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Biomineral repair of abalone shell apertures

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ABSTRACT

The shell of the gastropod mollusc, abalone, is comprised of nacre with an outer prismatic layer that is composed of either calcite or aragonite or both, depending on the species. A striking characteristic of the abalone shell is the row of apertures along the dorsal margin. As the organism and shell grow, new apertures are formed and the preceding ones are filled in. Detailed investigations, using electron backscatter diffraction, of the infill in three species of abalone: *Haliotis asinina*, *Haliotis gigantea* and *Haliotis rufescens* reveals that, like the shell, the infill is composed mainly of nacre with an outer prismatic layer. The infill prismatic layer has identical mineralogy as the original shell prismatic layer. In *H. asinina* and *H. gigantea*, the prismatic layer of the shell and infill are made of aragonite while in *H. rufescens* both are composed of calcite. Abalone builds the infill material with the same high level of biological control, replicating the structure, mineralogy and crystallographic orientation as for the shell. The infill of abalone apertures presents us with insight into what is, effectively, shell repair.

1. Introduction

As a model organism for biomineral research, the gastropod mollusc, abalone, has provided insights into many aspects of biomineralisation including gene expression (Degnan and Morse, 1995; Jackson et al., 2006, 2010) and the role of specific organic components in shell formation (Bedouet et al., 2012; Falini et al., 2011; Jolly et al., 2004; Le Roy et al., 2012; Mann et al., 2000, 2007; Marie et al., 2010; Shen et al., 1997; Weiss et al., 2000, 2001). Since nacre is the major component of the abalone shell, the attractive material properties of nacre, being light yet strong and crack-resistant (Jackson et al., 1988, 1989, 1990), accounts for the use of abalone shells as model systems for the study of the material properties of nacre e.g. (Chen et al., 2012; Espinosa et al., 2011; Lin and Meyers, 2009; Meyers et al., 2008). While nacre accounts for most of the abalone shell, the outermost layer is prismatic and the structure and crystallography of these two layers has also been investigated (Auzoux-Bordenave et al., 2010; Coppersmith et al., 2009; DiMasi and Sarikaya, 2004; Gilbert et al., 2008; Gries et al., 2009; Metzler et al., 2008).

A striking feature of abalone shell: the row of apertures along the dorsal margin (Fig. 1) provides us with another potential insight into the diversity of biomineralisation. As the growing shell is formed new apertures are fabricated in a regular manner along the longitudinal growth margin while the preceding apertures are simultaneously filled in. This is a very interesting biomineralisation scenario since, not only is it creating a perfect hole during shell fabrication (to expel waste material) and for chemotaxis, but also manages a biomineral infill program, or, repair mechanism. The obvious question arises: is the formation of the infill as well controlled as the original shell formation (biologically controlled) or simply a rough plugging (inorganically) of a gap? This study examines the nacre and prismatic layer of the shell and infill of three species of abalone in terms of mineralogy and crystallographic orientation in order to learn more about the aperture infill and to determine the extent to which it mimics the original and surrounding shell.

2. Materials and methods

2.1. Abalone specimens

Three species of abalone were considered: *Haliotis asinina*, *Haliotis gigantea* and *Haliotis rufescens*. Three adult specimens of each species were included in this study. Shells of *H. asinina* Linnaeus, 1758 from Australia (41°–10.5° S, 113°–153.5° E) were kindly provided by Professor Jackson and Professor Degnan. *H. gigantea* Gmelin, 1791 from Japan (31°–46° N, 130°–145.5° E) were kindly provided by Professor Endo (University of Tokyo). *H. rufescens* Swainson, 1822 from North America (25°–49° N, 125°–73° W) were kindly donated by Professor Taylor and Dr. Claverie (University of California). Examples of the shells of these three species are presented in Fig. 1.

