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TEXTURE ANALYSIS OF A GASTROPOD SHELL: CYPRAEA TESTUDINARIA

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ABSTRACT

Texture analysis of the four layers constituting the shell of the gastropod Cypraea testudinaria documents its very strong preferential orientation, and changes in strength and pattern. Two major components of the c-axis of the aragonite are observed at oblique angles, associated with {110} twin components in some layers.

Keywords: Aragonite, Shells, Texture, Cypraea testudinaria, Gastropoda, Mollusca, Biomineralization

INTRODUCTION

Gastropod shells are complex intergrowths of calcium carbonate and organic material, aggregates of proteins and glycoproteins. The nature of this organic material determines whether the calcium carbonate is deposited as trigonal calcite or orthorhombic aragonite, as well as the morphology of the structural elements [1,2], and the epitaxial relationship between the organic material and the crystals of calcium carbonate [3,4]. Investigations of gastropod shells usually emphasize the morphology [5,6,7], and when crystallography is mentioned it is usually on a passing note or it refers to the crystallographic properties of isolated elements.

We examined the preferred crystallographic orientations of the aragonitic shell of the gastropod Cypraea testudinaria Linnaeus, 1758, a large cowry (Figure 1), with X-ray texture analysis to investigate the bulk orientational properties of the shell, and to examine the correspondence between textures and morphology of the shell structures. We find this provides essential information to understand the physiology behind the complex shell structures, which may ultimately lead to new techniques to control the growth of individual crystals in compact aggregates.

MATERIAL

We chose the shell of C. testudinaria because it displays an arrangement of shell structures common to many gastropods [5,7]. It has four distinct layers (Figure 1): an outer "homogeneous" [8] layer, of densely spaced and tiny spherules; a comarginal crossed lamellar layer; a radial crossed lamellar layer; and an inner comarginal crossed lamellar layer. The lamellae of crossed lamellar structure are typically 10 μm thick, and several millimeters long and wide. They are composed of thin, parallel laths, which dip in opposite directions in alternating lamellae. If the plane of the lamellae is parallel to the margin (the edge) of the shell, the structure is "comarginal", if the plane of the lamellae is perpendicular to the margin, it is "radial". By examining the textures of these four layers, we may establish whether comarginal and radial crossed lamellar structures differ because of physiology - the same structure deposited at a right angle in different layers - or biomimetic differences, and we may also get an initial feeling of whether textures correlate with the morphology of shell structures or with the species. The shell is composed entirely of orthorhombic aragonite (Pmcn, a=4.96 Å, b=7.97 Å, c=5.74 Å).

