# The unique nano- and microstructure of twinned foraminiferal shell calcite

J. Lastam[1], E. Griesshaber[2*], X. Yin[2], U. Rupp3, I. Sánchez-Almazo[4], M. Heß[5], P. Walter[3], A. Checa[6], W. W. Schmahl[2]

1. Forschungszentrum Jülich, Institut für Energie und Klimaforschung, IEK-2, 52425, Jülich, Germany
2. Department für Geo- und Umweltwissenschaften, Ludwig-Maximilians-Universität München, 80333 Munich, Germany
3. Zentrale Einrichtung Elektronenmikroskopie, Universität Ulm, 89081 Ulm, Germany
4. Centro de Instrumentación Científica, Universidad de Granada, 18071 Granada, Spain
5. Biozentrum LMU München, 82152 Planegg-Martinsried, Germany
6. Departamento de Estratigrafía y Paleontología, Universidad de Granada, 18071 Granada, Spain, and Instituto Andaluz de Ciencias de la Tierra, CSIC-Universidad de Granada, Armilla, 18100, Spain

* Corresponding author: E. Griesshaber

## Supplementary Figures

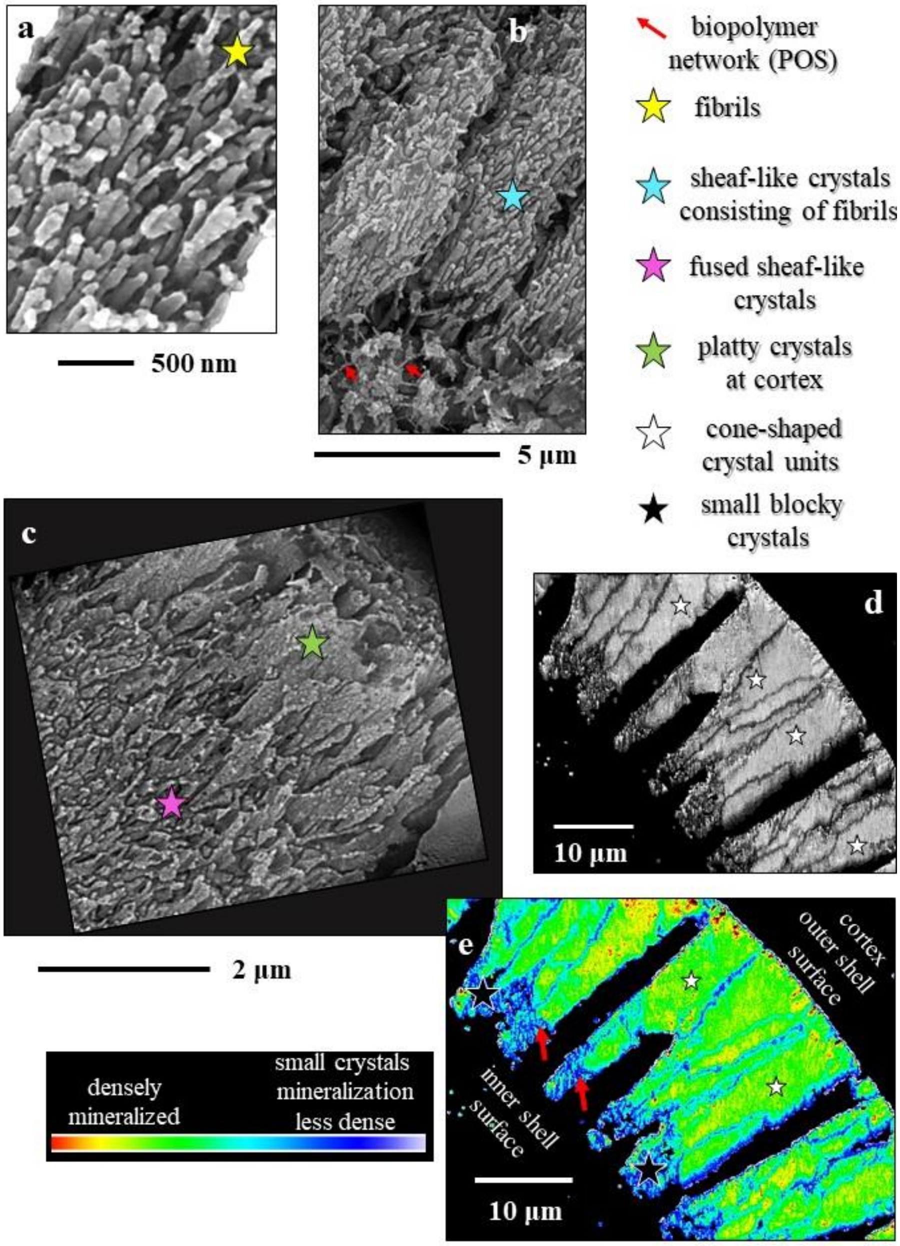


**Figure A1.** Visualization of fibril, platy, sheaf-like crystal and cone-shaped crystal morphologies. (a, b, c): BSE images of etched shell cross-section surfaces. (d, e): EBSD band contrast measurement images given in grey (d) and in color (e), depicting the sites of the POS, that of small blocky crystals at inner shell surfaces and the cortex at outer shell surface (e). (d, e): well visible are the cone-shaped units/entities that form the shell wall from the POS up to outer shell surface. Shell mineralization starts with the formation of minute fibrils at/within the POS (a, b). The fibrils form sheaf-like crystals (b). Towards the cortex the sheaf-like crystals consisting of fibrils fuse (c); out of the latter structure develop the irregularly shaped platy crystals that form the cortex (c). A cone-shaped crystal unit/crystal entity (d, e) comprises the fibrils, the sheaf-like crystals and the platy crystals at the cortex.

