solheim *et al.* 1979
Pamwak Rockshelter	Manus Island, Papua New Guinea	c. 12,000 – 5,000	*Trochus niloticus*** Ostreidae sp. *Nautilus pompilius* *Tridacna gigas* (sub-fossil?)	? ? ? Edge-ground adzes/gouges	Szabó 2005; Fredericksen *et al.* 1993
Kilu Cave	Buka Island, Papua New Guinea	c. 4000 – sub-recent	*Trochus niloticus* *Turbo marmoratus* shell *Terebralia palustris* *Conus* sp. *Tridacna* spp. *Nautilus* sp.	Fishhooks, rings? ? ? Ground spire ? ?	Szabó 2005; Wickler 2001; Spriggs 2001
Palandraku Cave (Aceramic unit)	Buka Island, Papua New Guinea	c. ?8000 – sub-recent	*Turbo marmoratus* shell *Oliva* cf. *carneola* *Nautilus* sp.	Fishhooks? Bead ?	
Duyong Cave	Central Palawan, Philippines	c.5,500 –2,000	*Conus* spp. *Tridacna gigas* (fossil) *Hippopus hippopus*	Ground/perforated spires Adzes Gouge	Szabó 2005; Fox 1970
Kamgot	Babase Island, New Ireland, Papua New Guinea	c. 3,300 – 2,900	*Haliotis* cf. *diversicolor* *Trochus niloticus* *Tectus pyramis* *Turbo marmoratus* shell *Cypraea annulus* *Cassis cornuta* *Conus* spp. *Spondylus* sp. Ostreidae sp. *Tridacna* spp. *Nautilus* cf. *pompilius*	? Fishhooks, rings, tattooing chisel? ? Fishhooks Beads Ornamental unit Rings, beads, adzes, curated items Perforated disc Perforated disc Adzes, rings ?	Szabó 2007; Szabó 2005; Szabó and Summerhayes 2002; Summerhayes 2000
Nenumbo	Reef Islands, southeast Solomon Islands	c. 3,000	*Terebra maculata* *Cassis cornuta* *Conus* spp. *Pinctada* sp. *Tridacna* spp.	Gouges Adze? Rings, beads, adzes, curated items ? Adzes, slingstone	Szabó 2005; Green 1979

Vao	Vao Island, northern Vanuatu	c. 2,700 – 2,500	*Trochus niloticus* *Trochus maculatus* *Tectus pyramis* *Cypraea tigris* *Conus* spp. *Tridacna* sp.	Rings ? ? Scraper/peeler Rings, beads, adzes Rings	Szabó 2005
WKO013A	Grande Terre, New Caledonia	c. 2,900 – 2,700	*Trochus niloticus* *Conus* spp. *Isognomon* sp. *Pinctada* sp.	Rings, fishhooks Rings, beads ? ?	
St Maurice-Vatcha	Isle of Pines,	c. 2,900 – 2,700	*Trochus niloticus*	Rings, fishhooks	Szabó 2005;
	New Caledonia		*Cassis cornuta* *Conus* spp. *Isognomon* sp. *Pinctada* sp. *Chama/Spondylus* sp. *Tridacna* spp. *Nautilus pompilius*	? Rings, beads ? ? Beads Rings, beads, adzes? Beads	
Naigani	Naigani Island, Fiji		*Strombus luhuanus* *Terebra maculata* *Conus* spp. *Pinctada* cf. *margaritifera* *Tridacna* spp.	? ? Rings, beads ? Beads	Szabó 2005; Best n.d.
Leta Leta Cave	Langen Island, Palawan, Philippines	c. 3,500	*Conus* spp. *Melo broderipii* *Strombus canarium* *Nassarius* spp.	Ground/perforated spires, rings 'Scoop' Beads Beads	Szabó 2005; Fox 1970
Parades Shelter	Langen Island, Palawan, Philippines	'Metal Age' ≤2000 BP	*Melo broderipii* *Conus* spp.	'Scoop' Ground/perforated spires	Szabó 2005; Fox 1970
Uattamdi	Kayoa Island, Maluku, eastern Indonesia	c. 3,200	*Trochus niloticus* *Cypraea* sp. *Cassis cornuta*? *Conus* sp. *Isognomon* sp. *Pinctada* sp. *Tridacna gigas* *Nautilus* cf. *pompilius*	Ring ? Beads Rings ? ? ? Pendant	Szabó 2005; Bellwood *et al.* 1998
Batu Puti	Central	'Metal Age' ≤2000 BP	*Trochus niloticus*	Ring	Szabó 2005; Fox
	Palawan, Philippines		*Turbo marmoratus* shell *Conus* spp.	Spoon Ground/perforated spires, rings	1970

TABLE 1

* Full data on radiocarbon dates, along with calibrations, are presented in Szabó 2005.

