J. exp. Biol. (1980), **86**, 345–347
Printed in Great Britain

SOUTH-SEEKING MAGNETIC BACTERIA

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(*Received* 29 *January* 1980)

During the past few years, a wide variety of living organisms have been found which biologically synthesize the ferrimagnetic mineral, magnetite (Fe_3O_4). First discovered as a biogenic material in the teeth of a primitive mollusc, the chiton (Polyplacophora, Lowenstam 1962), it has since been found as an organic precipitate in magnetically sensitive honey bees (Gould, Kirschvink & Deffeyes, 1978), homing pigeons (Walcott, Gould & Kirschvink, 1979) and bacteria (Frankel, Blakemore & Wolfe, 1979). In all of these organisms (except the chiton), the magnetite is apparently used to orient with or detect the direction and intensity of the earth's magnetic field (Kirschvink, 1979; Kirschvink & Gould, in review).

Magnetotactic bacteria, originally discovered by Blakemore (1975), are by far the most convincing and abundant example of magnetically sensitive organisms in existence. Their magnetite crystals passively align the bacteria with the earth's magnetic field like a 3-dimensional compass (Frankel *et al.* 1979). These micro-aerophilic bacteria normally live in the soupy, oxygen-poor mud/water transition zone in many freshwater and marine environments. If the mud is disturbed so that the bacteria are exposed to oxygen-rich water, the species discovered so far (all from the northern hemisphere) swim rapidly along the direction of magnetic *north*. Because the magnetic field dips downward in the northern hemisphere, the bacteria eventually reach the mud/water interface again and avoid poisoning themselves with oxygen. Moench & Konetzka (1978) have devised an elegant technique to purify the bacterial population based on their swimming response – the bacteria will swim towards the south magnetic pole of a bar magnet placed near their jar, purifying themselves into a characteristic little pellet containing millions of individual cells. (The north geographic pole is magnetically south, so the bacteria were still trying to go to the north and down.)

Two major questions concerning the behaviour of these bacteria need to be answered, however: (1) which way do they swim in the southern hemisphere, and (2) what do they do on the magnetic equator where the field is horizontal?

In an attempt to answer the first question, I used the technique described by Moench & Konetzka (1978) during November 1979 on a variety of freshwater muds collected from small streams and rivers in Victoria and New South Wales, Australia. At most of these localities, I found detectable concentrations of *south*-seeking magnetotactic organisms (Table 1); none of them naturally swam to the north as do the northern hemisphere species. This result is consistent with Blakemore's (1975)

Table 1. *Magnetic bacteria localities in Australia and Hawaii*

Locality	Latitude	Longitude	Water body	Relative population density
Mildura	34° 10′ S	142° 10′ E	Murray river	Moderate, south-seeking
Horsham	36° 42′ S	142° 11′ E	Small stream	Weak, south-seeking
Mt Gambier	37° 49′ S	140° 44′ E	Two crater lakes	None observed
Corryong	36° 10′ S	147° 57′ E	Small stream	Moderate, south-seeking
Canberra	35° 15′ S	149° 8′ E	Fyshwick sewage oxidation pond	Strong, south-seeking
Oahu, Hawaii	21° N	202° E	Small stream near H.I.G.	Moderate, north-seeking

hypothesis that the basic role of the swimming response is to help the bacteria find their home in the mud. (In the southern hemisphere, magnetic south generally leads down.) By far the best locality for collecting south-seeking magnetotactic bacteria was a sewage oxidation pond near Canberra.

The second question has not yet been answered. Knowing that both northern and southern hemisphere magnetic bacteria use the earth's field to swim down and into the mud suggests that they should not be able to survive on the magnetic equator. Other selective advantages may be involved, however, such as the ability of a small bacterium to move consistently in one direction despite the randomizing influence of thermal agitation (Brownian motion). Such a preferred orientation, for example, might help them escape from predators more successfully than would a random walk, or it may improve their food gathering ability by reducing the number of times they cross their own paths while foraging.

Clearly, it is important to check the magnetic equator carefully. As discussed by Kirschvink & Lowenstam (1979), the magnetite from magnetotactic bacteria may play a major role in the magnetization of marine sediments, particularly in areas far away from other sources of heavy minerals. This becomes very important in the study of the paleomagnetism of oceanic sediments, since the absence of a major magnetic input would reduce their magnetostratigraphic value. Further, if magnetotactic bacteria cannot survive long periods of time in the horizontal magnetic field of the magnetic equator, then during a geomagnetic reversal the population at any place will temporarily vanish. This is because the field at any point on the earth during a reversal must at some time be horizontal. The northern and southern hemispheres' marine magnetic bacterial populations would have to switch hemispheres during the slow transition process (10^4–10^5 years). Presumably, the freshwater strains would go extinct because they could not escape by moving along with the magnetic field, as would the marine forms. This line of reasoning would imply that freshwater bacteria periodically evolve from marine organisms after each reversal. The apparent absence of magnetic bacteria in the Mt Gambier crater lakes (Table 1), which have no natural outlet for post-reversal recolonization, supports this extinction idea. My additional observation of freshwater magnetic bacteria on the island of Oahu, Hawaii supports this re-adaption to freshwater hypothesis. Otherwise, how could freshwater bacteria reach an isolated oceanic island? An inert, wind-blown stage has not yet been reported in their life-cycle. There is certainly a great need for additional ecological and biological work on these creatures.

I greatly thank Drs J. Daly and M. W. McElhinny of the Australian National University and Dr B. J. J. Embleton of the C.S.I.R.O. for assistance during the field work. J. L. Gould and A. G. Fischer gave helpful comments on the manuscript. Supported by NSF grants EAR78-03204 and SPI79-14845.

REFERENCES

BLAKEMORE, R. P. (1975). Magnetotactic bacteria. *Science, N.Y.* **190**, 377–379.

FRANKEL, R. B., BLAKEMORE, R. P. & WOLFE, R. S. (1979). Magnetite in freshwater marine magnetic bacteria. *Science, N.Y.* **203**, 1355–1356.

GOULD, J. L., KIRSCHVINK, J. L. & DEFFEYES, K. S. (1978). Bees have magnetic remanence. *Science, N.Y.* **201**, 1026–1028.

KIRSCHVINK, J. L. (1979). Ph.D. Thesis, Princeton University, Princeton, N.J.

KIRSCHVINK, J. L. & GOULD, J. L. (1980). Organic magnetite as a basis for magnetic field sensitivity in animals. *J. comp. Physiol.* (in Press).

KIRSCHVINK, J. L. & LOWENSTAM, H. A. (1978). Mineralization and magnetization of chiton teeth: Paleomagnetic, sedimentologic, and biologic implications of organic magnetite. *Earth Plan. Sci. Lett.* **44**, 193–204.

LOWENSTAM, H. A. (1962). Magnetite in denticle capping in recent chitons (*Polyplacophora*). *Geol. Soc. Am. Bull.* **73**, 435–438.

MOENCH, T. T. & KONETZKA, W. A. (1978). A novel method for the isolation and study of a magnetotactic bacterium. *Archives of Microbiology* **119**, 203–212.

WALCOTT, C., GOULD, J. L. & KIRSCHVINK, J. L. (1979). Pigeons have magnets. *Science, N.Y.* **205**, 1027–1029.