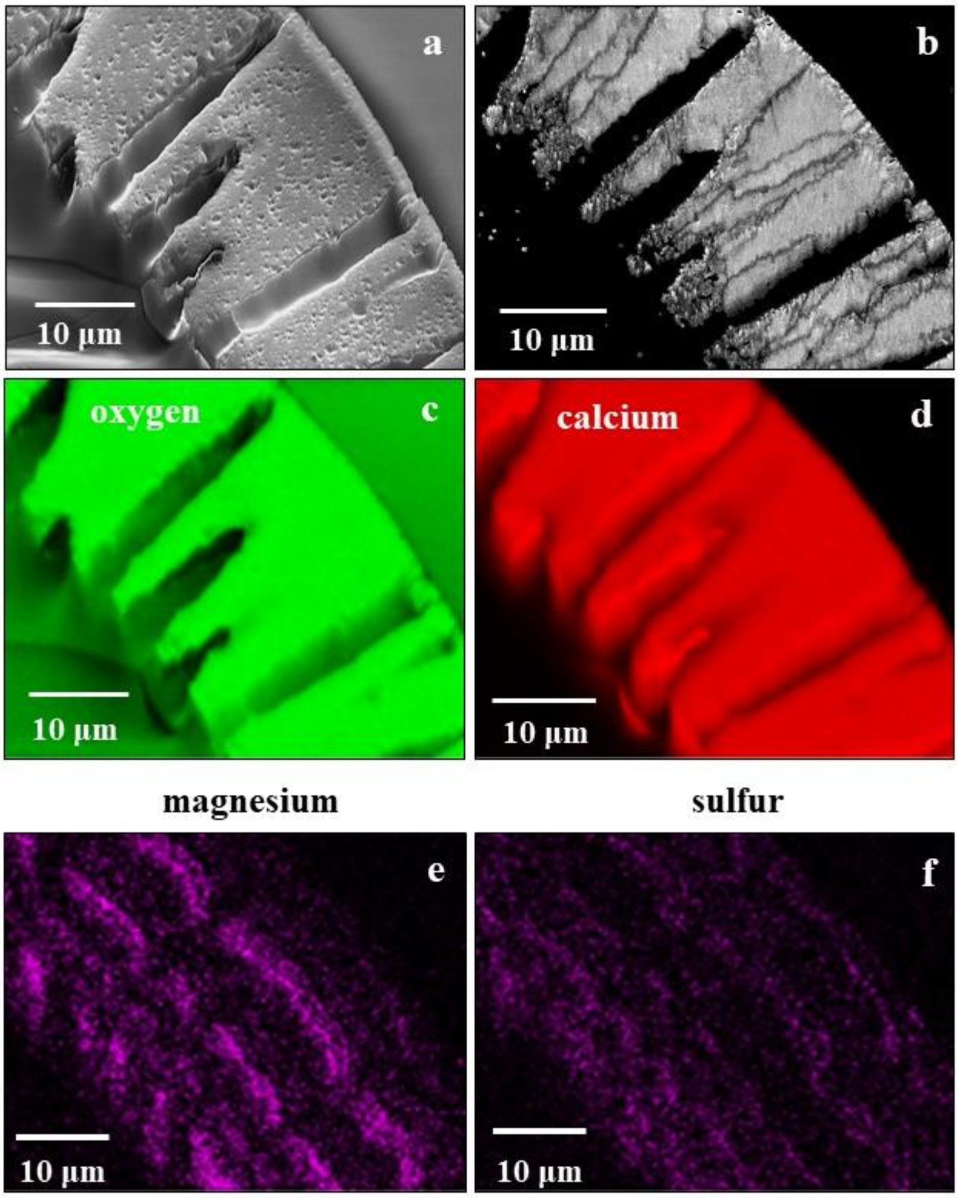


**Figure A2.** Zonation in magnesium (e) and sulfur (f) on cross-sections through *Pulleniatina obliquiloculata* shells. Sulfur is indicative of organic substance intercalation. Shell layers enriched in magnesium are also enriched in sulfur. (a): SE image; (b): EBSD band contrast measurement in grey; (c to f): oxygen, calcium, magnesium, sulfur distribution.

