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Aztec conch shell working: high-tech design

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Summary The nine Mexican turquoise mosaics in the British Museum have undergone intensive investigation to study the many natural materials selected for their manufacture. This paper describes the more detailed scientific study of one of these materials – conch shell. Using optical and scanning electron microscopy, it evaluates to what extent both the microstructural and decorative properties of conch shells were well understood by Aztec and Mixtec specialist craftsmen in central Mexico prior to the Spanish conquest in 1519. Sixteenth-century codices have shown the important role played by the form and colour of conches in Aztec cosmology, but this study reveals that these factors were not the only ones crucial to the selection of conch shell for use on the turquoise mosaics. The remarkable strength and toughness exhibited by the characteristic brick-and-mortar-like micro-architecture of conch shell enabled the mosaic craftsmen to fashion durable, three-dimensional components. In this context conch significantly outperforms the other species of shell present, whose use is restricted to small, flat, decorative tesserae (tiles). An interesting slant to this case study has been provided by materials technology scientists who have been publishing details of the remarkable potential of the conch shell structure for load-bearing applications in industry.

INTRODUCTION

For over a decade the nine Mexican turquoise mosaics in the British Museum have been the subject of intensive scientific investigation. This work characterized the variety of natural materials used in their manufacture and resulted in the publication of a popular book on the history, materials and techniques of the mosaics [1]. However, lack of space meant that much of the detailed research could not be included in this book; this contribution describes one such detailed scientific study. Using optical and scanning electron microscopy it evaluates to what extent both the microstructural and decorative properties of conch shells were well understood by Aztec and Mixtec peoples in central Mexico prior to the Spanish conquest in 1519. An interesting slant on this case study has been provided by recent publications from materials technology scientists, who have been highlighting the remarkable strength and toughness exhibited by the micro-architecture of the conch shell and its potential for load-bearing applications in industry.

METHODOLOGY

Optical microscopy, using a Leica stereo microscope, was carried out for the primary stage of examination of the

nine turquoise mosaics in the British Museum collections. These comprise two masks (Am, St.400 and Am1987, Q.3), a double-headed serpent (Am 1894,-.634), a knife with flint blade (Am, St.399), a helmet (Am, +.6382), a human skull (Am, St.401), a jaguar (Am, +.165), a shield (Am, St.397.a) and an animal head (Am, St.400.a). This phase identified the raw materials used, which include wood, resin, turquoise, shell, malachite, lignite, pyrite, agave fibre bindings, leather and gold (and later additions such as pearls, glass and gemstones). While turquoise is clearly the predominant material, the use of shell is extremely significant. It is through these shell elements that a greater understanding is reached of the relative importance of three criteria in the Aztec understanding of technological mastery: these criteria are material properties, decorative qualities and symbolic significance within the Aztec cosmology.

To increase our understanding of Aztec shell technology, scanning electron microscopy was carried out. A JEOL 840 scanning electron microscope (SEM) operating under high vacuum conditions was used on prepared (gold-coated) samples of conch shell, to examine the microstructure and also the outer and inner surfaces of the body whorl. This was also used to examine gold-coated samples of *Spondylus* (spiny oyster) shell. A Zeiss EVO variable pressure SEM was used to examine the microstructure of uncoated specimens of *Pinctada* – mother of pearl.

RESULTS AND DISCUSSION

Optical microscopy

The combination of significant colours, raw material and iconography of the turquoise mosaics was intrinsic to their high status and the purposes for which they were made [1]. Optical microscopy revealed a number of interesting observations. Three main species of shell were identified: spiny oyster (*Spondylus princeps*), mother of pearl oyster (*Pinctada mazatlanica*) and conch (*Strombus gigas*). Although the colours of these three shell species played a highly significant part in the decorative designs of the mosaics (Figures 1 and 2), coloured shell was not selected indiscriminately, irrespective of species, simply for its hue. For example, although many red, pink and orange coloured shells, such as *Strombus pugilis* (fighting conch), were available to Aztec shell craftsmen, *Spondylus princeps* and other *Spondylus* species were preferentially selected on account of their symbolic, ritual and cultural importance. This association between *Spondylus*, blood and fertility extended far beyond the confines of the Aztec Empire [2]. Part of the value of *Spondylus* may be attributed to the difficulty of procuring them from the ocean; divers frequently had to recover them from depths of between 25 and 60 metres. This traditional predilection for *Spondylus* also introduced some technological drawbacks. As the common name suggests, these bivalves are covered with spines that have to be removed. The radial bands of each valve have to be ground smooth and polished before tesserae (small tiles) can be cut and shaped for incorporation into the mosaic design. If, for example, the vivid red, pink and orange *Strombus pugilis* had been selected, no spine removal would be needed and the already extremely shiny and flat coloured inner surface would have required cutting and shaping but no grinding and polishing. Furthermore, as described below, the microstructure of *Strombus* outperforms that of *Spondylus* in terms of toughness and strength. In a theoretical scoring system, therefore, *Spondylus* was selected primarily for its symbolic importance, then for its colours and lastly for its working properties.

