Sea Urchin Teeth - A Mechanical, Chemical and Crystallographic Characterization of a Highly Optimised Biogenic Composite Material

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INTRODUCTION.

Sea urchin teeth are key biological objects for the study of optimization techniques of biomaterial properties employed by organisms. This is due to the fact that the purpose of the teeth is well known and therefore biomaterial optimization can be understood more easily.

In this study we have investigated keeled teeth of the sea urchin species *Paracentrotus lividus*. Sea urchin teeth are of high interest for bionic studies as the self-sharpening teeth consist of relatively mechanically weak calcite even though sea urchins have the reputation to be able to chew basaltic substrate. To understand the optimization features and mechanisms present in sea urchin teeth we have studied their microstructure with electron backscatter diffraction (EBSD) together with energy and wavelength dispersive x-ray analyses (EDX and EPMA). The nanomechanical properties were mapped by instrumented nanoindenation testing.

RESULTS.

Our investigations reveal that the teeth – a Mg-calcite dominated composite biomaterial – are distinctly harder than inorganically precipitated calcite and even exceed the hardness of dolomite. They show a strong structuring of their mechanical properties that can be correlated to variations in major element chemical composition. Their hardness is positively correlated to their magnesium contents that content varies between 1-4 wt-%, Na content is around 0.3 wt-%. Nanohardness of the tooth scatters between 3.5 GPa and over 8 GPa compared to values of 3.0 GPa ± 0.2 GPa, 7.3 GPa ± 0.1 GPa 9.2 GPa ± 0.9 GPa measured on the (104) planes of inorganic calcite, dolomite, and magnesite crystals, respectively.

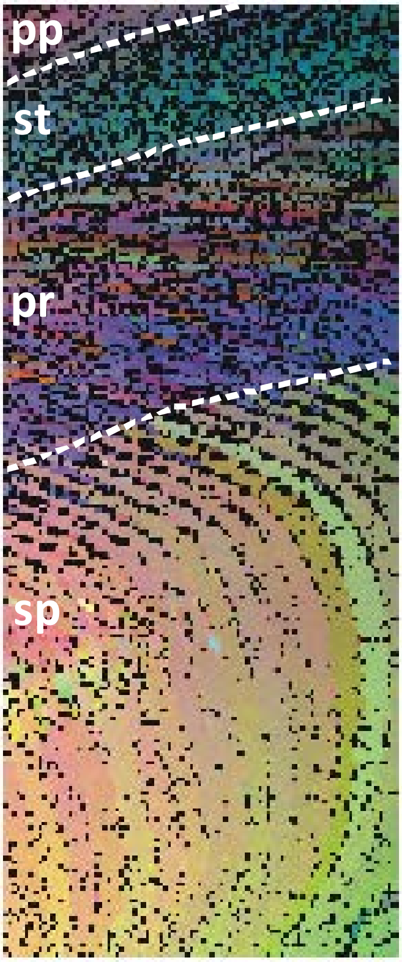

fig 1. EBSD map measured on a tooth of a sea urchin. The crystallographic orientation is represent with the three Euler angles. Every Euler angle is represented by one channel of the RGB color scheme. To emphasize the small missorientations Every color channel has a color range of 8 degree. Sinlge buiding portions as primary plates (pp),stone (st), prisms (pr) and secondary plates (sp) are distinctly missoriented towards each other but also within these units less missoriented units (e.g. single platelets) can be differentiated.

EBSD measurements reveal that mean preferred crystallographic orientations of crystals composing distinct building portions of the tooth are tilted to each other by 3-5°. Within each building unit the orientation of constituting subunits, such as single platelets, varies by 1-2°. The dimensions of single platelets are in the order of 10-30 µm in width and 100-500 µm in length. Primary platelets are smaller than secondary platelets. We regard the entire sea urchin tooth as a hierarchically assembled mesocrystal with a mosaic-crystal arrangement. Its self-sharpening feature is enabled by a close interplay of highly evolved micro- to nanostructure, textural properties, distinct calcite grain size variations and an alternation of incorporated organic polymers.

Geologic calcite has an anisotropic Youngs-modulus. The mesocrystal sea urchin tooth in contrast shows in diffrent sections the same Youngs-moduli within similar building units. This implies that sea urchin biocalcite behaves as an isotropic material regarding its elastic constants.

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palabras clave: Biomineralización, Dientes de erizo de mar, EBSD, EPMA, Nanoindentation, Mesocristal, Material compuesto biogenético

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