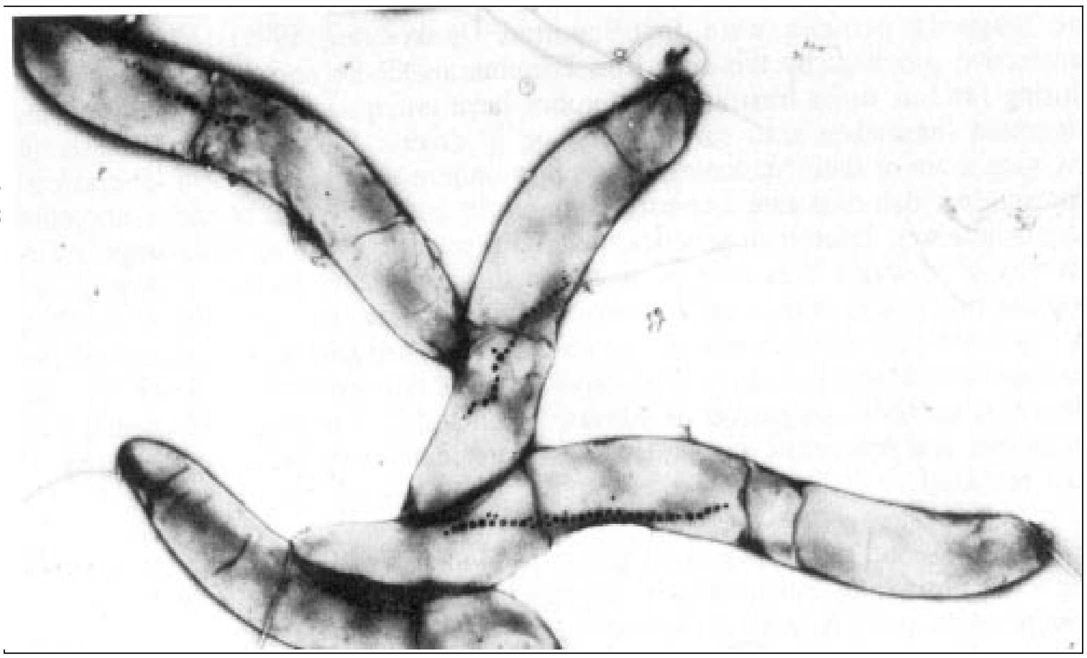
Inside…

The IRM Quarterly

FALL 1995, VOL. 5, NO. 3 INSTITUTE FOR ROCK MAGNETISM



Cells of Aquaspirillum magnetotacticum, *containing chains of magnetosomes. From "Magnetotactic magnetogens", by R.P. Blakemore and N.A. Blakemore, in* Iron Biominerals, *1990.*

IRM Hosts Workshop on Sedimentary Biogeomagnetism

Stefanie
Brachfeld
IRM

A two-day interdisciplinary workshop brought together 29 invited participants from the five research communities of magnetism, geology, biology, organic chemistry, and inorganic chemistry, to assess the state of cooperative research, and to recommend promising avenues for future efforts.

WHY SEDIMENTARY BIOGEOMAGNETISM?

The 1994 Santa Fe Workshop on Rock Magnetism, Geodynamics, and Environmental Magnetism, produced recommendations for focus areas of interdisciplinary research involving rock magnetism and other fields. Researchers felt that in order to make truly new contributions in the area loosely called "Magnetic Effects (or Proxies) of Chemical Change," we need to integrate current rock-magnetic research approaches with their natural geological and biological bases. Thus originated the idea for a new interdisciplinary field, which was launched by the Sedimentary Biogeomagnetism Workshop at the University of Minnesota, sponsored by the IRM and the NSF Paleorecords of Global Change Research Training Group (RTG).

CONFERENCE OUTLINE

On September 2 and 3 approximately 30 geologists, geophysicists, physicists, chemists and biologists, all with magnetic inclinations (no pun intended) gathered in Minneapolis to discuss interdisciplinary approaches to studying biomineralization of magnetic minerals and their role in rock-magnetic and paleomagnetic records.