** No sign of working on recovered fragments, however the presence of the raw material is incongruous with the nature of the midden. In the case of Ille Cave, the midden is composed of fresh- and brackish-water species. A Pamwak Rockshelter, the midden is dominated by estuarine/mangrove species. In both cases, raw materials derive from coral reef habitats.

Island Southeast Asian and western Pacific sites from which data are drawn for this study including geographical location, chronological positioning, shells used as raw materials and formal shell artefact types. Data taken from Best(n.d.), Szabó(n.d.), Fox (1970), Vermeij (1978), Solheim *et al.* (1979), Fredericksen *et al.* (1993), Summerhayes (2000), Spriggs (2001), Wickler (2001), Szabó (2007), Szabó *et al.* (2007).

consistently selected for artefact production with only minor spatial and temporal variation (Szabó, 2005) (see Table 1). Space prohibits a discussion of all of these raw materials, so the focus here will be on three of the taxa with the widest spatio-temporal distribution: *Trochus niloticus*, *Turbo marmoratus* and *Conus* spp. (Figure 2). The various members of the Tridacnidae (giant clams) are important raw materials over an extended timespan, though the frequent selection of fossil or sub-fossil specimens for working complicates any discussion of fracture properties and their relationships to working. For further information on giant clam structure and associated working techniques, readers are referred to Moir (1990), Smith (1991) and Szabó (2005).

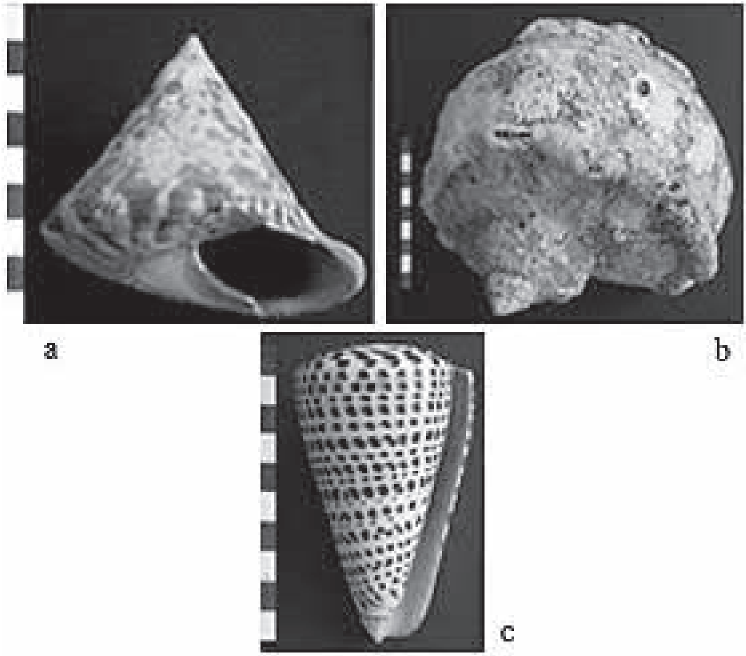

FIGURE 2

The three major species under consideration; (a) *Trochus niloticus* (Gastropoda: Trochidae); (b) *Turbo marmoratus* (Gastropoda: Turbinidae); (c) *Conus leopardus* (Gastropoda: Conidae).

MICROSTRUCTURE AND FRACTURE

Molluscan shell is composed of multiple layers, the structure and composition of which vary from taxon to taxon. The outermost layer is generally a proteinaceous coating (periostracum), however in some taxa, such as the cypraeids (cowries), this is absent (Watabe, 1988: 69). The calcareous layers below the periostracum are either calcitic or aragonitic forms of calcium carbonate ($CaCO_3$), or a combination of both, and may occur in a variety in microstructures and combinations. Different microstructures can, and frequently do, occur within the same shell.

Whether aragonite or calcite, $CaCO_3$ crystals are laid down in a variety of defined microstructural types. These types include nacreous, foliate, prismatic, cross-lamellar, spherulitic and homogeneous/granular structures (Wilbur & Saleuddin, 1983: 257). I will discuss only three in further detail, as these are the microstructural arrangements of direct relevance to the taxa under consideration. These are nacreous, prismatic and cross-lamellar microstructures.

TROCHIDAE AND TURBINIDAE

Trochid and turbinid shells have a nacreous ('mother-of-pearl') interior, and simple prismatic exterior layer. Nacreous microstructures are always constructed of aragonite, while prismatic forms can be generated from either calcite or aragonite. In the case of tropical trochids and turbinids, the prismatic layer is aragonitic (Watabe, 1988: 74). Prismatic structures have a higher organic content than either nacreous or crossed-lamellar microstructures, and this organic component is very strong, with prismatic structures being greater in tensile strength than crossed-lamellar microstructures (Currey, 1988: 191-192). The elongate prismatic crystals are aligned perpendicular to the periostracum, and this, combined with the high organic content, means that cracks generally travel directly through the prismatic layer with little lateral dissipation (Currey, 1988: 191).