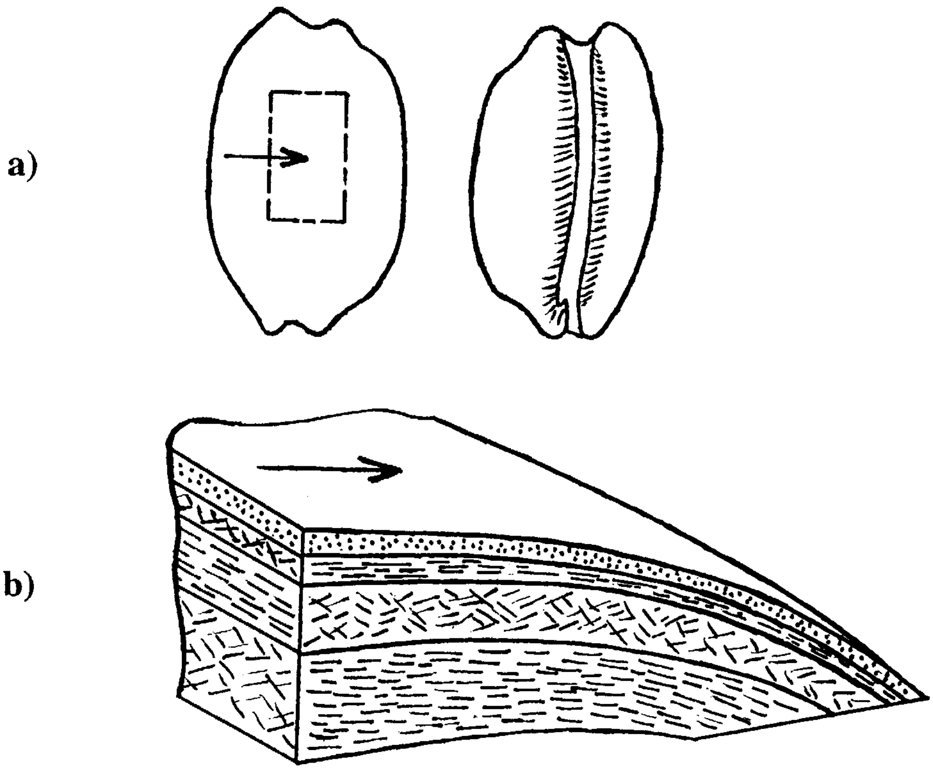

Figure 1: Schematics of a cowry (a) (dotted lines show the piece removed for X-ray experiments) and cross section of the layer stacking (b). Top to bottom are: homogeneous, outer comarginal, radial and inner comarginal layers. The arrow is the growth direction of the shell.

METHODS

We removed a piece of the shell from the dorsum, which was as flat as possible (Figure 1). The growth direction of the shell was marked by an arrow. First we measured the exterior of the shell (the homogeneous layer), and the interior (the inner comarginal crossed lamellar layer). Then the inner comarginal crossed lamellar layer was removed with dilute hydrochloric acid to expose the radial layer, which was measured, and then removed by acid to expose the outer comarginal crossed lamellar layer.

Four pole figures, (111), (012), (102) and (221), were measured with an X-ray pole figure goniometer. Raw data were corrected for background and defocusing. These pole figures are rather complex (Figure 2). To facilitate interpretation an ODF was calculated [9]. Observed and recalculated pole figures compare favorably (Figure 2). From the ODF (001), (010), (100) and (110) pole figures were calculated and used for the interpretation (Figure 3).

RESULTS

Figure 2 shows the normalized experimental and WIMV recalculated pole figures for the inner comarginal layer. It illustrates the typical quality of the refinement obtained. In detail, sample symmetry is triclinic. The texture is remarkably strong as denoted by the high texture indexes. It exhibits a single crystal character, with ODF maximum up to 1600 m.r.d. for the inner comarginal layer and at least 200 m.r.d. for others (Table 1).

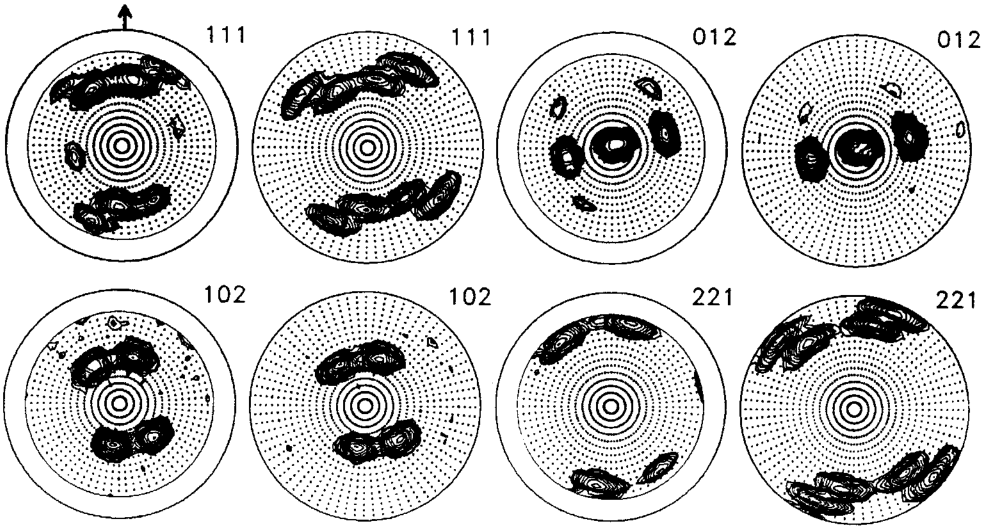

Figure 2: Experimental-normalized and WIMV recalculated pole figures of the inner comarginal layer. Triclinic sample symmetry, Logarithmic contours, 5°x5° dot symbols below 1 m.r.d.. Equal area projection. Arrow indicates the growth direction.