Subir K. Banerjee started the conference by proposing the following list of topics as the most important questions to be answered in sedimentary biogeomagnetism:

- Formation and dissolution of iron minerals through biomineralization and biologically mediated reactions.
- Physical and chemical characteriztion of biomineralized magnetic minerals, or BMM *[ed. note: not to be confused with Bruce M Moskowitz!]*.
- Recognition of BMM in nature.
- Relative importance of BMM as constituents of soils and sediments.
- Extraction of proxy records:
  Paleoredox changes
  Paleoproductivity
  Paleorecords of global environmental change

SESSION SUMMARY

The conference consisted of three sessions, 1) Biogeochemistry and

Workshop *continued on page 7…*

Visiting Fellows' Reports

Among the guests at the *IRM* this summer and fall, **Phil Schmidt** and **Dave Clark**, up from Down Under for an informal visit, looked into the sources of a magnetic anomaly. **Pieter Vlag**, from CEREGE, Aix-en-Provence, investigated the rock magnetic record of climate change in Maar lakes. **Ellen Platzman** of University College brought a set of enigmatic paleomagnetic samples and attempted to identify the cause of anomalous NRM orientations.

Phil Schmidt and **Dave Clark**

CSIRO Division of Exploration and Mining

Magnetite-Hematite Exchange Coupling

Although much of our work at CSIRO assisting minerals exploration companies is mundane, occasionally we are presented with a problem that is quite exciting. The one we brought with us to the IRM, after attending the Boulder IUGG in July, concerned the interpretation of a routine magnetic survey carried out by an exploration company. The company had found a large magnetic anomaly which could not be explained on the basis of the susceptibility of mineralized material intersected in a drill hole. We were called in and selected samples from a number of diamond drill cores and subsequently showed the anomaly to be due to remanent magnetization. Most samples possessed Koenigsberger ratios (Q) >> 1 and one was found with a Q = 1230. If the samples had been from the surface we would have suspected lightning to be the cause. However, high Qs are required to explain the anomaly, so we have no reason to doubt their reality. From k-T results (77K to 960K) the material is massive hematite with very finely subdivided magnetite.

The experiments we wanted to perform were hysteresis measurements using Micromag and heating of a low-temperature (LT) SIRM from 20K to 300K, using the MPMS. During the latter, the isotropic point was clearly evident but we were somewhat surprised when the sample passed through the Morin transition that its magnetic moment increased dramatically. The hematite should not have been magnetized by the LT SIRM. The question was, was the hematite magnetized by the small residual field (< 0.03G), or was the hematite exchange coupled to the magnetite?

With the able assistance of IRM staff we designed an experiment to eliminate one of the possibilities. We would repeat the first experiment, but immediately after imparting the LT SIRM, apply a negative field. The magnitude of the negative field would be large enough to cancel any residual field (-1 G was chosen). The result was, the applied negative field did not change the sign of the moment acquired by hematite. Therefore, we concluded that the hematite and magnetite are very closely intergrown, and are exchange coupled.

Ellen Platzman
University College, London

Relationship Between Rock Magnetic Properties and Paleomagnetic Observations in Greenschist Grade Dyke Rocks from Southern Spain.

The principal aim of this project was to characterize the rock magnetic properties of a suite of greenschist grade dyke rocks and to try and relate the results to the three components of remanent magnetization observed in these samples.