In gastropod nacreous microstructures, nacre is laid down as rounded and flattened crystals distributed across the growing edge of the shell. As they are deposited, stacks form. These stacks expand both horizontally and vertically with growth, and eventually coalesce to form the solid sheets (Wilbur & Saleuddin, 1983: 260-261). Organic material is found within and between stacks (Watabe, 1988: 77).

Nacre is one of the toughest molluscan structures and has the ability to stop cracks better than prismatic forms (Currey, 1988: 186). Unlike prismatic structures, where fractures travel easily through the surface running adjacent to the elongate crystals, the overlapping sheets combined with conical stacks of differing diameters in nacreous structures make the path of the fracture much more complex. As with prismatic structures, cracks travel through the organics rather than the crystals, but the non-linearity of such organics in nacreous structures dissipate and spread the force (Figure 3a). What results is a very rough fracture at the micron level (Currey, 1988: 186). Nacre is tough when force is applied perpendicular to sheet direction, however it is certainly not tough if force is applied in the same direction as sheet orientation. In the case of the latter, the nacre will peel apart easily into aragonitic plates (Figure 3b). Separation of sheets also occurs with the loss of organics through diagenetic processes – a taphonomic headache frequently encountered by archaeomalacologists.

These features of microstructure and fracture mean that fractures are unpredictable within the Trochidae and Turbinidae on a number of levels. Firstly, the prismatic and nacreous layers respond differently to force, and secondly, fractures in the nacreous structure itself are unpredictable. This unpredictability of fracture would be accentuated when force is considerable and suddenly applied (as in direct percussion). This 'impact force' is substantially less predictable and able to be controlled than, say, compressive force (e.g. cutting/sawing, where compression is coupled with friction) where force is not as great or imparted solely at the brief moment of contact. Given that the stress that induces fracture is a function of force per area, the blunter the percussive object the less successful and predictable the fracture is likely to be. Thus, if force can be concentrated on a smaller area, either through the use of a more angular percussive instrument or secondary percussion, the risk of undesired breakage is lessened. In terms of working trochid and turbinid shell, then, greater precision and control would be achieved through cutting, sawing, grinding or indirect percussion.

CONIDAE

Cones exhibit a nearly wholly crossed-lamellar structure and are aragonitic. The structure is made up of first, second and third-order lamella. The third-order lamellae are the smallest structural unit and are tiny elongate crystals oriented in the same

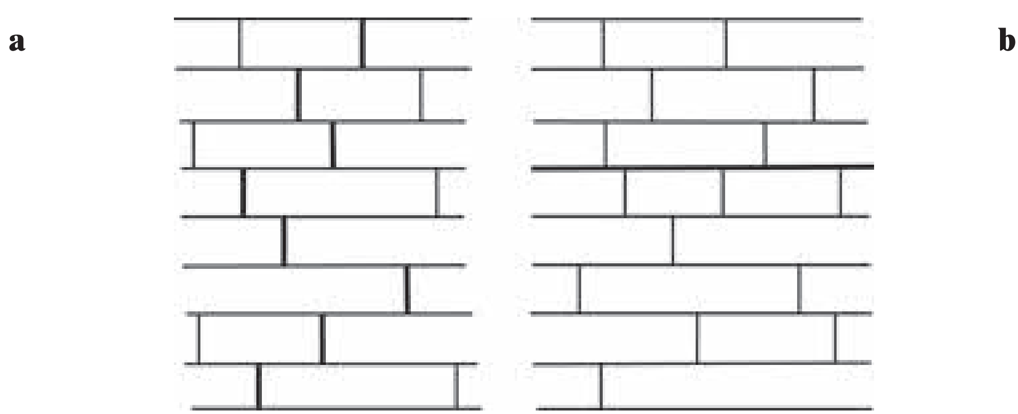

FIGURE 3

3a: Schematic diagram of the path of a fracture through nacre running from the outer to inner surface of the shell. After Currey (1988: 188). 3b: Schematic diagram of the path of a fracture through nacre running parallel to the outer and inner surfaces of the shell. After Currey (1988: 188).

direction. These are stacked to form second-order lamellae, which are in turn stacked to form first-order lamellae (Watabe, 1988: 82). What results are long rod-like structures, with the crystals lying horizontally across the long axis of the first-order lamellae (Figure 4). Between lamella, the direction changes markedly, usually by about 70° to 90° (Currey & Kohn, 1976: 1615). In *Conus*, there are three differently oriented cross-lamellar layers sandwiched together. The inner and outer layers are angled transversely to the long axis of the shell, while the inner layer is oriented in a parallel direction to the same axis (Currey & Kohn, 1976: 1616-1617). The organic content in crossed-lamellar formations is rather low compared to prismatic and nacreous microstructures, with thin membranes surrounding lower-order lamellae (Watabe, 1988: 91; Dauphin & Denis, 2000: 376).

