Acta Mineralogica–Petrographica, Szeged, XLI, Supplementum B, 2000

THEORETICAL MODELS OF MAGNETIC-FIELD RECEPTORS BASED ON SUPERPARAMAGNETIC MAGNETITE

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Numerous animal species use the Earth's magnetic field for their orientation (see WILTSCHKO & WILTSCHKO, 1995). However, the nature of the postulated "magnetic sense organ" is still a matter of speculation. Recently, a structural candidate for a magnetic field receptor in homing pigeons could be identified (HOLTKAMP-RÖTZLER et al., 1997): clusters of superparamagnetic (SP) magnetite crystals (with grain sizes between 2 and 5 nm) in close association to magnetically sensitive nerves; the cluster size typically amounts to 3 µm.

The question therefore rises as to how a magnetoreceptor based on SP magnetite could work, for SP particles do not behave like compass needles as, for example, single-domain magnetites found in magnetic bacteria. In SP particles, the magnetisation vector **m** can rotate more or less freely within the crystal; as a consequence, the external magnetic field $\mathbf{H}_0$ will (on average) align **m** parallel to $\mathbf{H}_0$ but not the SP particle itself. A torque receptor therefore will not work in the case of SP particles.

Three new receptor models were developed to the point of making quantitative predictions which are testable by experiments. The working principle of each model receptor is a transformation of magnetic field energy into mechanical strain, an idea originally presented by KIRSCHVINK & GOULD (1981). However, as shown in WINKLHOFER (1999), their model, the so-called elastic rod transducer, is founded on physically wrong assumptions leading therefore to results that stand in contradiction with experimental facts. The newly formulated receptor models predict an extension of the SP clusters along the axial direction of an externally applied magnetic field $\mathbf{H}_0$ with the amount of deformation being a measure of field intensity. Since the strain ellipsoid indicates the axial direction of $\mathbf{H}_0$ but not its polarity, such a receptor would be in accordance with the characteristics of the inclination compass of migratory birds as deduced from behavioural experiments.

The amount of strain depends on the viscoelastic properties of the embedding medium, where three cases are distinguished here:

A) SP particles in an elastic matrix (e.g., the cytoskeleton);

B) SP particles in a liquid surrounded by a vesicle membrane;

C) SP particles attached to the membrane of a vesicle or a cell.

It is demonstrated for each model that – even in the comparatively weak geomagnetic field – the magnetic field induced strain is sufficiently large to be detected by molecular mediators of cellular mechanotransduction such as the cytoskeleton or mechanosensitive ion channels in the cell membrane.

Several possibilities are discussed of how small variations in geomagnetic field intensity could be resolved by a so-called active magnetoreception, that is by reversing magnetic field induced changes in receptor shape through regulation of internal control parameters, as for example the osmotic pressure difference across the receptor membrane.

References

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