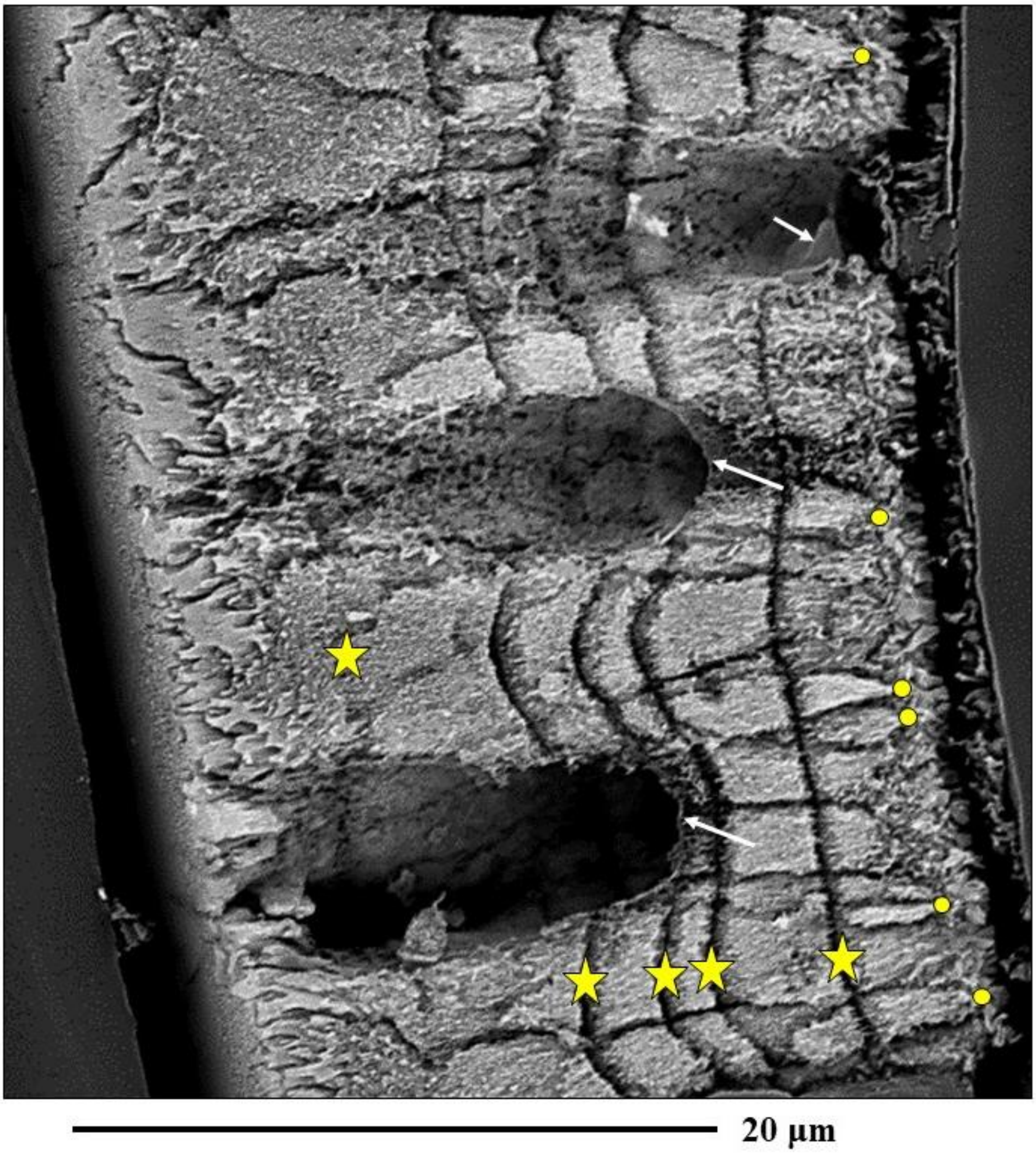

**Figure A3.** BSE image of an etched cross-section through the shell wall of *Pulleniatina obliquiloculata*, sagittal cut. Well observable is the organic lining at the inner surface of the pores (white arrows), the start of growth of the sheaf-like crystals at/in the POS (yellow dots) and traces of organic linings (OOL) left behind from the different stages of shell formation and, at shell wall growth, incorporated within the shell wall calcite (yellow stars). These organic layers do not change structural and crystallographic characteristics of the crystals. The latter features are steadily transmitted from the POS to the cortex, also across a particular organic layer incorporation.