As with nacre, crossed-lamellar structures offer no clean line of fracture through the shell. While cracks can travel with relative ease for a short distance, the direction of lamellae will suddenly change. Thus, energy has to travel along the tortuous path of alternating lamellae, or break through the stacks (Figure 5). The three differently oriented layers of crossed-lamellar formations mentioned above further complicate the nature of cracking.

The angle at which the lamellae are laid down in relation to the growing edge is important to note with regards to fracture patterns. In bivalves, the first order lamellae are oriented parallel to the shell margin in a concentric arrangement, and in gastropods they are arranged parallel to the lip (Watabe, 1988: 82). This means that compressive or tensile force at the margin of the bivalve or lip of the gastropod will result in a fracture that runs parallel to the growing edge and does not tend to journey into the body of the shell. In *Conus*, this property of breakage may be magnified by the presence of sculptural growth lines on the external surface of the shell, which also run parallel to the lip (Vermeij, 1993: 50). This type of fracture is thought to be related to predator defense. It is also worthy of note that *Conus* spp. reabsorb about 25% of the inner whorls of the shell as they grow, which serves both to provide a larger internal cavity for the animal and free $CaCO_3$ to thicken the body whorl (Vermeij, 1993: 33-34).

DIAGENETIC PROCESSES AND FRACTURE PATTERNS

With the death of the animal, the organic components of the shell begin to break down swiftly. For nacreous shell, the breakdown is particularly fast due to the higher organic content. Experimental work with the gastropod *Calliostoma ligatum* (Gastropoda: Trochidae) has shown that after only three days the shell loses about half its original strength in compression (Vermeij, 1993: 50-51). The loss of strength is less drastic for shells with a smaller organic fraction (Zuschin *et al*., 2003: 57). With regards to tropical depositional contexts, Vermeij's (1993: 51) observation that organic decay is faster in warmer temperatures has especial significance (also Zuschin *et al*., 2003: 57). In the con-

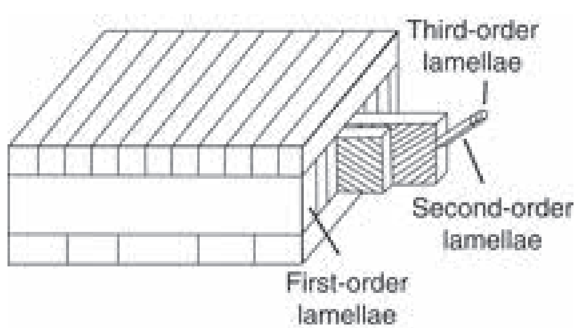

FIGURE 4

Schematic rendering of a generalised cross-lamellar microstructure showing first-, second- and third-order lamellae. Adapted from Su *et al*. (2004: fig. 1d).

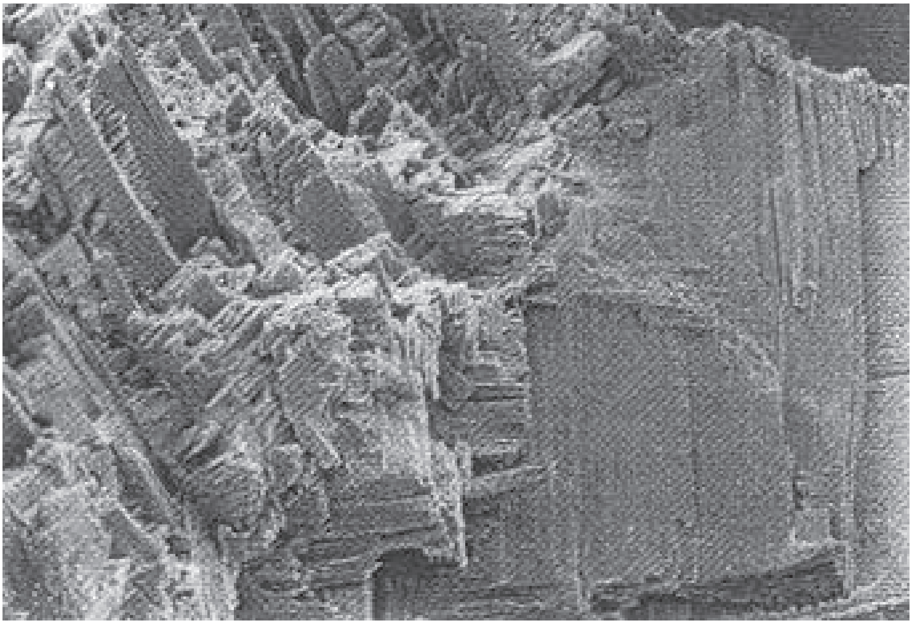

FIGURE 5
Scanning Electron Microscope micrograph of fracture in *Conus*. After Currey (1988).

