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19. The < 53- μ m fraction of the fly ash, which was obtained by mechanical sieving, was introduced into a microparticle classifier (Bahco 6000). Several size fractions were obtained and were subsequently identified by means of light and electron microscopy. The identified size fractions were mixed with Josephine loam soil to produce fly ash concentrations up to approximately 5 percent (by weight). The mixtures were cropped to alfalfa for approximately 1 year. The values shown in Fig. 1b are average values for samples collected from the early- and late-season clippings of the crop. Strontium in the plant materials was analyzed by neutron activation analysis.

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Magnetotactic Bacteria at the Geomagnetic Equator

Abstract. *Magnetotactic bacteria are present in fresh water and marine sediments of Fortaleza, Brazil, situated close to the geomagnetic equator. Both South-seeking and North-seeking bacteria are present in roughly equal numbers in the same samples. This observation is consistent with the hypothesis that the vertical component of the geomagnetic field selects the predominant polarity type among magnetotactic bacteria in natural environments.*

Several species of magnetotactic bacteria have been observed in aquatic sediments of the Northern and Southern Hemispheres (1-5). Each bacterium contains magnetosomes consisting of enveloped, single-domain magnetite particles. The magnetosomes are often arranged in chains with a magnetic dipole moment, parallel to the axis of motility, sufficiently large that the cell is oriented along the geomagnetic field lines as it swims (6, 7). Cells with North-seeking pole forward swim North along the magnetic field lines; cells with the South-seeking pole forward swim South. Because of the inclination of the geomagnetic field, North-seeking cells migrate downward in the Northern Hemisphere and upward in the Southern Hemisphere; South-seeking cells migrate downward in the Southern Hemisphere and upward in the Northern Hemisphere. Magnetotactic bacteria in Northern Hemisphere sediments are almost exclusively North-seeking (1-3), while bacteria in Southern Hemisphere sediments are almost exclusively South-seeking (4, 5). Thus downward directed motion is advantageous for, and upward directed motion is detrimental to, survival of these organisms; and the vertical component of the geomagnetic field selects the predominant cell polarity. If magnetotactic bacteria exist at the geomagnetic equator

where the magnetic field lines are horizontal, neither polarity should be selected. We report the observation of various morphological types of magnetotactic bacteria in aquatic sediments close to the geomagnetic equator. North-seeking as well as South-seeking bacteria are present in roughly equal numbers in the same sediment samples.

Samples of fresh water and marine sediments were collected in the vicinities of Fortaleza and Rio de Janeiro, Brazil. At these locales, the total intensity of the geomagnetic field is 0.25 to 0.28 gauss (8), approximately one-half the intensity at locales in New England and New Zealand where magnetotactic bacteria have previously been found. Fortaleza is situated close to the geomagnetic equator (inclination < 4°) while at Rio de Janeiro the inclination of geomagnetic field is 25° to 30° South. Magnetotactic responses of bacteria in sediment samples were observed in uniform magnetic fields, up to 3 gauss, provided by a pair of Helmholtz coils mounted on either side of a Nikon SMZ-10 stereomicroscope. The magnetic field axis was aligned parallel to the horizontal component of the geomagnetic field. The direction of current flow in the coils and hence polarity of the imposed magnetic field was selected with a toggle switch. Bacteria from sediment samples collect-

ed in Fortaleza migrated along the magnetic field lines, some in the field direction (North-seeking) and roughly equal numbers in the same sample opposite to the field direction (South-seeking). When the imposed field was reversed, both groups of bacteria executed U turns and swam opposite to the initial direction. Bacteria from sediment samples collected in Rio de Janeiro migrated opposite to the field direction (South-seeking) only, and also reversed direction on reversal of the field. Migration rates of bacteria from both locales were comparable to those of other magnetotactic bacteria.

The bacteria were subjected to a demagnetizing procedure by exposing them to and subsequently slowly moving them away from an alternating 60-Hz magnetic field over 1000 gauss produced by a small hand-held magnetic tape degausser. North-seeking and South-seeking bacteria from Fortaleza were first separated by their magnetotactic response, placed in separate water drops on a microscope slide, and then exposed. Whereas before exposure all the bacteria in each drop swam exclusively in the field direction, or opposite to the field direction, after exposure each drop contained approximately equal numbers swimming in and opposite to the field direction. Similar results, previously reported for other magnetotactic bacteria (4), were also obtained with South-seeking bacteria from Rio de Janeiro. Thus each bacterial magnetic dipole is essentially a single magnetic domain and cannot be demagnetized. However, the polarity can be reversed (2) and the demagnetization procedure results in the reversal of about one-half of the dipoles of the bacterial population in each drop. Preliminary electron microscope studies show that North- and South-seeking bacteria from Fortaleza are morphologically identical and contain intracytoplasmic electron opaque particles (9). Magnetosomes consisting of intracytoplasmic, enveloped, magnetite particles are a characteristic of all magnetotactic bacteria studied to date (10-12).

