ing program cannot assess damage to the animals.

"Dramatic, obvious effects, such as whales floating to the surface will be detected, but some effects will be too subtle—such as changes in reproduction, mortality, and growth rates," Wellgart said.—*M. Catherine White*

Rock Magnetism Linked to Human Brain Magnetite

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This piece was written to help inform science teachers, students, and journalists about some of the latest developments in the geophysical sciences. It will also appear in Earth in Space, *published by AGU.*

Magnetite has a long and distinguished career as one of the most important minerals in geophysics, as it is responsible for most of the remanent magnetization in marine sediments and the oceanic crust. It may come as a surprise to discover that it also ranks as the third or fourth most diverse mineral product formed biochemically by living organisms, and forms naturally in a variety of human tissues [*Kirschvink et al.*, 1992].

Magnetite was discovered in teeth of the Polyplacophora mollusks over 30 years ago, in magnetotactic bacteria nearly 20 years ago, in honey bees and homing pigeons nearly 15 years ago, but only recently in human tissue.

Research in the somewhat obscure geophysical field of rock magnetism led to many of these more recent discoveries, as many of the instruments and techniques developed for these studies lend themselves directly to the problem of finding ferromagnetic materials in tissue samples.

Most recently, extension of these rock-magnetic techniques to biological materials has pointed to the presence of a biological surprise: a new cell type loaded with crystals of biogenic magnetite, which we have dubbed "magnetocytes."

Several important clues concerning the organization of magnetite crystals in the human brain were present in our original magnetic data, which in fact led to the discovery of these new cells. Over the past 20 years, geophysicists working in the field of rock magnetism have developed sensitive techniques to determine whether the magnetic crystals within a sample are close to each other. It turns out that the magnetic field of one crystal upon its neighbor will cause distinctive shifts in the coercivity spectrum of a sample. This inhibits the acquisition of an isothermal remanent magnetism (IRM) but aids in its demagnetization [e.g., *Cisowski*, 1981].

These effects are present in virtually all vertebrate tissues examined to date, including the human brain, implying that the human magnetite crystals are not isolated from each other.

Calibration studies of these interaction effects done with bacterial magnetites and the more sensitive techniques of anhysteretic remanent magnetization (ARM) [e.g., *McNeill and Kirschvink*, 1993] indicate the magnetite crystals in the brain are present in clumps with a minimum of 50 or more particles per clump. Hence, rather than one crystal per 100 brain cells, there is less than 1 cell in 5000 with one of these magnetite clumps.

Unfortunately, the rock magnetic data do not place an upper limit on the number of crystals present per cluster—something on the order of at least 50 is needed, but it could just as well be 10,000.

More recent work suggests that the upper number may be more correct. Recently, we have found that pellets of the Jurkat strain of human T-lymphocytes have peculiar magnetic dipole patterns when viewed with three-dimensional magnetic resonance imaging (MRI) microscopy [*Ghosh et al., 1993*]. The number density of these patterns, along with the magnetite concentrations measured with SQuID magnetometry, implied the presence of between 1000 and ~10,000 magnetite crystals per dipole pattern.

We also have evidence that magnetocytes are naturally present in tissues, rather than formed as some bizarre differentiation product in the cell cultures. In collaboration with our group, M. H. Nesson of Oregon State University has disaggregated normal mouse brain tissue with multiple freeze-thaw cycles and used our "magnetic finger" technique to pull out magnetic objects. This technique allows cell fragments only a few microns across to be extracted, and these fragments contain hundreds of single-domain magnetite crystals nearly identical to those in the human brain. The close packing arrangement is precisely what is needed to produce the magnetic interaction effects noted above.

The biological function of these magnetocytes is as yet unknown. They are definitely not used to detect the geomagnetic field, as they do not contain the linear chains of crystallographically aligned magnetite crystals as do magnetotactic bacteria, protozoans, migratory fish, and birds.

At the risk of engaging in speculation, our best guess is that the magnetite crystals are important for biochemistry. The lipid-bilayer membranes surrounding the magnetite crystals in bacteria contain several hundred distinct proteins of unknown function. It is easy to show that these proteins reside in a local, static magnetic field that ranges from 0.2 to 0.5 T (2000 to 5000 Gauss) produced by the enclosed magnetite crystal.

Although these field strengths are probably too weak to produce significant magnetomechanical orientations in diamagnetic molecules, which need fields approaching 1 T, they are well within the range needed to produce dramatic effects on the electronic spin states of reaction intermediates. Controlling the decay path of a triplet state, for example, only requires magnetic fields on the order of ~10 mT or 100 Gauss [e.g, *McLaughlin*, 1989].

As magnetite biomineralization evolved nearly 2 b.y.a. [*Chang and Kirschvink*, 1989], evolution has had ample opportunity to incorporate magnetically mediated reactions into biochemistry. Rock magnetism may yet induce another field of study.—*Joseph L. Kirschvink, California Institute of Technology, Pasadena, Calif.*

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New Map for Climate Change, Ecosystems Researchers

PAGE 180

A new map of the land cover regions of the conterminous United States and its accompanying digital data set can provide scientists with a new tool for investigating the ecosystem effects of climate change.

The map combines satellite imagery, digital elevation, ecoregion, and climate data sets to build a database containing 159 separate land cover regions across the lower 48 states. Each of the map's regions has a unique combination of vegetation and land cover types. Typical vegetation or land cover patterns commonly found in each region are listed in the map's legend.

Additional small-scale maps depict the length of vegetation greenness, the onset of greenness, and peak greenness.

The map, "Seasonal Land Cover Regions," is available for $3 from USGS Map Distribution, Box 25286, MS 306, Denver Federal Center, Denver, CO 80225; the complete digital data set and documentation for the map are available on CD-ROM for $32 from Customer Services, EROS Data Center, Sioux Falls, SD 57198.

Atmospheric Information Available on Gopher

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The Atmospheric Sciences Department at the University of Illinois, Urbana-Champaign, is opening a new full-scale World Wide Web (WWW) server, The Daily Planet. This envi-