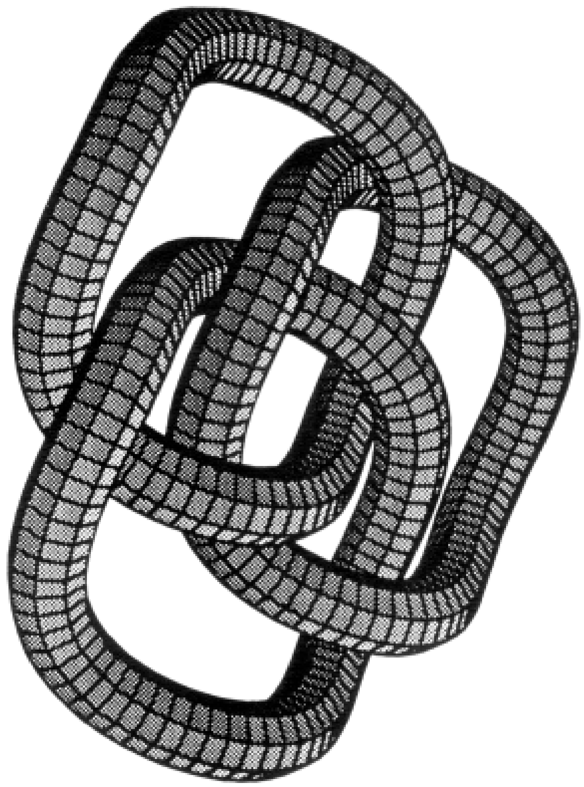
The Malaguide dykes are a suite of Miocene mafic dykes intruded vertically into a previously formed thrust stack in the Betic Cordillera of southern Spain. In thin sections these rocks show a coarse granular igneous texture with primary hornblende, moderately altered zoned calcic plagioclase, primary ilmenite, secondary sphene and chlorite, and abundant opaques. Initial results from K-Ar whole rock analysis suggests that the dykes were intruded into the surrounding graphitic phyllitic schists at 21.8± 5 Ma. during the final stages in the orogenic evolution of the internal zones of the Betic Cordillera.

Previous paleomagnetic results from the unmetamorphosed External Zones of this orogenic belt show clockwise rotations of up to 180°. Records from the Internal Zones, however, are scarce because most of the rocks have been metamorphosed and deformed over a long period of time. The Malaguide dykes can potentially provide us with critical information which will allow us to constrain the vertical axis rotations in this part of the orogenic belt.

Initial results suggest that these dykes have undergone as much as 120° of clockwise rotation since their emplacement. The data are complex, however, and an understanding of the magnetic carriers is essential to our interpretation of the remanence.

The NRM in many of the dykes is composed of three components of magnetization . The lowest temperature component usually unblocks at temperatures less than 200°C and appears to be in the direction of the present day magnetic field. There is a suggestion that this component may also be present at the lowest coercivities (<20mT). It is often unstable and poorly defined, however, and was therefore not investigated further. The intermediate temperature component is unblocked between 200° C and 450°- 500° C. It has a negative inclination of approximately -45° and is rotated approximately 120° from the reference direction. This direction correlates well with the direction obtained from the highest coercivity component, which is not completely isolated in fields on the order of 100 mT. The component of magnetization with the highest blocking temperature is isolated between 450° and 600° C, decaying linearly to the origin of the vector plot. The declination of this vector is similar to the declination of the intermediate temperature component, but its inclination is horizontal. This direction correlates well with the direction of the component of NRM isolated between approximately 15

VF Reports *continued on page 5…*



Borromean Ring Knot, generated by Christoph Geiss using Mathematica

Current Abstracts

A list of current research articles dealing with various topics in the physics and chemistry of magnetism is a regular feature of the IRM Quarterly. *Articles published in familiar geology and geophysics journals are included; special emphasis is given to current articles from physics, chemistry, and materials-science journals. Most abstracts are culled from* INSPEC *(© Institution of Electrical Engineers),* Geophysical Abstracts in Press *(© American Geophysical Union), and* The Earth and Planetary Express *(© Elsevier Science Publishers, B.V.), after which they are edited and condensed for this newsletter. An extensive reference list of articles—primarily about rock magnetism, the physics and chemistry of magnetism, and some paleomagnetism—is continually updated at the* IRM. *This list, with more than 2700 references, is available free of charge. Your contributions both to the list and to the Abstracts section of the* IRM Quarterly *are always welcome.*

AMS

Borradaile, G., and M. Stupavsky
Anisotropy of magnetic susceptibility: measurement schemes, *Geophys. Res. Lett., 22,* 1957-1960, 1995.
The precision of AMS determination is enhanced by measuring susceptibility in directions with a uniform orientation distribution that include the four body diagonals. Some standard 10.5 cm^3 samples with mean susceptibility < 10^{-4} SI possess too few "magnetic" grains for petrofabric interpretation whatever the measurement strategy. Their AMS should be interpreted only if they pass fabric homogeneity tests.