In order to determine experimentally the effect of a vanishing vertical magnetic field, sediments samples from New England initially containing exclusively North-seeking bacteria were placed in a Mumetal enclosure in New England in which the magnetic field intensity was less than one hundredth the intensity outside the enclosure. The polarities of bacteria from both experimental and control samples placed outside the enclosure were monitored periodically over several weeks, that is, many bacte-

rial generations. In the experimental samples, numbers of South-seeking cells increased with time until the ratio of South-seeking bacteria to North-seeking bacteria approached 1.0. No such changes occurred in the control samples. Thus, in natural habitats and in laboratory experiments neither cell polarity is selected in the absence of a vertical magnetic field. These findings complement previous observations that a predominant cell polarity is selected, depending on the sign of the vertical component of the ambient magnetic field (4). Because oxygen is toxic for these microaerophilic or anaerobic organisms (1), cells whose polarity causes them to be directed toward and kept in the sediments and away from the water surface will be favored.

Because of the horizontal orientation of the magnetic field at the geomagnetic equator, the motion of magnetotactic bacteria there will be directed horizontally. This could be advantageous to bacteria of either polarity in reducing detrimental upward migration, compared to random motion. Extended straight-line motion could also be advantageous as an escape response, for population dispersal, and as a means of outrunning chemical diffusion and finding more suitable environments (5, 13, 14). Their magnetism would also cause cells to localize in regions of high magnetic flux density surrounding materials with high magnetic susceptibility in the environment (7, 15); and bacteria that are within about 4 μm of each other will experience magnetic interactions stronger than thermal energy. These interactions may be advantageous but would not favor either polarity at any latitude.

Since the total intensity of the geomagnetic field in Brazil is less than one-half the intensity of the field in New England, Brazilian bacteria would need larger magnetic moments on the average to maintain the same ratio of magnetic-to-thermal energy and hence the same degree of alignment in water at ambient temperatures for the magnetotactic response (7). This hypothesis could be confirmed by detailed electron microscope studies of their magnetosomes or by observation of their swimming response in the magnetic field direction as a function of magnetic field strength (16).

Finally, the presence of magnetotactic bacteria at the geomagnetic equator implies their ability to survive periodic reversals or excursions of the geomagnetic field (17) even at latitudes with large inclination. Because of the nondipolar

contribution to the geomagnetic field, the field intensity at any point on the earth's surface does not completely vanish during reversal, but does fluctuate in magnitude and rotate through zero inclination. During the reversal period of thousands of years, the distribution of magnetic dipole strengths of a bacterial population in a given locale could shift in response to decreasing and increasing field conditions, and the relative numbers of South- and North-seeking cells in the population could change in response to changes in the magnetic inclination.

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Prostacyclin: A Potent Antimetastatic Agent

Abstract. *Metastasis is the principal cause of failures to cure human cancers. Prostacyclin is a powerful antimetastatic agent against B16 amelanotic melanoma cells. This effect, which may result from the platelet antiaggregatory action of prostacyclin, is potentiated by a phosphodiesterase inhibitor. Inhibitors of prostacyclin synthesis increase metastasis. Prostacyclin and agents that may increase endogenous prostacyclin production or prolong its activity are suggested as new antimetastatic agents.*

The ability of primary neoplasms to metastasize is a major obstacle in the search for a cure for human cancers. The development of a metastasis represents the terminal stage of an intricate series of events in which malignant cells, released from a primary tumor, disseminate to distant sites principally by way of the circulatory system (1). Most tumor cells dispersed by this route die (1). However, primary neoplasms have a mosaic of cellular potentials (1), and subpopulations of cells may have inherent biological properties that guarantee their survival. One of these properties may be the ability of the tumor cells to interact with and attach to host platelets (2), thus enhancing their potential to lodge in the microvasculature (arrest) and adhere to vascular endothelium. Alternatively, after arrest, tumor cells may initiate the formation of surrounding, protective

platelet thrombi until extravasation is completed (3). Anticoagulant therapy with aspirin (2, 4), dipyridamole (5), heparin (6), and warfarin (6, 7) has been attempted in the hope of reducing metastasis. However, results to date are inconclusive. The studies we describe here were designed to determine if prostacyclin (PGI_2), the most potent antithrombogenic agent known (8), would reduce tumor cell metastasis.

Subcutaneous B16 amelanotic melanoma (B16_a) tumors were maintained in syngeneic C57BL/6J mice (Jackson Laboratory). Cell suspensions from primary tumors were obtained by a modification (9) of our described procedure (10).

Injection of B16_a cells into their syngeneic host resulted in the consistent appearance of metastatic foci in the lung, liver, and spleen (Table 1). Metastatic