30 Million year old traces of the bone-eating worm *Osedax*

S. Kiel[1], W.-A. Kahl[1], J. L. Godert[2], G. W. Rouse[3]

[1] Institute of Geosciences, Christian-Albrechts-University Kiel, Ludewig-Meyn-Straße 10, D-24118 Kiel, Germany, wak@min.uni-kiel.de
[2] Burke Museum, University of Washington, Box 353010, Seattle, WA 98195-3010, USA
[3] Scripps Institution of Oceanography, University of California, San Diego, 9500 Gilman Drive, La Jolla, CA 92093, USA.

Aims

Osedax is a recently discovered siboglinid polychaete that consumes bones on the seafloor. Its bacterial symbionts of *Osedax* produce collagenolytic enzymes enabling them to live on cholesterol and collagen as primary carbon sources, and this worm can consume entire whale skeletons within a few years [1, 2]. *Osedax* produces characteristic boreholes that start as boreholes on the bone's surface and lead to cavities inside (Fig. 1C, D).
Whale bones from 30 Million year old deep-water rocks exposed in Washington State, USA [3], show traces similar to those made by *Osedax* today. To document their morphology and to ensure that they were not made by other boring organisms, we studied the cavity morphology by X-ray micro-computed tomography.

Method

The fossilized whale bones were extracted from the enclosing rock by acid etching. One specimen was scanned using the SkyScan 1172 device of the experimental and theoretical petrology group at Kiel University with a beam energy of 100 kV, a flux of 100 µA and a 0.5 mm thick aluminum filter with a resolution of 8 µm. Image analysis and volume rendering was done using the SkyScan software CT-analyser.

Results

The cavities inside the bone show different morphologies depending on the structure of the bone, as visualized in the micro-CT based renderings (Figs. 1D, F). All numbered boreholes on Fig. 1A lead into two large cavites that occupy most of the interior of the figured specimen. Below borehole number 1 on Fig. 1A only the area just beneath the surface is destroyed and the trabecular (spongy) bone below appears to be intact (Fig. 1C). Below boreholes 6 and 7 on Fig. 1A the interior of the bone is completely excavated, only the floor of the bone still shows remnants of the original trabecular structure (far right on Fig 1A). These remnants of trabecular bone on the margins of this cavity with multiple boreholes suggest that the original bone had mostly trabecular structure. Cavities in mostly solid bone (Fig. 1E) are smaller and consist of a chimney leading from the bone's surface to its interior where the cavity branches into several lobe-like extensions (Fig. 1F) and thin elongate tubes approximately parallel to the bone's surface. The chimneys are elongate or globular in shape, have approximately the same diameter as the hole in the bone's surface or are slightly wider, and are about 0.2 to 0.3 mm high. The lobe-like extensions are interpreted here as having housed the branched root system of *Osedax*, whereas the elongate tubes were part of the vascular system of the bone itself and it is unclear whether *Osedax* extended also into these tubes. The investigated cavities in solid