An even more pronounced example of this process of raw material evaluation is provided by the use of the mother of pearl oyster (*Pinctada mazatlanica*). This bivalve species was also obtained by diving. The use of the silvery, iridescent shell of *Pinctada* on the turquoise mosaics is largely a combination of decorative effect and symbolism. Where used as eye inserts, for example on the mask of Xiuhtecuhtli (Figure 3), its nacreous (pearly) quality is intended to suggest reflective optical properties, giving this mask an arresting presence. On the jaguar figure, *Pinctada* is used freely to simulate the silvery sheen of the animal's pelt, reinforcing the fearful role of the jaguar in Aztec cosmology. However, the structure of *Pinctada* is even less stable than that of *Spondylus* – see below and Figure 4. The fragile *Pinctada* valves needed careful cutting and shaping with sharp-edged obsidian or flint blades to avoid fracturing and delamina-

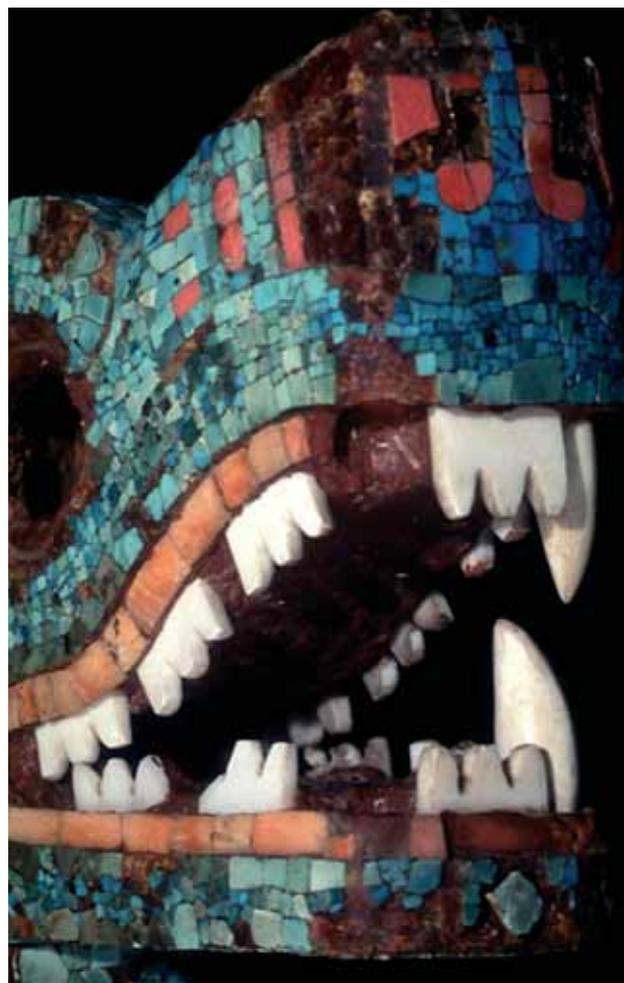


FIGURE 1. Open mouth, right head of the double-headed serpent (Am 1894,-634) showing the three-dimensionally carved white conch (*Strombus*) shell teeth and fangs set into resin mixed with red pigment



FIGURE 2. Back of a knife (Am, St.399) showing the eagle warrior's costume where geometric inserts of white conch are dramatically set against the green malachite and red spiny oyster (*Spondylus*) shell and incised white conch semicircles containing coloured resin

tion. Its theoretical score sheet highlights the decorative and symbolic qualities offered by its silvery iridescence, but its working properties are problematic. On the jaguar figure, incised *Pinctada* tesserae display damage and fracture and, overall, there has been a high loss of tesserae from this figure.