text of shell as a raw material for artifact production, then, nacre will be more prone to splitting between sheets (shearing), and will not preserve as well as shells with a low organic fraction and non-organic-reliant matrix (e.g. the crossed-lamellar Conidae and Tridacnidae). If a shell shows evidence of having been collected as a raw material post-mortem, such diagenetic processes have a bearing on the working process itself.

PATTERN AND VARIATION IN SHELL-WORKING TECHNIQUES

The Trochidae

Worked *Trochus niloticus* fragments and artifacts are consistently present at low levels in palaeolithic, neolithic, and Metal Age[1] archaeological deposits. From worked pieces recovered, it is apparent that direct freehand percussion was only applied as a technique for the initial stages of reduction – effectively, to break up the shell into desired and manageable fragments (Figure 6a). The finer work of creating preforms, for fishhooks, rings and perhaps further unidentified formal artifacts, was carried out by delicately chipping back the shell with a sharp point using either an indirect percussion or pressure flaking technique (Figure 6b). Resulting preforms and manufacturing waste display a regular series of small indentations along the worked margins (Figure 6b and c). Where evidence of further manufacturing stages exist, the technique applied is invariably grinding (on a flat grindstone), with freehand manual abrasion being applied to less-accessible parts of the artifact, including the inner margins of rings and fishhooks (Figure 6b, c and d) (see also Szabó, 2007). Based on current evidence, these working techniques, and the order in which they are performed, are standard throughout the Holocene across Island Southeast Asia and Near Oceania.

The application and order of these techniques demonstrates an intimate knowledge of the nature of the raw material. As detailed above, *Trochus niloticus* shell is composed of two sandwiched microstructures (prismatic and nacreous) that have different fracture properties and thus it is difficult to shape *Trochus niloticus* through the application of direct freehand percussion alone. The tightly

[1] Island Southeast Asia, lacking a separate ‘bronze’ or ‘iron age’, has a ‘Metal Age’ visible from c. 2,200 b.p.