Gregoire, V. et al.
Shape anisotropy versus magnetic interactions of magnetite grains: experiments and application to AMS in granitic rocks, *Geophys. Res. Lett., 22,* 2765-2768, 1995.
The magnetic fabric of ferromagnetic granitic rocks results from both the shape preferred orientation of individual magnetite grains and their distribution anisotropy through interactions between neighboring grains. Measurement of the low-field anisotropy of single MD magnetite grains shows a linear correlation between anisotropy degree and aspect ratio. Interactions between two elongated grains were studied experimentally in "aligned" and "side-by-side" configurations. Shape and distribution anisotropies are parallel lineations in the former case and perpendicular in the latter. Interaction effects are most important when the particles are separated by less than two or three grain diameters.

Biogeomagnetism

Penninga, I. et al.
Remanence measurements on individual magnetotactic bacteria using a pulsed magnetic field, *J. Mag. Magn. Mater., 149,* 279-286, 1995.
Pulsed-magnetic-field remanence measurements were made for individual, killed, undisrupted cells of three different types of magnetic bacteria. The measurement technique involved the observation of aligned, individual magnetotactic bacteria with a light microscope as they were subjected to magnetic pulses of increasing amplitude. For MM cells the hysteresis loop is square, with coercive field varying from cell to cell, consistent with just two magnetization states for the single chain. For MR and MMP cells, the hysteresis loops are not square, indicating that there are several different magnetization states, and that individual cells can be demagnetized.

Chemistry

Sahota, J. T. S., S. G. Robinson, and F. Oldfield
Magnetic measurements used to identify paleoxidation fronts in deep-sea sediments from the Madeira Abyssal Plain, *Geophys. Res. Lett., 22,* 1961-1964, 1995.
Rock magnetic measurements proved successful in characterizing paleoredox fronts in a sediment core containing multiple turbidites. Previous trace-element studies and observations of sediment color indicated that turbidite emplacement resulted in reductive diagenesis and the formation of paleoxidation fronts. The new magnetic results indicate low concentrations of magnetic minerals in the turbidites, reflecting destruction of magnetic particles by reductive diagenesis.

Climate Change

Schmidt, P. W., and G. E. Williams
The neoproterozoic climate paradox: equatorial paleolatitude for Marinoan glaciation near sea level in South Australia, *Earth Planet. Sci. Lett., 134,* 107-124, 1995.
New paleomagnetic analyses and geological observations of Neoproterozoic (650-600 Ma) redbeds from the Marinoan glaciogenic sequence confirm the Neoproterozoic climate paradox in South Australia: frigid strongly seasonal climate, permafrost, and grounded glaciers near sea level in equatorial paleolatitudes. Resolution of this paradox may illuminate Precambrian planetary dynamics and the change in global state during the Ediacaran.

Sun, W.-W, S. K. Banerjee, and C. P. Hunt
The role of magnhemite in the enhancement of magnetic signal in the Chinese loess-palaeosol sequence: An extensive rock magnetic study combined with citrate-bicarbonate-dithionite treatment, *Earth Planet. Sci. Lett., 133,* 495-505, 1995.
A detailed rock magnetic study of loess and paleosol samples before and after CBD treatment reveals details related to paleoclimate change. CBD treatment removes all maghemite grains and the finest magnetite grains. For the paleosol samples, CBD treatment resulted in decreases of approximately 70% in saturation magnetization (J_s), 80% in susceptibility k, and 90% in anhysteretic remanent magnetization (ARM). In contrast, loess samples showed no significant reduction after CBD treatment. The diminished values of Js, k, and ARM in the paleosols after CBD treatment are similar to the corresponding loess values.