Table 1: ODF maxima and Texture Index for the four shell layers

Layer	Outer	Outer comarginal	Radial	Inner comarginal
ODF max. (m.r.d.)	440	280	201	1658
Texture Index	78	41	32	432

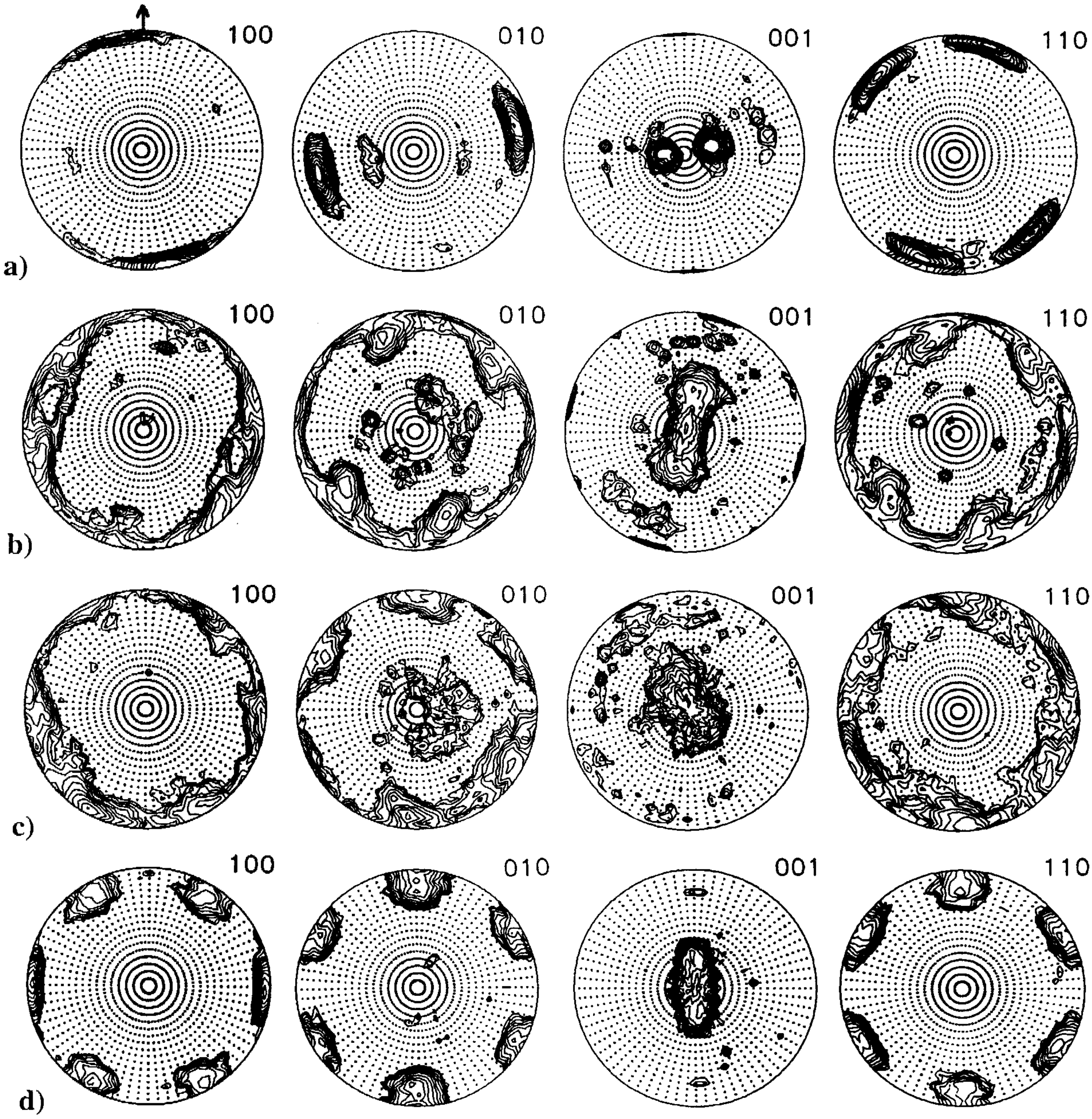

Figure 3: ODF recalculated {100}, {010}, {001} and {110} pole figures for the inner comarginal (a), radial (b), outer comarginal (c) and outer (d) layers. Maxima (m.r.d.): (a) >100, (b) 25, (c) 28 and (d) 55. Logarithmic contours, equal area projection.