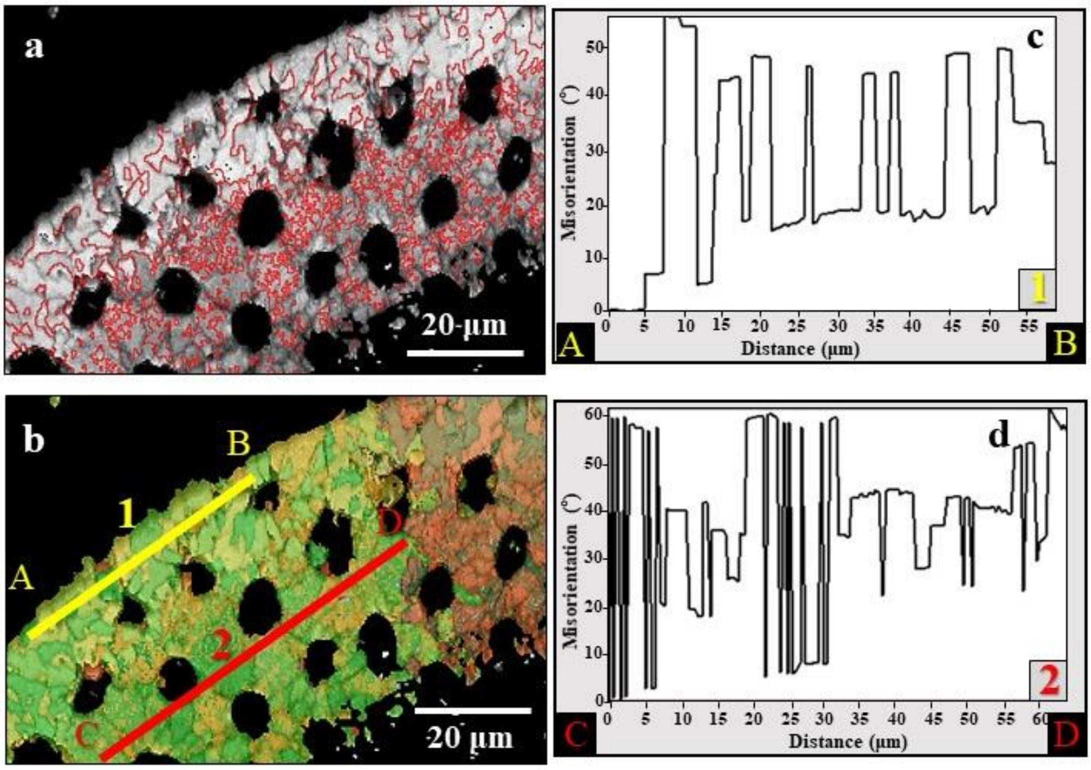


**Figure A4.** Tangentially oriented cuts through the shell of *Pulleniatina obliquiloculata* visualizing: (a) the distribution of 60° grain boundaries (red lines), (b) the jagged morphology and strong interlinkeage of cone-shaped units/entities and (c, d) the degree of misorientation between the cone-shaped crystal entities. As the misorientation versus distance diagrams along profiles A to B (c) and C to D (d) show neighboring cone-shaped units are misoriented to each other, by variable degrees, and are not related to each other through a twin relationship (the systematic 60° misorientation). (a): EBSD band contrast measurement, given in grey, superimposed with 60° misorientation boundaries, given in red. (b): EBSD scan visualizing in color crystal orientation; the color-code is shown in Fig. 8a. (b): Yellow and red lines indicate the trace of misorientation profiles 1 and 2. Corresponding misorientation versus distance diagrams are presented in Figs. A4c and A4d.