Magnetic Microscopy

Proksch, R. B., et al.
Magnetic force microscopy of the submicron magnetic assembly in a magnetotactic bacterium, *Appl. Phys. Lett.*, *66*, 2582-2584, 1995.
A magnetic force microscope (MFM) was used to image topography and magnetic forces from a chain of submicron single-domain magnetic particles in isolated magnetotactic bacteria. The noncontact MFM data were used to determine the magnetic moment of an individual bacteria cell, of order 10^{-13} emu, consistent with the average moment of bacteria for the sample obtained by SQUID magneteometry. The results represent the most sensitive quantification of an MFM image to date.

Paleointensity

Garnier, F. et al.
Geomagnetic field intensity over the last 42000 years from core SOH-4, Big Island, Hawaii, *J. Geophys. Res.*, in press, 1995.
187 successful Thellier experiments on samples from 100 flows have provided a record of absolute paleointensity for the last 42 kyr. A refined K/Ar technique provided the 42 kyr age, and a linear extrusion rate was assumed to the present. The remanence resides in low-Ti magnetite for 75% of the samples and titanomagnetite for the remainder; both groups yielded reliable paleointensity determinations. Inclinations are anomalously shallow (and in some cases negative) during the interval 16-38 kyr, but otherwise consistent with a geocentric axial dipole. Calculated paleointensities range from 18 to 79 microtesla, with characteristic fluctuations of 20-25 microtesla peak-to-peak amplitude, and a mean value of 45 microtesla.

Stoner, J. S., J. E. T. Channell, and C. Hillaire-Marcel
Late Pleistocene relative geomagnetic paleointensity from the deep Labrador Sea: regional and global correlations, *Earth Planet. Sci. Lett.*, *134*, 237-252, 1995.
Three long piston cores from the deep Labrador Sea appear to record Late Pleistocene variations of relative paleointensity. Two of the cores extend back into isotope stage 6, the third into stage 5. The cores contain high detrital carbonate (DC) and low detrital carbonate (LDC) layers, some of which correspond to North Atlantic Heinrich events. Except for these layers, NRMs normalized by k, ARM or SIRM correlate well, and show no correlation with bulk magnetic parameters. The composite record from the Labrador Sea cores is strongly correlated to a composite of Mediterranean and Indian Ocean records, suggesting that all are records of dipole field variations.

Tauxe, L., T. Pick, and Y. S. Kok
Relative paleointensity in sediments: A pseudo-Thellier approach, *Geophys. Res. Lett.*, *22*, 2885-2888, 1995.
We present a method for normalizing sedimentary records for estimating relative paleointensity of the geomagnetic field, similar to that successfully used to obtain absolute paleointensity from thermally-blocked remanences. It has the advantages that it is more effective in removing unwanted viscous remanence, thereby improving agreement among various records, and that it allows the estimation of the uncertainty in the paleointensity calculated.

Physics

Morup, S., et al.
Spin-glass-like ordering of the magnetic moments of interacting nanosized maghemite particles, *Phys. Rev. B*, *52*, 287-294, 1995.
For samples of interacting nanosized maghemite particles, the apparent blocking temperatures obtained from Mossbauer spectroscopy and zero-field-cooled magnetiaztion curves are nearly identical, but the values obtained from decay of remanence are much lower. These results do not accord with the Neel model for SP relaxation, but can be explained by an ordered spin-glass-like state at low temperature. At a critical temperature a transition to an SP state occurs, and the transition temperature varies with the average interparticle distance.