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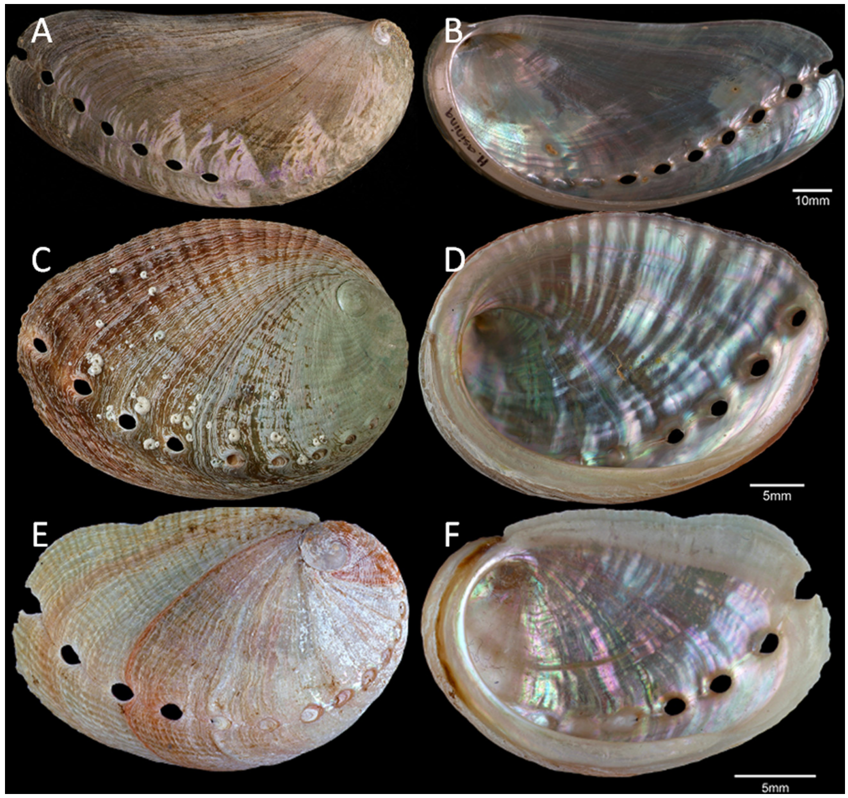

Fig.1. Shells of three species of abalone: *H. asinina*, *H. gigantea* and *H. rufescens*. Exterior (A, C, and E) and interior (B, D, and F) of shells of *H. asinina*, *H. gigantea* and *H. rufescens*, respectively. Scale bars = 10, 5 and 5 mm, respectively.

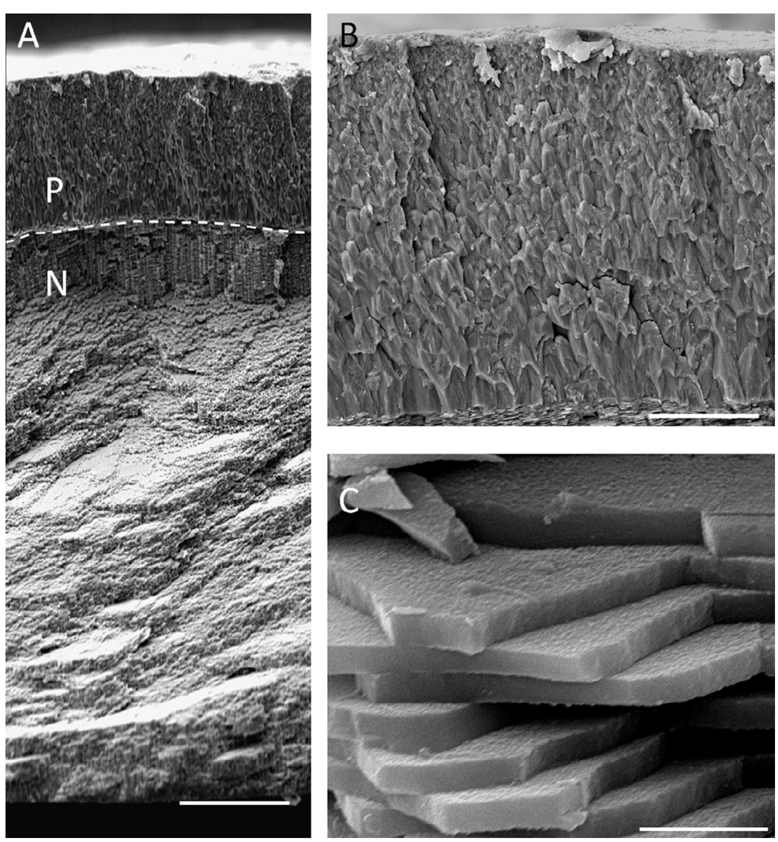

Fig.2. Prisms and nacre of *H. asinina* shell. Secondary electron images of fractured shell section of *H. asinina* revealing, (A) outer prismatic (P) layer and inner nacreous (N) layer with interface between the two layers indicated by dashed white line. Higher magnification images of, (B) prismatic layer and, (C) nacreous layer. Scale bars = 200 μm, 50 μm and 2 μm, respectively.