FIGURE 3. Mask of Xiuhtecuhtli (Am, St.400) with mother of pearl (*Pinctada*) shell eye inserts and white conch shell teeth

Hitherto it has been clear that the selection of *Spondylus* and *Pinctada* by Aztec specialist craftsmen has been less influenced by their working properties as raw materials than by their symbolic value and by their colour or iridescence. However, even at the primary stage of optical microscopic examination, it was apparent that the white conch (*Strombus gigas*) on the turquoise mosaics had to fulfil additional requirements. Figures 1 and 2 display the effective use of the whiteness of the conch juxtaposed against the varied blue and turquoise tesserae, the green of the malachite and the vivid red, pink and orange colours of the *Spondylus*. But there were a considerable number of useful bivalve and gastropod shells with white colours and smooth surfaces that Aztec or Mixtec craftsmen could have selected. Why was none of these chosen? Part of the answer lies in the great status and ritual significance of the conch in ancient Mesoamerican cultures, where it is routinely depicted in association with important people and events of the watery underworld. Such a symbolically charged mollusc would therefore be a natural choice of raw material for the prestigious turquoise mosaics.

The second part of the answer lies in the fact that throughout Mesoamerican and Caribbean prehistory, conch provided the raw material for heavy-duty functional tools such as axes and adzes [3], and was also fashioned into intricate jewellery and figurines. All these items needed to be carefully carved and most importantly, be hard-wearing and durable. Such properties were needed for key elements of the turquoise mosaics, such as the double-headed serpent, Figure 1. Here, far more was required than just the manu-

facture of small flat white shell tesserae, as the three-dimensional carving of the serpent teeth and fangs necessitated a strong and tough raw material for which conch was the perfect choice.

There are missing teeth on the double-headed serpent, but this is far less likely to be attributable to fracturing of the conch shell than to a failure of the resin to hold them in place, particularly as mixing hematite pigment with the resin to give the red of the serpents' mouths impacted on the latter's adhesive properties [4]. Likewise on the mask of Xiuhtecuhtli (Am, St.400), Figure 3, and on the serpent mask (Am1987, Q.3) where white conch shell was used for the original teeth, there are losses where the resin plus pigment bond has not held, but there is no damage to the extant conch teeth. The toughness of conch allowed the craftsmen to fashion discs with a central hole, which were used as firm surrounds for sockets containing pyrite eyes, as in the human skull mosaic and animal head. On the latter, a conch shell ring hook was carved as a suspension loop inserted into the top of the head. White conch shell forms the circular surround to a polished fragment of dark green, nodular malachite on the helmet. Figure 2 displays more than just the dramatic use of the brilliant white geometric conch shell inserts juxtaposed against the green malachite and red *Spondylus* tesserae on the back of the knife, it reveals the careful incising of semicircles into the conch shell tesserae for infilling with decorative coloured resin. These particular conch tesserae are themselves carefully carved into a subrounded semicircular shape. The point need not be belaboured that any raw material selected needs to be very stable to allow for such careful shaping and incising on such a small scale and conch satisfies these demands. It is noteworthy that the knife's mosaic haft reveals the use of more than just white conch shell. For the miniature details on the eagle warrior's face, the use of reddish *Spondylus* for the lips and eyes has been rejected in favour of the stronger conch shell, an orange-red variety in this instance. This may have been on account of the less reliable nature of *Spondylus* as a durable material for tiny pieces. There is some loss to the mosaic decoration on the eagle warrior's hands, which hold the end of the flint blade, but sufficient survives to show the careful use of pink and orange conch shell to mark out nails at each finger end. There is also striking use of large rectangular pink segments from queen conch (*Strombus gigas*) shell on the underbelly of the haft.

SCANNING ELECTRON MICROSCOPY

The Zeiss EVO variable pressure SEM was used to examine the microstructure of uncoated specimens of *Pinctada mazatlanica* mother of pearl shell. Figure 4 shows its characteristic laminated structure. Although it provides a lustrous, silvery iridescent nacreous surface that is attractive for decorative effects, this shell has little mechanical strength or toughness. The SEM image shows how the prep-



FIGURE 4. Scanning electron microscope (SEM) image of the laminated, friable microstructure of *Pinctada* mother of pearl oyster shell