Reversals

Algeo, T.
Geomagnetic polarity bias patterns through the Phanerozoic, *J. Geophys. Res.*, in press, 1995.
Phanerozoic geomagnetic polarity bias patterns have been reconstructed using polarity data from 278 stratigraphic formations of Cambrian to Jurassic age, combined with data from an established geomagnetic polarity timescale for the Cretaceous to Recent. In addition to the well-known Cretaceous Normal Superchron and Kiaman Reverse Superchron, four other first-order polarity features are recognized: 1) a Middle Cambrian-Middle Ordovician Reverse Polarity Bias Interval (PBI); 2) a Late Ordovician-Late Silurian Normal PBI; 3) an Early Jurassic Normal PBI; and 4) a Middle Jurassic Normal PBI.

Glatzmeier, G. A., and P. H. Roberts
A three-dimensional self-consistent computer simulation of a geomagnetic field reversal, *Nature*, *377*, 203-209, 1995.
A three-dimensional, self-consistent numerical model of the geodynamo is described, that maintains a magnetic feild for over 40,000 years. The model, which incorporates a finitely conducting inner core, undergoes several polarity excursions and then, near the end of the simulation, a successful reversal of the dipole moment. This simulated magnetic field reversal shares some features with real reversals of the geomagnetic field, and may provide insight into the geomagnetic reversal mechanism.

Holt, J. W., and J. L. Kirschvink
The upper Olduvai geomagnetic field reversal from Death Valley, California: a fold test of transitional directions, *Earth Planet. Sci. Lett.*, *133*, 475-491, 1995.
High-resolution records of the upper Olduvai geomagnetic field reversal were obtained from two localities in steeply-dipping lacustrine sediments. The different bedding atitudes allowed the first positive fold test of transitional directions from any geomagnetic reversal. In addition, variations in lithology allowed a comparison of transitional records from different sedimentary environments. A high-coercivity component carried by SD and PSD titanomagnetite is interpreted as primary, based on positive fold and reversal tests, and stratigraphically-bound reversals.

McFadden, P. L., and R. T. Merrill
Fundamental transitions in the geodynamo as suggested by paleomagnetic data, *Phys. Earth Planet. Int.*, *91*, 253-260, 1995.
The cessation of reversals during the Cretaceous Superchron indicates that the geodynamo has two basic states: reversing and non-reversing. The fundamental transitions between states at the beginning and end of the Superchron may reflect a change from a predominantly oscillatory dynamo to a steady one (caused, for example, by a change in the relative roles of the omega and alpha effects). Such a model predicts reduced secular variation during polarity superchrons. The surface integral of angular standard deviation of paleomagnetic directions, used as a proxy of PSV, does in fact show reduced secular variation during the Cretaceous Superchron.

Rock Magnetism

Kelso, P. R., and S. K. Banerjee
Effect of hydrostatic pressure on viscous remanent magnetization in magnetite-bearing specimens, *Geophys. Res. Lett.*, *22*, 1953-1956, 1995.
Experiments on natural and synthetic MD magnetite at 0.1 and 100 MPa (room temperature, 0.1 mT field) showed linear VRM growth with log t at both pressures. There was little change in the rate of VRM acquisition between the two pressures. Thus for similar rocks at depth,

VRM enhancement by thermal fluctuations will dominate over effects due to pressure.

Meillon, S., et al.
Existence of a direct phase transformation from hematite to maghemite, *Philos. Mag. Lett., 72*, 105-110, 1995.
A simple grinding process has been found to result in direct phase transformation from hematite (antiferromagnetic alpha-Fe_2O_3) to maghemite (ferrimagnetic gamma-Fe_2O_3), demonstrated by both crystallographic and magnetic measurements. A shearing component related to the grinding is thought to be responsible for movement of the oxygen planes in the transformation.

Secular Variation

Courtillot, V. and J.-P. Valet
Secular variation of the Earth's magnetic field: from jerks to reversals [Concise Review Paper], *C. R. Acad. Sci. Paris, 320, s. IIa*, 903-922, 1995.
Statistical anlysis of paleomagnetic directions form lavas younger than a few million years confirms the overwhelming dominance of the axial dipole and the presence of a small persistent axial quadrupole. There seems to be an as-yet unexplained departure from perfect symmetry between the normal and reversed states. The significance of other terms, most notably non-axial quadrupoles, is open to discussion. These could result in part from the limited geographic coverage of sampling sites. The picture which emerges is that of a simple, low-degree, persistent field with superimposed random variations, reminiscent of the present-day nondipole field, whose actual variance structure is a promising area for research..