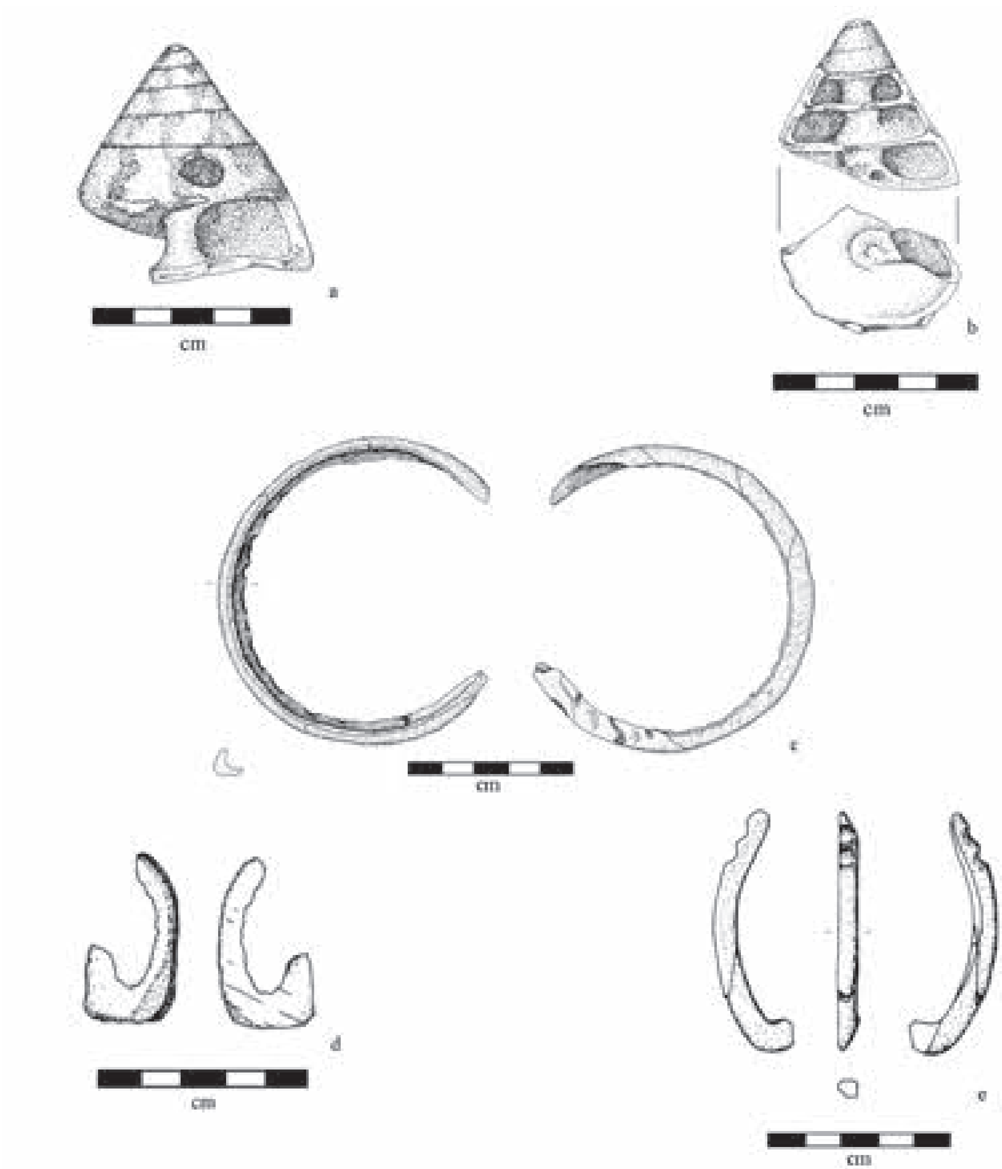

FIGURE 6

Working of trochid shells (*Trochus niloticus* and *Tectus pyramis*): 4a: *Tectus pyramis* shell reduced through the application of direct free-hand percussion. Kamgot, New Ireland province, Papua New Guinea (Test-pit 1, Unit II/III, spit 9). 4b: Trochus niloticus shell reduced through the application of direct freehand percussion. Kamgot, New Ireland province, Papua New Guinea (Test-pit 2, Unit II, spit 8). 4c: *Trochus niloticus* ring preform; the inner surface has been chipped into shape with a sharp point and the upper surface has been ground. Batu Puti, Palawan Island, Philippines (Square 4, 60 cm below surface). 4d: Broken *Trochus niloticus* fishhook preform; note grinding on the faces and chipping around the inner margins. Kamgot, New Ireland province, Papua New Guinea (Test-pit 2, Unit II, spit 4). 4e: Fully ground and abraded broken *Trochus niloticus* fishhook. Site 13A, Grande Terre, New Caledonia (Zone II, G3: 32 cm).

focused application of force, in the form of chipping with a sharp point, allowed *Trochus*-workers to effectively reduce the raw material with less risk of undesired fracture. Cutting or sawing would have allowed similar – if not greater – levels of control, however evidence for the application of this technique is currently lacking[2]. It is not, however, lacking from the sequence of techniques applied to *Turbo marmoratus* (see below).

It is notable that there is no evidence for the use of *Trochus niloticus* specimens collected post-mortem. In light of the high organic content of both prismatic and nacreous structures, it is possible that this is an intentional choice to avoid unpredictable fracture and workability associated with a loss of shell structural integrity.

The Turbinidae

Working of the shell of *Turbo marmoratus* has a long history in the Island Southeast Asian and Near Oceanic regions (see Table 1), with little spatio-temporal variation in the selection and ordering of reduction techniques. Direct percussion was only used in the initial stages of reduction; firstly to remove the thickened, irregular keel at the shoulder of the body whorl, and then to detach large sections of body whorl (Figure 7a-c). A combination of cutting and/or sawing, and chipping with a sharp point was used to generate blanks and preforms (Figure 7d-e). Where curved outlines were desired, the edge of the cutting implement was positioned perpendicular to the shell surface, while straight edges were achieved through sawing with the cutting edge parallel. Where formal artifact types in *Turbo marmoratus* have been identified, they are invariably one-piece fishhooks. Finishing of the artifact was achieved through manual freehand abrasion. As with *Trochus niloticus*, there is currently no evidence for the use of *Turbo marmoratus* shell collected post-mortem.

The Conidae

The working of *Conus* spp. shells is strongly associated with the mid-late Holocene. Worked shell assemblages associated with the Lapita cultural complex of the western Pacific are invariably dominated by *Conus*-working, and conids assume a far greater importance as a raw material with the materialization of the neolithic of Island Southeast Asia. The majority of associated formal artifacts utilizes the sturdy spire and/or shoulder sections of the shell, and includes rings in varying diameters and widths, beads, and ground and perforated spires.