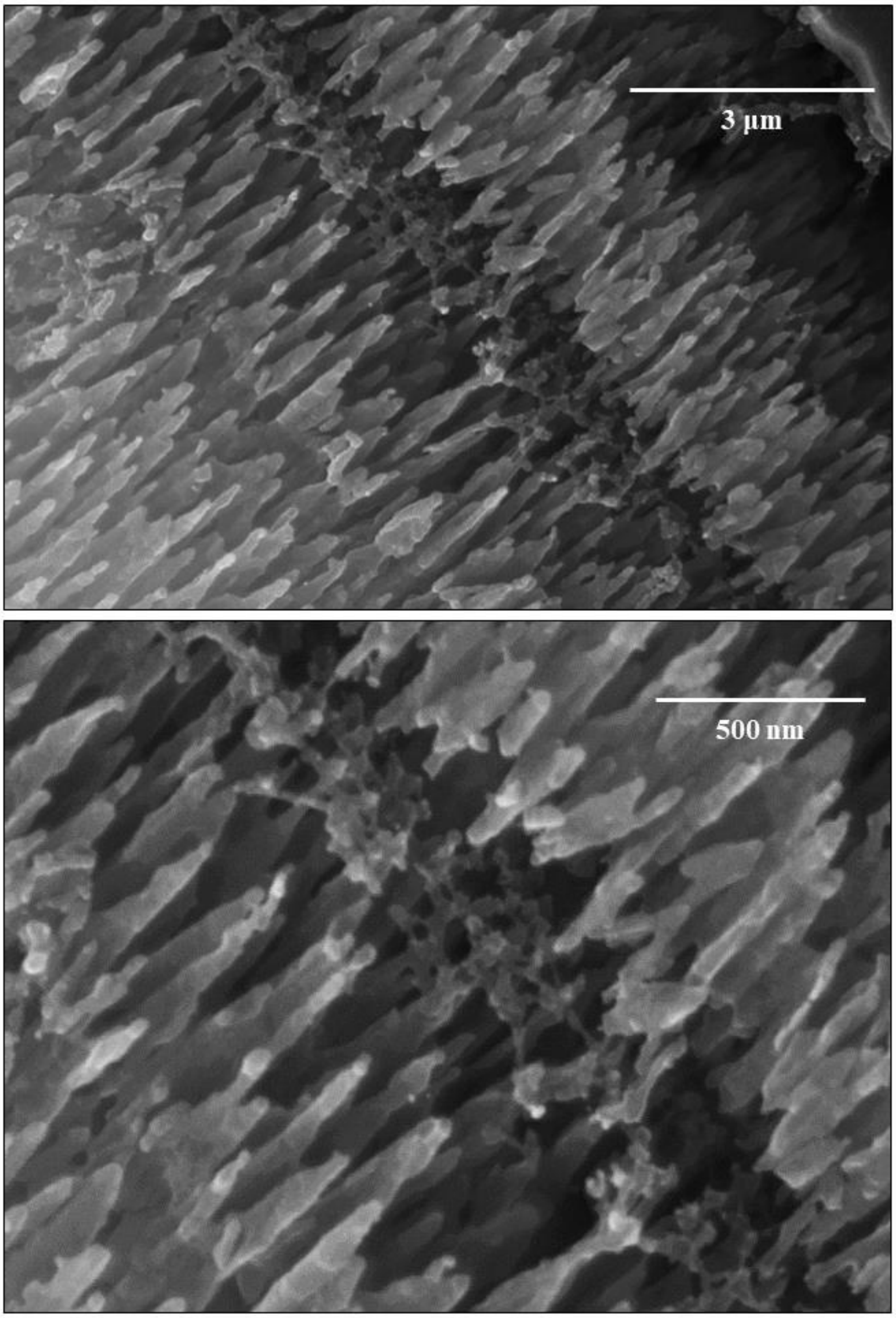


**Figure A5.** BSE images visualizing for the planktonic species *Globigerinita glutinata* the fabric of the outer organic lining (OOL), demonstrating its reticulate structure and visualizing the smooth transfer of crystallized mineral across the OOL and resumption/continuation of further crystallization. Unpublished data.