The inner layer displays the simplest texture (Figure 3). This texture can be described by **a** axes at 10° from the growth direction, and **c** axes inclined by 16° from the normal to the shell surface in two symmetrical components.

In the radial layer, the two **c** axis components are inclined about 25° with respect to the surface normal, as a result of a rotation around <110>. In addition the (100) and (010) pole figures exhibit six poles, produced by a combination of the two c-axis components and {110} twin component, as explained in Figure 4 which represents the theoretical (100), (010), (001) and (110) pole figures assuming Gauss components of 5° and 10° of halfwidth for the two c-axis components. On this figure the two orientations related by {110} twin-like relationship are indexed for the 10° component. All components so far described consist of the alignment of [110] at 16° from the perpendicular to the growth direction with 25° tilted c-axes. Based on bulk texture measurements alone it can not be decided if actual twinning is present or if pseudo hexagonal aragonite crystals are arranged in a twin-like pattern.

The outer comarginal layer has a similar texture to the radial one, but rotated by 30° approximately, around the normal of the pole figures, and with a weaker texture strength.

The texture of the outer layer, resembles the one of the inner layer, rotated by about 90° around the sample surface normal. In addition {110} "twinning" is present with pseudo-hexagonal orientation patterns in the (100), (010) and (110) pole figures.

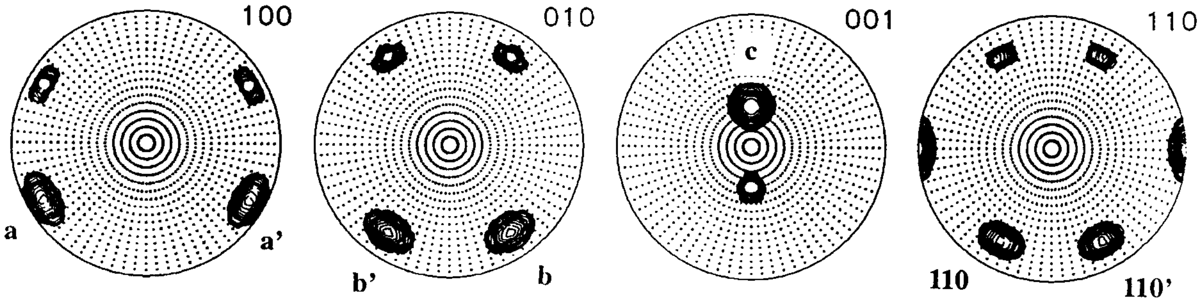

Figure 4: Theoretical {100}, {010}, {001} and {110} pole figures which illustrate the observed components of the radial layer. Poles dispersion of 5° and 10° to distinguish the two c-axis components. On the 10° poles we show the two twin-related orientations. Logarithmic contours, equal area projection.

DISCUSSION

The shell of Cypraea testudinaria is highly textured - the patterns we observe are prominent, not merely small features on top of a randomized background. The traditional view is that acicular or prismatic aragonite crystals are elongated parallel to the c-axis, but we find the laths of the crossed lamellar structures are inclined with respect to at least two axes, representing more complex forms.

The complex physiology of shell formation in Cypraea testudinaria and other cowries is reflected in the textures. The outer comarginal and the radial crossed lamellar layers, which have similar textures, are juvenile features. They are deposited by incremental growth in a thin zone along the edge of the shell by the mantle of the young, growing animal. Upon reaching adult size, incremental growth ceases, the aperture of the shell is partly covered by a thickened lip, and the mantle is extended to cover the outside of the shell as well. In this life stage, shell material is deposited over large areas of the shell - inside as well as outside - by modified, disjunct sections of the mantle. This is reflected in the distinct textures of the inner comarginal crossed lamellar and the outer homogeneous layers.

It is interesting, that the two, otherwise very similar, comarginal crossed lamellar layers have different orientations. Consequently, the laths in these layers are not crystallographically equivalent, suggesting differences in the organic matrix, controlling the properties of the calcium carbonate [2,3,4]. On the other hand we observe for this sample significant deviations from the usually admitted growth relationships, with <100> and <001> respectively aligned with the growth direction and the sample normal.

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