A tribute to the legacy of Heinz Lowenstam (1912-1993): The impact of magnetite biomineralization on paleoseismology, animal navigation, and weak electromagnetic effects

JOSEPH L. KIRSCHVINK*[12], ATSUKO KOBAYASHI[2] AND JUNLE JIANG[1]

[1]California Institute of Technology, Pasadena, CA 91125 USA; *Kirschvink@caltech.edu

[2]Earth Life Science Institute, Tokyo Institute of Technology, Meguro, Tokyo, Japan

Heinz Lowenstam's (1962) [1] discovery that the radular teeth of the *Polyplacophoran* mollusks (the chitons) were hardened with layers of biochemically-precipitated magnetite (Fe_3O_4) solved a puzzle about the origin of shoreline-level notches in the uplifted reef exposures in the tropical island of Palau. However, that singular observation launched several other fields, ranging from the systematic study of bio-minerals, to the use of the shoreline notches to gauge paleo-tsunami risk, and provides a biophysical mechanism for the effects of a weak, extremely low-frequency magnetic fields.

Lowenstam's suggestion that the chitons might be using magnetite for navigation presaged the discovery of magneto-tactic bacteria, as well as the discovery of biogenic magnetite in numerous other animals, including migratory and homing arthropods, fish, amphibians, reptiles, birds, and mammals. It also led to the systematic investigation of biomineralization.

In the uplifted rock islands of Palau, Lowenstam (1974) [2] estimated that animal grazing was eroding shorline intervals by up to a few mm/year, implying that the present in-dentations (up to 7m) could at most be a few thousand years old. This presents a tectonic puzzle, as many of the rock islands contain remnant paleo-notches that are uplifted ~10m. This may imply a previously unrecognized tsunami threat for the Pacific Basin from the Palau – Yap trench system.

Although often present in background levels of a few ppb to ppm, biogenic magnetite also provides a biophysical explanation for the ability of weak, ELF oscillating magnetic fields to produce a variety of suprising effects on cell growth and preservation [3], perhaps including inhibition of freezing [4].

[1] Lowenstam, H. A. (1962). *GSA Bull*. **73**: 435-438; [2] Lowenstam, H. A. (1974). In: The Sea E. D. Goldberg. New York, N.Y., John Wily & Sons**:** 715-796; [3] Kobayashi et al., (1995). *Nature* **374**: 123-123; [4] Kobayashi, A. and J. L. Kirschvink (2014). *Cryobiology* **68**(**2**): 163-165.