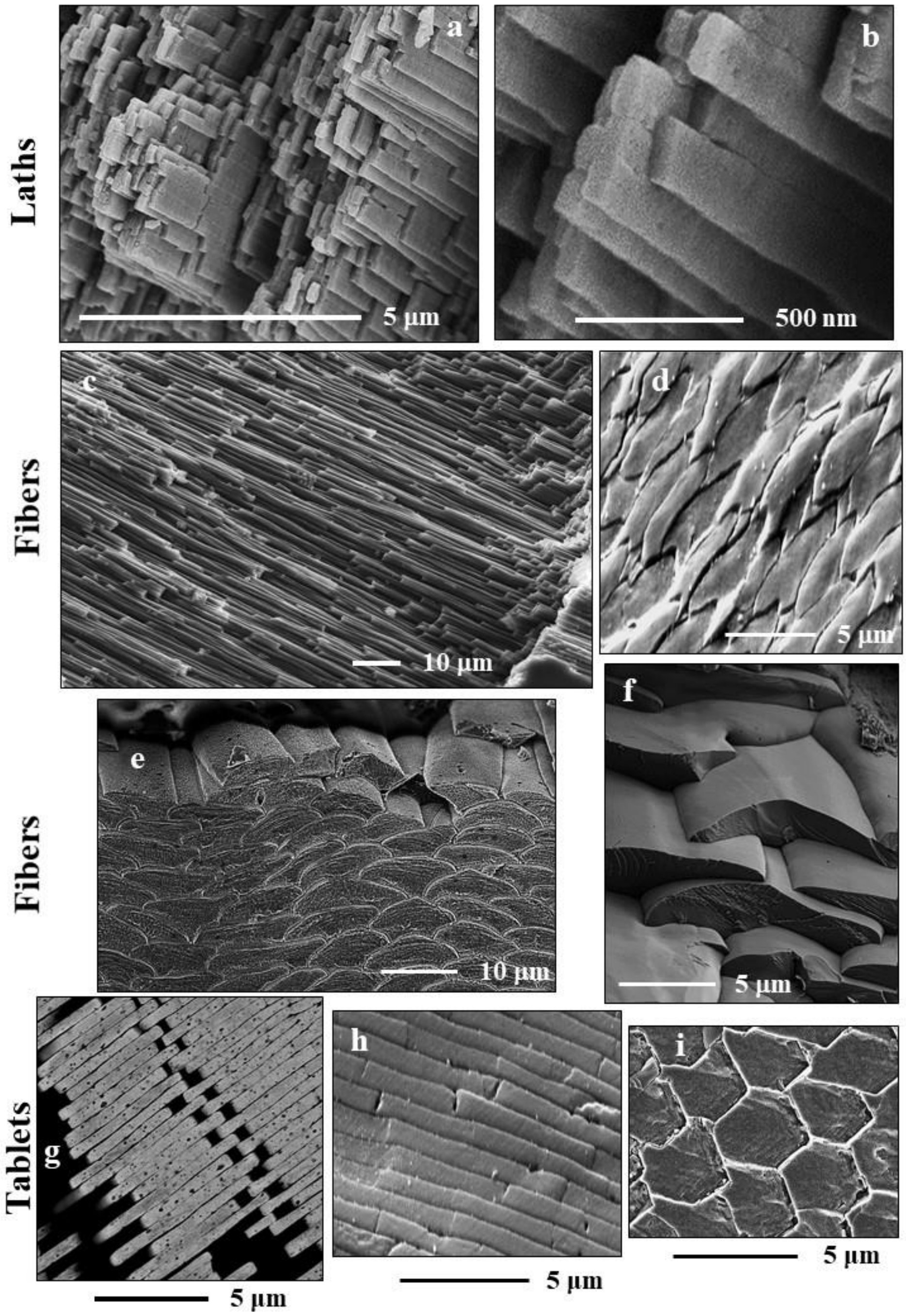


**Figure A6.** BSE images visualizing the regularity of carbonate crystal morphologies that comprise bivalve, gastropod and brachiopod shells. (a, b): assembly of aragonite laths to crossed-lamellar and complex-crossed-lamellar arrangements in *Glycymeris glycymeris* shells. (c, d): assembly of calcite fibers in the calcitic fibrous layer of *Mytilus edulis* shells. (e, f): assembly of calcite fibers in the fibrous shell layer of the brachiopods *Laquens rubellus* (e), and *Notosaria nigricans* (f). (g): columnar arrangement of aragonite tablets in the nacreous shell layer of the gastropod *Haliotis ovina*. (h, i): sheeted assembly of aragonite tablets in the nacreous shell layer of the bivalve *Mytilus edulis*. See also[24-27].