Hagstrum, J. T., and D. E. Champion.
Late Quaternary geomagnetic secular variation from historical and ^{14}C dated lava flows on Hawaii, *EJ. Geophys. Res.*, in press, 1995.
A paleosecular variation (PSV) record has been obtained for the last 4400 years, based on paleomagnetic data from 191 sites in historical and dated Hawaiian lava flows. The record resembles that obtained from Lake Waiau, but with inclinations closer to the expected dipole value of 35 degrees (compared to an average of 27 degrees for the sediments). The rate of PSV determined from the lavas is highly variable, ranging from less than half a degree to more than 20 degrees per century. A pronounced shift in inclination, from 25 to 40 dgerees occured between 1030 and 975 years BP.

Zheng, H., T. Rolph, and J. Shaw
A detailed paleomagnetic record for the last interglacial period, *Earth Planet. Sci. Lett., 133*, 399-351, 1995.
Paleomagnetic study of a late Quaternary loess-paleosol sequence in central China has shown two episodes of anomalous geomagnetic field behavior in soil complex S1, which spans the last interglacial. The age of the younger episode is estimated at 89-75 ka, comparable with the age of a geomagnetic event recognized in the Arctic Ocean and Greenland Sea. The older episode is associated with a low relative paleointensity, and has an estimated age of 130-110 ka, consistent with age estimates for the Blake Event.

Tectonics

Tarduno, J. A. and W. Sager
Polar standstill of the Mid-Cretaceous Pacific plate and its geodynamic implications, *Science, 269*, 956-959, 1995.
Paleomagnetic data from the Mid-Cretaceous Mountains suggest that Pacific plate motion during the Early to Mid-Cretaceous was slow, less than 0.3 degree per year, resembling the polar sandstill seen in coeval rocks of Eurasia and North America.There is little evidence for a change in plate motion that could have precipitated the major volcanic episode of the early Aptian that formed the Ontong Java Plateau. During the volcanism, oceanic plates bordering the Pacific plate moved rapidly. Large-scale northward motion of the Pacific plate began after volcanism ceased. This pattern suggests that mantle plume volcanism exerted control on plate tectonics in the Cretaceous Pacific basin.

Timescales

Hall, C. M., and J. W. Farrell.
Laser $^{40}Ar/^{39}Ar$ ages of tephra from Indian Ocean deep-sea sediments: tie points for the astronomical and geomagnetic polarity time scales, *Earth Planet. Sci. Lett., 133*, 327-338, 1995.
Two Neogene ash layers from ODP Site 758 have been dated with high precision by laser $^{40}Ar/^{39}Ar$, enabling an evaluation of previously assigned ages for O isotope stage 19.1, for the Matuyama-Brunhes boundary, and for the termination of the Nunival subchron. The dates are consistent with ages based on the astronomically-derived geomagnetic polarity timescale (ADOPTS), and are significantly older than ages from the radiometrically derived geomagnetic polarity timescale (RDGPTS) of Mankinen and Dalrymple (1979).

Kent, D. V., P. E. Olsen, and W. K. Witte.
Late Triassic-earliest Jurassic geomagnetic polarity sequence and paleolatitudes from drill cores in the Newark rift basin, eastern North America, *J. Geophys. Res., 100*, 14,965-14,998, 1995.
A detailed reversal stratigraphy has been determined for a 30 million year interval from late Triassic to early Jurassic. A composite stratigraphic section of 4660 m from drill cores in the Newark basin contains 59 polarity intervals. A geomagnetic polarity timescale was constructed by assuming that the cyclic lacustrine strata had a Milankovitch periodicity and by anchoring the palynological Triassic/Jurassic boundary to 202 Ma. The cyclostratigraphically calibrated record provides a reference section for the history of geomagnetic reversals during the late Triassic and early Jurassic.

