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MAGNETOTACTIC ALGAE

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During the last years evidence has been accumulated that living organisms may use the geomagnetic field for orientation and navigation[1].

The discovery of magnetotactic bacterias by R.Blackmore in 1975[2] and the spectroscopic studies by R. Frankel[3] are landmarks in this field since besides the unequivocal evidence of tactic response to magnetic fields the physical mechanism of orientation via the geomagnetic field is reasonably well understood. The magnetotactic bacterias have a chain (or two) of cristals of magnetite in the interior of cytoplasm, visible by electron microscopy, and the interaction between the magnetic moment of this chain and the geomagnetic field is responsable to the orientation. The movement is given by the flagellas and they swim along the field line. The dimensions of each cristal of

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the chain are characteristic of magnetic monodomaines.

Several morphological different types of magnetotactic bacterias were observed in freshwater and marine water collected in North[2,3] and South[4,5,6] hemispheres as well in the geomagnetic equator[5]. South-seeking bacterias swam forward the South while North-seeking to the North.

Magnetotactic bacterias collected in South-hemisphere sediments are almost exclusively South-seeking while cells from North-hemisphere sediments are almost exclusively North-seeking. In the geomagnetic equator it is seen roughly equal number of North-seeking and South-seeking bacterias in the same sediment samples.

We report here the first observation of an eukariote microorganism which responds to the magnetic field in a similar way as the magnetotactic bacterias: the flagelar green algae Chlamydomona collected in samples from the Rodrigo de Freitas lagune in Rio de Janeiro.

Rodrigo de Freitas is a coastal lagune, with sometimes fresh-water and other times marine waters predominating. It is located in the Rio de Janeiro metropolitan area and the parameters of waste disposal are overloaded. In this strongly polluted lake tons of fish are killed periodically by unbalanced aquatic ecosystem[7].

Due to its geological situation the lagune receives iron from ferruginous waters of the "Aguas Férreas" district in Rio de Janeiro which arrive as ground waters to its hydrographical bassin.

H_2S is common in the bottom of the lagune and combines with the iron salts and oxides to form sulphides, from precipitate to colloidal form, which colour the anaerobic layer at the bottom in black.

Samples with water and mud were collected at a depth of about 20 cm from the surface of the lagune. The organically polluted waters are in the saprobic biological zone, with bacterial population decomposing the organic matter, and with plankton of the blue green algae Anabaena and Oscillatoria and sometimes a Brachionus plicatilis O.F. Mueller. These characteristics denote a β-mesosaprobic zone of pollution[7,8].

Drops of liquid were observed in an optical microscope in the presence of a magnetic field. Two types of magnetotactic South-seeking microorganisms were observed, with population densities from 100 to 5000 cells per milliliter. A smaller one with typical bacterial size of about 1 μm, and another with larger size than bacteria, with 5 to 7 μm diameter. These are solitary free swimming cells, pyriform to spherical shape, with light green colour of chrophyll and flagella at the anterior end.

By fixation with osmic acid 1% in chromic acid solution 1% the cell stays pyriform to rounded but never fusiforme. After fixation a cup shaped chloroplast is observed and there are four to five pyrenoids. A red eyespot stigma is observed at about a distance of 1/6 diameter of the cell from the external membrane, anteriorly. The cell wall shows about 10 to 12 slightly ondulated contour, but never blunt processes.

With iodine solution a cup shapped chloroplast appears, with 3 blue coloured spots: 2 lateral and another one at the posterior end of the cell. One observes the structure of one central blepharoplast for one flagella.

This characteristics suggest a Chlamydomonas algae of the Pleichloris sub-genus[9]. In view of its magnetotactic response the specific name Chlamydomonas magnetotatica seems appropriate.

It is observed that this algae migrate under the microscope to the south magnetic pole under the action of the geomagnetic field with the same characteristics of South-seeking magnetotactic bacterias. Near the end of the drop (at about 30 μm) these microorganisms swim randomically.

Samples containing these cells were also observed in uniform magnetic fields up to 4 gauss provided by a pair of Helmholtz coils mounted on the base of the microscope. A film sequence of the movement was made and one observes that the movement is well described by a cylindrical helix allongated trajectory aligned to the field line. The velocity of these algae at field up to 3 gauss was determined by cinematography and was found to be about 60 microns per sec.

Near the end of the drop these algae stop and rotate around themself. This rotation is probably due to the flagella action. When the sample is very rich in South-seeking magnetotactic algae it is observed that these organisms forms something like a planar crystal structure at the end of the drop with side-by-side cells arrangement. When the magnetic field due to the coil was reversed the algae executed U-turns and swam opposite to the initial direction. The time response of this U-turn is of the order of 0.5 to 0.8 sec.[10].

Demagnetization procedure was made with small magnetic tape degausser by exposing these algaes to and subsequently slowly moving away an alternating (60 Hz) strong magnetic field. The sample was observed in the microscope and during exposure to the field the moviment was randomic. When the strong field was cut out it is observed that a significant number of algaes was North-seeking while others remains South-seeking. Thus each cells have magnetic dipoles which are essentially single magnetic domain and cannot be demagnetized; however the polarity can be reversed.

In all the magnetic bacteria it has been shown that the magnetic monodomains are constituted by magnetite. In the case of Chlamydomonae algae it has not yet been possible to determine the nature of the intracelular magnetic material. Although it is also possibly magnetite other magnetic mineral such as pyrrhotite, Fe_7S_8, the only magnetic sulphide, cannot be ruled out due to the ecological ambient of the Lagoa Rodrigo de Freitas.

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10. Measurement of the diameter of the U-turn gives an estimation of the magnetic moment of this alga to be $\sim 1.4 \times 10^{-11}$ emu. (about 10 times the magnetic moment of the bacteria). This estimated value of the magnetic moment gives a U-turn time of the order of 0.8 sec. in accordance to measurement time.