Reduction sequences for all ring and spire artifacts involve the initial removal of most, or all, of the body whorl of the shell. This was achieved through the application of one of two techniques: direct percussion or sawing. When direct percussion was used, the first blow was directed at the centre of the body close to the lip. Given the tendency of *Conus* shells to split parallel to the lip as part of their predator defense mechanisms (see above), this first blow frequently results in a long sliver of shell with one long edge being the sharpened lip surface (Figure 8a). These fragments are frequently referred to as 'knives' in post-excavation sorts. Successive blows to the body were then applied concentrically around the shell surface until the anterior portion of the shell came away (Figure 8b). Only the body whorl required such treatment, as this whorl is considerably thicker than the internal architecture, which fractures easily (see above). The cross-lamellar microstructure means that, while fracture surfaces may be rough, fractures do not travel for any considerable distance into the shell. What seems to influence fracture more is the growth lines which run down the shell in an anterior-posterior direction.

The 'broad' *Conus* bracelets frequently recovered from deposits associated with the Lapita cultural complex (Figure 8c), generally utilize 2-5 cm of the posterior body whorl in their construction. The risk of longitudinal splitting of the body whorl associated with direct percussion appears to have prompted a labor-intensive solution in their manufacture. Manufacturing waste from a series of Lapita sites indicates that the anterior and posterior of the shell were separated by means of sawing, concentrically, around the body whorl (Figure 8d). The application of compressive force and abrasion, rather than impact force, made fracture considerably more predictable. It is likely that this greater investment of time accorded to broad *Conus* rings had a direct link to value, with these artifacts being the only ornaments in the Lapita shell artifact repertoire that were consistently –and often repeatedly – curated (Szabó & Summerhayes, 2002; Szabó, 2005) (Figure 8c). The final stages of shaping and finishing, for all artifacts, include a mixture of grinding, chipping with a sharp point, and freehand abrasion (Figure 8e-f).

[2] Smith (1991, 2001) has claimed cutting as part of the reduction sequence for *Trochus niloticus* fishhook manufacture, however this interpretation has not been reduplicated by recent work (Szabó, 2005) that interpreted these relatively smooth edges as fracture along natural growth lines.