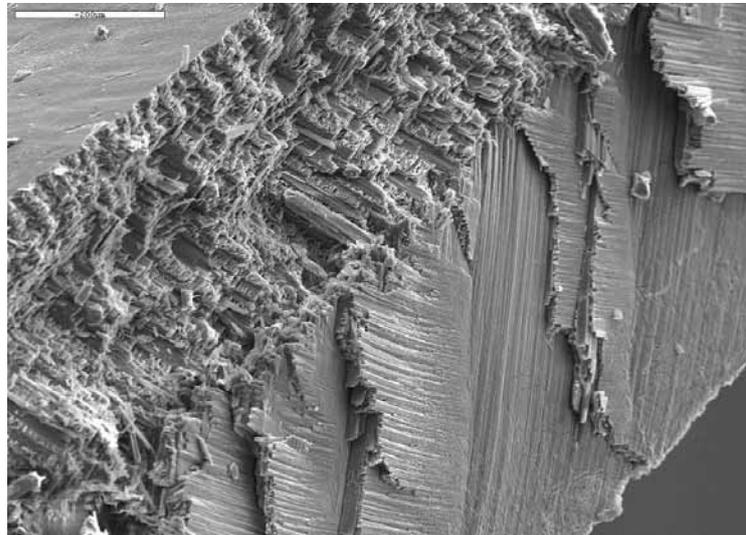


FIGURE 5. SEM image of the characteristic structure of *Strombus* conch shell

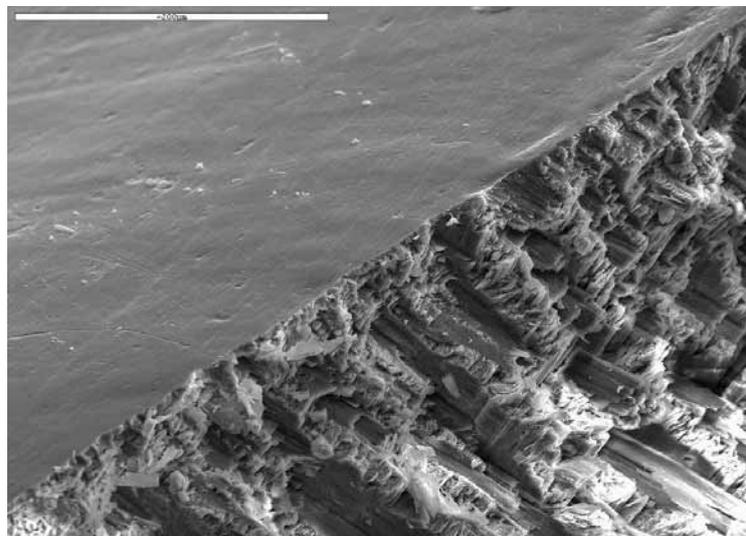


FIGURE 6. SEM image featuring the smooth inner surface of *Strombus* conch shell (showing at the top of the image)

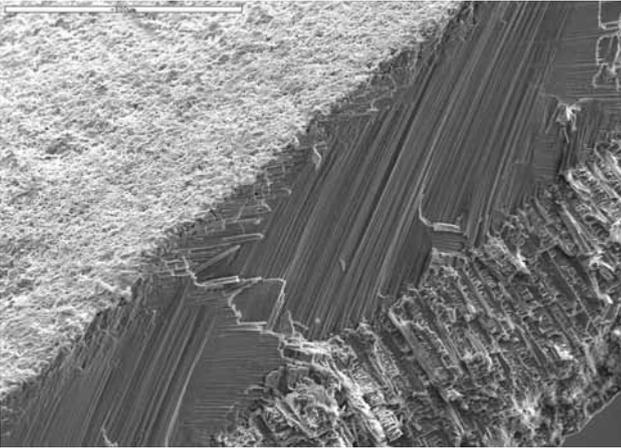


FIGURE 7. SEM image featuring the rough outer surface of *Strombus* conch shell (showing at the top of the image)

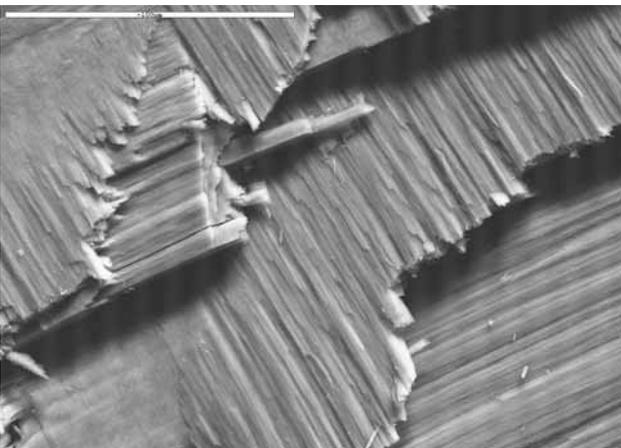


FIGURE 8. SEM image of the crossed-lamellar structure of *Strombus* conch shell

ation of one small sample for microscopy resulted in a series of stress fractures that fragmented the platy structure of the shell.

The JEOL 840 high vacuum SEM was used on gold-coated samples of conch shell to examine the microstructure (Figure 5) and also the outer and inner surfaces of the body whorl. Figure 6 shows the smooth flat inner surface of the conch shell that is in direct contact with the living body of the mollusc. Its relatively few imperfections render it ideal for use as mosaic tesserae; all that would be required is cutting, shaping and affixing to a substrate such as wood or bone. This inner surface contrasts markedly with the rough outer surface, Figure 7.

