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SUPERPARAMAGNETIC MAGNETITE IN THE UPPER BEAK TISSUE OF HOMING PIGEONS

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Introduction

Ferromagnetic material is commonly detected in many organisms, although it is normally present only in minute amounts. With the exception of magnetotactic bacteria its role is not clear. It could be a merely accidental by-product of metabolism, it could play a role in the iron household of the organism, or it could serve a particular function as in the case of magnetite dentical capping in chitons or represent part of a magnetoreceptor.

Here we try to study this question for the case of homing pigeons. WALCOTT et al. (1979) were the first who detected permanently magnetic material in the pigeon head. They found it in tissue between the dura and the skull and identified the concentrated material by Curie temperature measurement as magnetite. This result was in contrast to similar experiments of PRESTI & PETTIGREW (1980) who found no visible magnetic structures in the skull, but reproducible, inducible, magnetic remanence in the neck musculature of the pigeon, which they attributed to the presence of magnetite. Both of these investigations did not come so far to resolve size and nature of individual magnetic particles, nor identify their exact location and possible structural arrangement within the tissue.

Measurement of induced and remanent magnetization

We obtained a first indication of the presence of ferromagnetic material in the pigeon upper beak tissue by a series of magnetization measurements with a SQUID magnetometer, carried out in a similar way as described by WALCOTT et al. (1979) or PRESTI & PETTIGREW (1980). The fresh unfixed tissue did not show a detectable remanent magnetization, but an induced magnetization when measured in 1 Oe. After appr. 30 min, the tissue changed to a state where it did acquire a remanent magnetization (10^{-6} to 10^{-7} emu) after exposure to 1000 Oe. These results indicated to us that the fresh tissue must have been changing rapidly its original structure, probably due to desiccation, thus altering the magnetic particle configuration.

Identification of iron concentrations by Prussian Blue reaction

As next step in our attempt to localize the magnetic material we looked for concentrations of Fe(III) using the Prussian Blue reaction (Tanka and Berschauer, 1969). We made serial histological sections of paraplast and plastic (Epon) embedded upper beak skin from 7 homing pigeons. In the Prussian Blue treated sections iron enrichments show up intensively blue. This way we found in the upper beak skin up to six isolated sites of Fe (III) enrichments arranged in sets of cellular elements, which extend over appr. 200 µm and always occur in the same skin layer (Stratum laxum of the subcutis). They are arranged in connective tissue strands between fat cells. At higher magnification, the Prussian Blue stained regions are resolved to accumulations of discrete, opaque and intensely blue granules of 1 to 3 µm diameter.

Transmission electron microscopy

These granules can be resolved as clusters of extremely fine-grained particles with diameters between 1.5 and 5 nm. Selected area diffraction patterns of these particles show a powder diagram characteristic of fine-grained crystalline magnetite. In combination with the black colour of the clusters in the light microscope these findings are diagnostic for magnetite. We did not detect any other magnetite particles outside the clusters, although the entire tissue was scanned very carefully. Our detection of magnetite in the pigeon tissue confirms the earlier findings of WALCOTT et al. (1979) and PRESTI & PETTIGREW (1980) as described above. However, the grain size observed here is such that superparamagnetic behaviour should be expected for the material at room temperature (BUTLER & BANERJEE, 1975).

Low temperature magnetization measurements

In order to further characterize the magnetic properties of the observed magnetic particles in the tissue low temperature measurements were carried out using a Quantum Design MPMS-XL SQUID magnetometer. A section of the upper beak skin (thickness approx. 1 mm) was embedded in a diamagnetic resin. "Zero-Field cooled" (ZFC) and "Field-cooled" (FC) curves were measured for different applied fields. The ZFC-FC-curves show paramagnetic behaviour up to temperatures of around 20 K. A broad peak is visible at higher temperatures (around 140 K). At applied fields of 100 and 150 G this peak is shifted to slightly higher temperatures (~ 160 K) and disappears at 200 G.

For the remanence decay the sample was initially cooled in zero applied field, then magnetically saturated (H_{appl} 25 kG) at 5 K, and then the remanent magnetic moment was measured in zero field as a function of the temperature. In order to obtain the distribution of the blocking temperatures the remanence curve was differentiated. The data were fitted assuming a log-normal distribution of blocking temperatures as described by BLANCO-MANTECÓN & O'GRADY (1999). We have fitted the data with 3 log-normal distributions. The occurrence of a low and an intermediate blocking temperature (3.4 and 17.3 K) is similar with the studies on synthetic magnetites by BLANCO-MANTECÓN & O'GRADY (1999) who described a bimodal distribution in blocking temperatures due to the growth process by which the particles are formed. The third component is characterized by a blocking temperature of ~ 110 K.

The influence of an applied magnetic field on the peak temperature of ZFC-curves has previously been observed for magnetite (LUO et al., 1991) and γ-Fe_2O_3 (SAPPEY et al., 1997). LUO et al. attribute the increase of T_B with H to the dipole interaction of the particles in a system with a random anisotropy. They also observed an increase of the peak temperature with increasing concentration of magnetite particles.

Taking into consideration the electron microscopical observation the results of the magnetic measurements are interpreted as a combination of two effects: The rapid decay of the magnetization at low temperatures is an indication for very small superparamagnetic particles. The peak at higher temperatures can be attributed to the clusters which consist of agglomerated magnetite particles. This interpretation is supported by the TEM investigations which showed that within the cluster the distribution of the magnetite particles is not completely homogeneous. There are regions with agglomerated and dispersed particles. The results do not give any evidence for single domain particles.

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