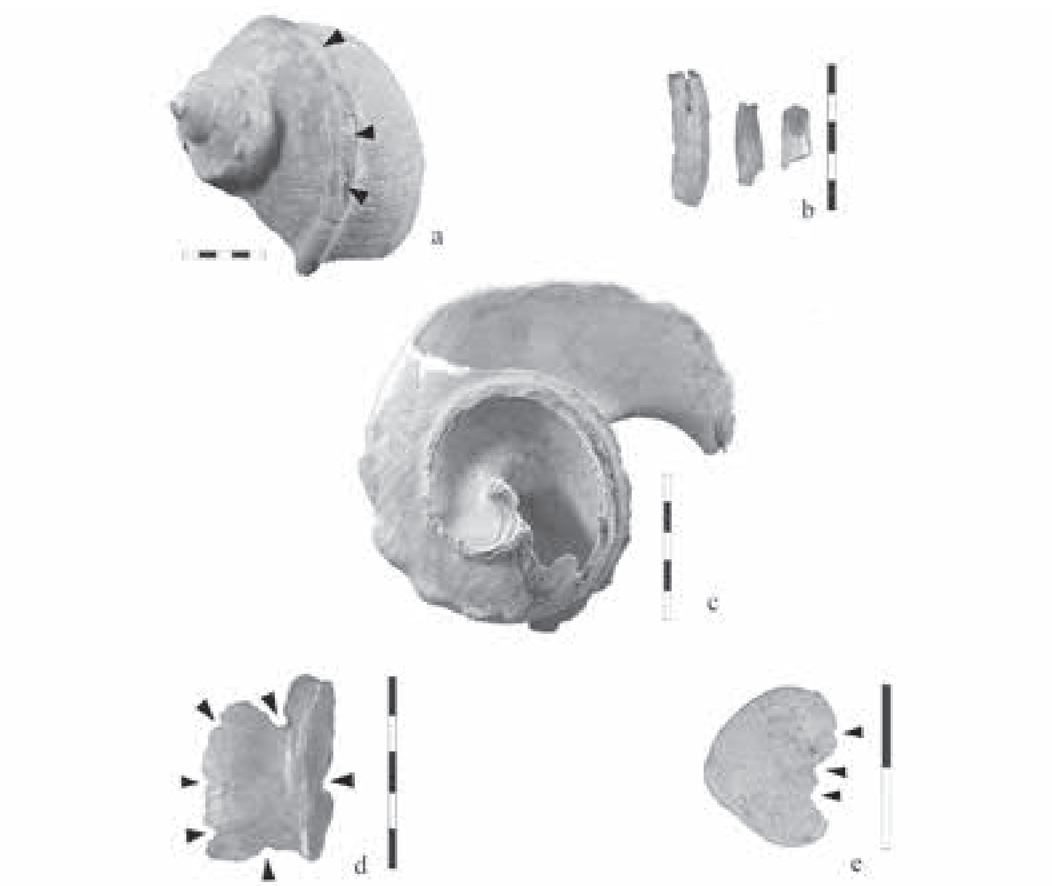

FIGURE 7

Working of *Turbo marmoratus*: 5a: Whole *Turbo marmoratus* shell with raised keel at shoulder knocked away by direct percussion. Golo Cave, Gebe Island, eastern Indonesia (LM6: 210-220 cm). 5b: Detached segments of the shoulder keel of *Turbo marmoratus*. Kilu Cave, Buka Island, Papua New Guinea (Test-pit 2, Layer I:2). 5c: Reduced *Turbo marmoratus* shell; reduced through direct percussion and chipping with a sharp point. Golo Cave, Gebe Island, eastern Indonesia (LM6:195-200 cm). 5d: Chipped nacreous layer of the shoulder section of a *Turbo marmoratus* body; ventral view. Kilu Cave, Buka Island, Papua New Guinea (Test-pit 2, Layer I:17). 5e: Cut and chipped *Turbo marmoratus* body piece; possible rotating fishhook preform; dorsal view. Palandraku Cave, Buka Island, Papua New Guinea (Test-pit 1, Layer V/VI:13).

In contrast to *Turbo marmoratus* and *Trochus niloticus*, there is consistent evidence for the selection of post-mortem specimens as raw materials, as indicated by taphonomic signatures such as beach-rolling and the action of marine bio-eroders and epibionts (Figure 8g). The relatively low organic content of cross-lamellar structures means that the use of post-mortem shell offers no great disadvantage in itself. If, however, the shell has been structurally damaged by organisms such as sponges which bore into the shell, structural integrity will be compromised in idiosyncratic ways.

CONCLUSION

The preceding examples of artifact manufacture in *Trochus niloticus*, *Turbo marmoratus* and *Conus* spp. all demonstrate that technological choices are attuned to the specific structural and physical properties of each taxon. This is not to say, however, that raw materials are in any way prescribing the way in which they are to be worked. While different raw materials are more or less suited to particular working techniques, there are always a number of ways to achieve a desired

FIGURE 8

Working of *Conus* spp.: 6a: Lip of *Conus litteratus* or *Conus leopardus* detached through direct percussion. Kamgot, New Ireland province, Papua New Guinea (Test-pit 2, Unit II, spit 4). 6b: Body whorl of a *Conus litteratus* detached through direct percussion. Naigani, Fiji (3ext, level A4). 6c: Broken and curated *Conus* sp. broad ring fragment. St Maurice-Vatcha, New Caledonia (surface). 6d: Body whorl of a *Conus* sp. shell detached through sawing. Nenumbo, south-east Solomon Islands (YZ-23, base of Grey layer 2). 6e: *Conus litteratus* or *Conus leopardus* ring preform; note zone of repaired predator damage on exterior. Naigani, Fiji (9, level B3). 6f: Ground and abraded *Conus* sp. small ring. Naigani, Fiji (4, Level A3 feature 4).6g: Water-rolled, ground and perforated *Conus* sp. spire. Leta Leta, Palawan Island, Philippines (no provenance details).

end. In this respect, it is noteworthy that cutting and sawing are techniques frequently applied to *Turbo marmoratus* but not *Trochus niloticus*, despite the structural parallels. An understanding of the properties of raw materials is clearly important, but technological choices are not reducible to these variables alone.

If technological practices and choices are understood as having strong cultural elements, then the mapping of technological choices assumes a cultural – and culture-historical – significance (Dobres, 2000; Szabó, 2005). While this is not the venue for an in-depth assessment of the relevance of the above conclusions for issues in Asia-Pacific culture history, it is worthy of note that the selection of, and technological approaches to, raw materials discussed in this paper [together with others discussed within Szabó (2005)] shows great spatio-temporal constancy over the Island Southeast Asian and Pacific regions. This lends little support to neolithic population replacement theories (e.g. Bellwood, 1997). However, neither does it entirely support arguments for an indigenous genesis for the Near Oceanic neolithic (e.g. Smith & Allen, 1999), as links in shell-working practices between the western Pacific Islands and Island Southeast Asia are consistently present throughout, at least, the Holocene. Formal shell artefact types and methods of manufacture speak more of regional continuity and a shared history across the Island Southeast Asia/Melanesia boundary. What is clear, however, is that in order to effectively understand the form and production techniques of shell artefacts, the limitations and possibilities inherent in the raw materials must be considered.

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