Geophysical Research Abstracts,
Vol. 10, EGU2008-A-03110, 2008
SRef-ID: 1607-7962/gra/EGU2008-A-03110
EGU General Assembly 2008

Nanostructures of the aragonitic otolith of cod (*Gadus morhua*) - environmental implications

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Fish otoliths are used in a very diverse range of applications in fisheries, fish ecological and environmental studies. They are composed of $CaCO_3$ usually as aragonite, and organic matter. Variations in Ca and/or organic matrix deposition result in the formation of cyclic growth increments, which are the basis for sclerochronological studies. Observed by SEM cod (*Gadus morhua*) otoliths exhibit regular growth primary increments $\sim$ 4-6 μm in width. Primary increments are composed of a thick incremental unit (L-zone) consisting of layers of acicular fibres of 0.4 to 0.9 μm in width, and a thinner unit (D-zone) appearing like narrow ridges less than 1 μm in width in which the organic matrix predominates. According to Gauldie (1993, 1998) the organic matrix plays a key role in controlling the formation of the different layers and shape of otoliths. This organic matrix is composed of proteins, glycosaminoglycans and lipids, and is species dependant. Topographical relationships between the mineral and organic components are also important to understand the processes involved in biomineralisation.

AFM images reveal that the thin aragonitic acicular fibres are composite structures. The most common structure is that with elongated and parallel lamellae with granular surfaces. The granules are mainly round with a diameter smaller than 50 nm, and are surrounded by a thin dark layer. This layer is interpreted as an organic and/or amorphous zone. Some granules present features suggesting that they have a heterogeneous composition. Individual fibres exhibit an irregular banding pattern, perpendicular to their long axis. In some parts, the acicular fibres are composed of several contiguous

and parallel elongated units, crossed cut by growth lines. A profile along such lamellae shows that the average thickness of each growth unit is about 32 nm.

The presence of lines separated by 32 nm suggests a periodic otolith growth pattern at the intra-day level. Assuming an averaged 3 μm thickness for a single daily increment, a 32 nm thickness represents time duration of about 15 minutes. The presence of such growth lines allows us to hypothesise that very precise environmental and biological reconstructions will be possible in the future.

Dauphin and Dufour, Micron (in press). doi:10.1016/j.micron.2007.11.007