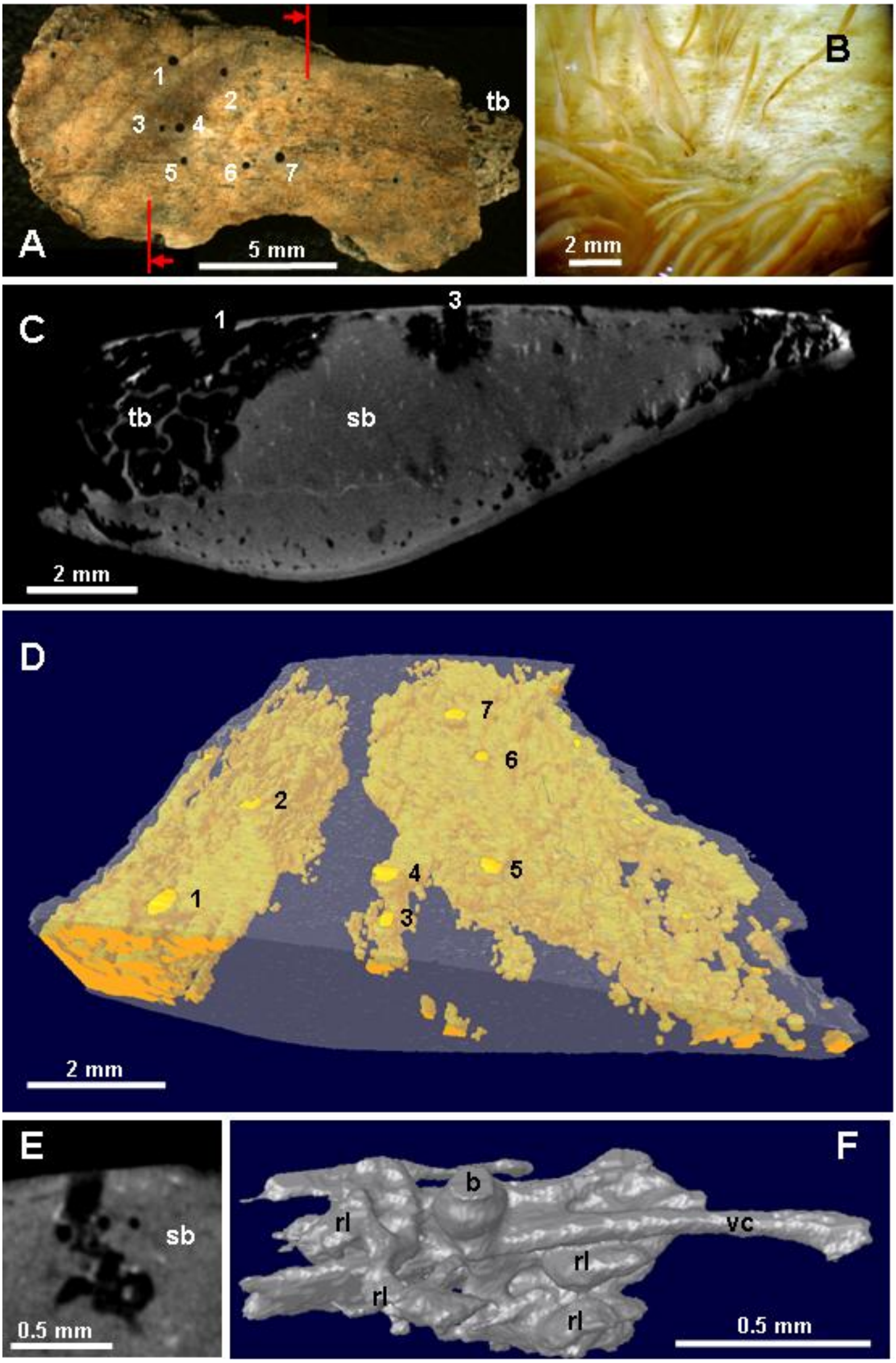

Figure 1: Fossil and modern whale bones bored by *Osedax*. *(A)* Rib fragment of a fossil whale with *Osedax* borings, view on surface with circular boreholes, those shown in Fig. 1D are numbered; arrows delimit reconstructed section in fig. *D*; tb, remnants of trabecular bone *(B)* View on modern whale bone colonized by *Osedax*

rubiplumus for comparison. *(C)* Reconstructed image of a CT scan through holes 1 and 3 in figs. *1A* and *1D*, note destroyed trabecular bone just below the left borehole. *(D)* Rendering of the trace fossils; bone material in transparent blue, boreholes and cavities in yellow. *(E)* Rendering of a cavity in solid bone; only a single borehole leads into it and it is assumed to have been excavated by a single individual of *Osedax*; the three small, elliptical holes in the upper half are vascular canals. *(F)* Rendering of a cavity in solid bone. b, borehole on bone's surface; rl, root lobe; sb, solid bone; tb, trabecular bone; vc, vascular canal of the bone.

bone reach a maximum depth of 1 mm below the bone's surface and a maximum lateral extend of 1.7 mm (excluding the long tubes that we interpret as vascular tubes of the bone) and they are here considered to reflect the size and shape of the ancient *Osedax*' root system.

Conclusion

The traces in the fossil whale bones reported here resemble those produced by *Osedax* in modern whale bones (Fig. 1B). The investigated cavities in solid bone are considered to reflect the size and shape of the ancient *Osedax*' root system. The geologic age of these trace fossils (~30 Million years) coincides with the first major radiation of whales, suggesting an evolutionary link between *Osedax* and its main food source.

References:

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