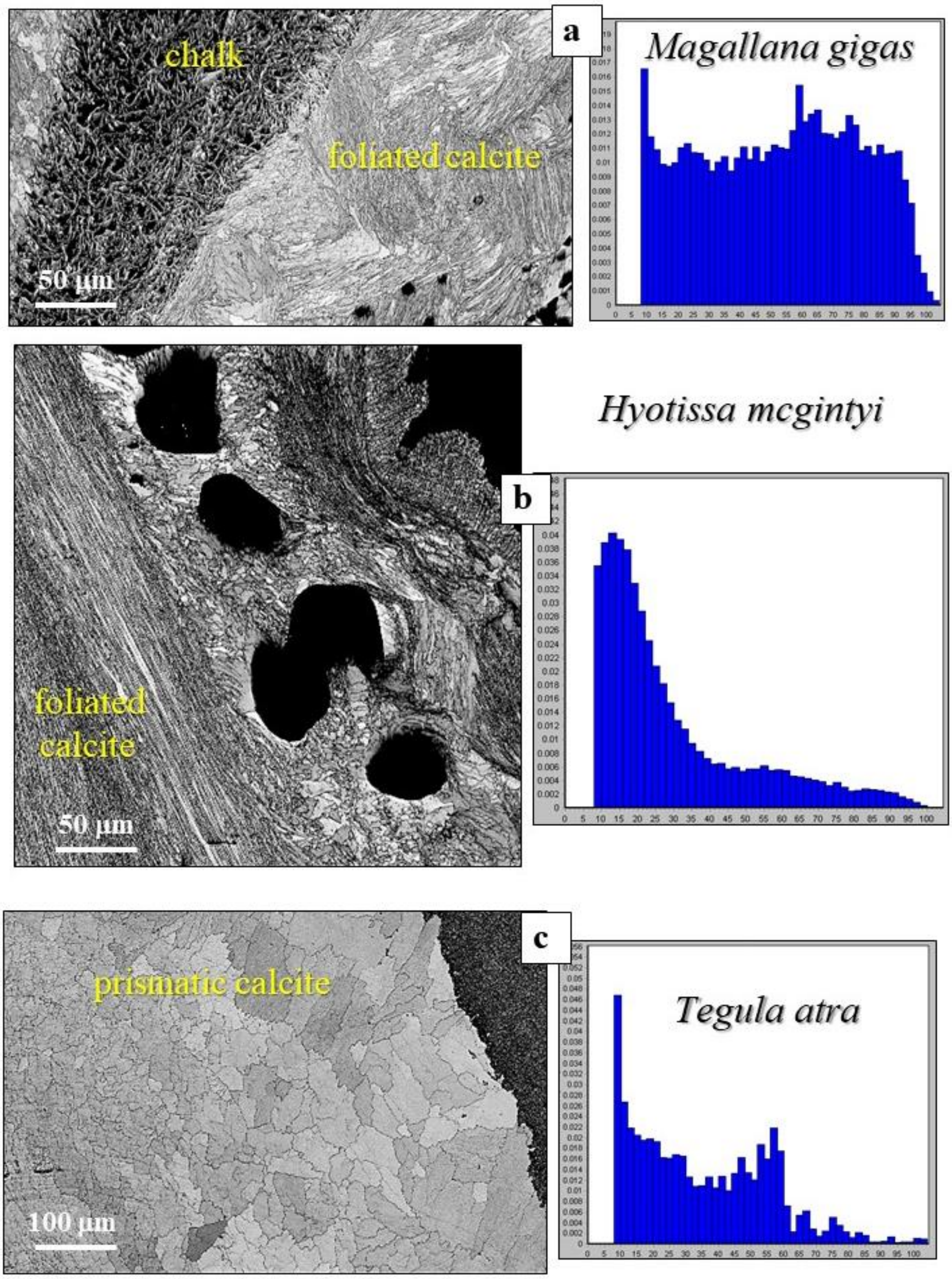


**Figure A7.** EBSD band contrast measurement images (in grey) visualizing carbonate crystal assemblies formed of crystals with irregular morphologies. (a) the chalk section in the shell of the oyster *Magallana gigas*, (b) around voids and cavities in the shell of the oyster *Hyotissa mcgintyi* and (c) assemblies of prisms in bivalve and gastropod shells, shown here for the gastropod *Tegula atra*. The corresponding misorientation angle distributions show a wide range of misorientations between the crystals, the systematic misorientation at 60°, indicating the <001> twin relationship, is not observable in the misorientation angle distribution diagrams.