Materials scientists have recognized that conch shells owe their extraordinary mechanical properties to a hierarchically organized structure, Figure 5. This can be observed at a nanostructural level with single crystals of CaCO_3 of 4–5 nm, at a microstructural level with ‘bricks’ of 0.5–10 μm and, ultimately, with layers of 0.2 mm in the mesostructure [5].

The SEM examination revealed that conch shell has crossed-lamellar structure (Figure 8) and that the angle between two second-order lamellae is 70–90 degrees [6], thus forming a natural high-strength composite mate-

rial. Studies of modern conch (*Strombus gigas*) shell have recorded that this material is 10 to 30 times stronger, and as much as 1000 times tougher, than its principal constituent aragonite (CaCO_3), because it has a brick-and-mortar-like micro-architecture. The proteins surrounding the aragonite crystals that make up 99% of conch shell change the toughness by permitting fractures to be absorbed without shattering the material [7]. Crack deflection, delocalization of damage and viscoplastic deformation of these organic areas are the most important mechanisms contributing to the unique mechanical properties of conch shells [5]. The high fracture resistance is correlated to the extensive micro-cracking that occurs along the numerous interfaces within the shell microstructure [8, 9]. *Strombus gigas* also has a remarkable capacity to regenerate tissue after the shell is damaged [10].

CONCLUSIONS

Strombus and *Spondylus* shells enjoyed elevated status within the Aztec cosmology and the iridescence of *Pinctada* shell mirrored reflective optical properties when used on objects. All three were selected by Aztec and Mixtec specialist artisans for incorporation into the Mexican turquoise mosaics on account of their ritual significance and decorative allure. However, only *Strombus* can claim to have been selected as much for its extraordinary working properties as for its gleaming whiteness and symbolic resonance. Scanning electron microscopy has revealed the highly ordered structure of conch shell that comprises calcium carbonate and a series of organic binders that underpin its toughness. The use of conch shell on the turquoise mosaics for purposes in which tensile strength and fracture toughness are important indicates that the Aztec and Mixtec craftsmen had an empirical understanding of conch shell’s outstanding mechanical properties.

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REFERENCES

1. McEwan, C., Middleton, A., Cartwright, C. and Stacey, R., *Turquoise mosaics from Mexico*, British Museum Press, London (2006).
2. Paulsen, A.C., ‘The thorny oyster and the voice of god: *Spondylus* and *Strombus* in Andean prehistory’, *American Antiquity* **39** (1974) 597–607.
3. Cartwright, C.R. ‘Shell and stone tools’ in ‘Archaeological survey of Barbados: second interim report’, P.L. Drewett, *Journal of the Barbados Museum and Historical Society* **38** (1988) 196–204.
4. Stacey, R.J., Cartwright, C.R. and McEwan, C. ‘Chemical charac-

- terization of ancient Mesoamerican “copal” resins: preliminary results, *Archaeometry* **48**(2) (2006) 323–340.
5. Menig, R., Meyers, M.H., Meyers, M.A. and Vecchio, K.S., ‘Quasi-static and dynamic mechanical response of *Strombus gigas* (conch) shells’, *Materials Science and Engineering A* **297** (2001) 203–211.
 6. Hou, D.F., Zhou, G.S. and Zheng, M., ‘Conch shell structure and its effect on mechanical behaviors’, *Biomaterials* **25** (2004) 751–756.
 7. Kamat, S., Su, X., Ballarini, R. and Heuer, A.H., ‘Structural basis for the fracture toughness of the shell of the conch *Strombus gigas*’, *Nature* **405**(6790) (2000) 1036–1040.
 8. Kuhn-Spearing, L.T., Kessler, H., Chateaul, E., Ballarini, R., Heuer, A.H. and Spearing, S.M., ‘Fracture mechanisms of the *Strombus gigas* conch shell: implications for the design of brittle laminates’, *Journal of Materials Science* **31** (1996) 6583–6594.
 9. Kamat, S., Kessler, H., Ballarini, R., Nassirou, M. and Heuer, A.H., ‘Fracture mechanisms of the *Strombus gigas* conch: II-micro-mechanics analysis of multiple cracking and large-scale crack bridging’, *Acta Materialia* **52** (2004) 2395–2406.
 10. Su, X., Zhang, D. and Heuer, A.H., ‘Tissue regeneration in the shell of the giant queen conch, *Strombus gigas*’, *Chemistry of Materials* **16** (2004) 581–593.