...VF Reports *continued from page 2*

and 50 mT. It is a direction which is difficult to interpret.

Preliminary IRM acquisition experiments gave curves highly suggestive of a magnetite carrier. High temperature susceptibility studies performed on a Geofyzika kappabridge at Oxford University generally showed a gradual decrease of susceptibility with temperature with a more marked decrease above 500°. One sample showed a clear Hopkinson peak between 500°-575°C. Finally, AMS studies corroborated earlier thin section work and showed that there was no strong magnetic fabric in these rocks.

I hypothesized two grainsize fractions for the carriers of the intermediate and high temperature components of magnetization and went to IRM to test this hypothesis. At IRM I worked extensively on three pieces of equipment: 1) The Micromag to obtain hysteresis parameters of whole rock chips; 2) The Lakeshore AC Susceptometer to obtain information on the frequency dependence of susceptibility; 3) The MPMS to do a (low-T) thermal demagnetization of SIRM to check for transitions and SP (superparamagnetic) size material. Anisotropy of remanence, SEM images, reflected light microscopy and pARM were also examined in a small number of samples to try and identify the carriers of the remanent magnetization.

VF Reports *continued on page 6*…

…VF Reports *continued from page 5*

The results of these experiments present a complex picture. The hysteresis experiments show that the paramagnetic minerals dominate the magnetic response of the samples. They also show that the remanence resides almost exclusively in a PSD (pseudo-single domain) grainsize fraction. Follow-up SEM work corroborated this as we found an overwhelming predominance of ilmenite both primary and as exsolution lamellae along hornblende cleavage planes. On the Lakeshore we observed that there is virtually no variation of susceptibility with frequency either at room temperature or at low temperature, which indicates that there is no appreciable contribution to the magnetization from SP grains.

MPMS experiments show a number of low temperature transitions suggesting that some samples contain both magnetite and pyrrhotite. The higher temperature component of magnetization is therefore almost certainly carried by magnetite while the intermediate temperature component may be carried by pyrrhotite. Significant loss of NRM between 300-350° C on some of the thermal decay curves corroborates the observation that pyrrhotite is sometimes present. In most cases, however, the intermediate component is not completely demagnetized at temperatures well above the curie temperature of pyrrhotite (400 °C) making this explanation somewhat questionable.

On my return to University College London I intend to follow up this work with a detailed investigation of the thermal behavior of multiple orthogonal components of IRM to look closely at the relationship between the intermediate and high temperature components of magnetization. In addition, I intend to investigate various possible explanations for the low inclination observed in the high temperature component. As this work has effectively ruled out a flattening fabric in these rocks I intend to look at other macrostructural explanations as well as the possibility that the magnetite crystallized during a reversal. In the latter case the low inclinations may be representing a complete overlap of the blocking temperature spectra of a secondary normal polarity remanence and the original reversed polarity vector. Although much still needs to be done significant progress was made during my stay at IRM.

Pieter Vlag

CEREGE, Aix-en-Provence

Rock Magnetic Properties of Maar Lake Sediments

For my PhD. research, I study the rock-magnetic properties of the Maar lake sediments from Lac St. Front (Massif Central, France). Down-core susceptibility records of these sediments show a strong correlation with environmental changes. Low susceptibilities correspond with moderate climatic periods, while high susceptibilities correspond with cold climatic periods. Correlation of the susceptibility records with ARM and IRM records revealed that susceptibility changes correspond with variations in magnetic concentration. Microprobe and SEM images indicated that (Ti-)magnetites are the main carriers of the magnetic signal.

The aim of this research is to study (1) the possible effect of environmental changes on the grain size and composition of the magnetic minerals of the St. Front lake sediments and (2) to combine the rock magnetic data with paleomagnetic and paleointensity observations. Another aim of this study is to compare the rock magnetic properties of the basalts and soils of the catchment area of the St. Front Maar lake with the rock magnetic properties of the lake sediments.

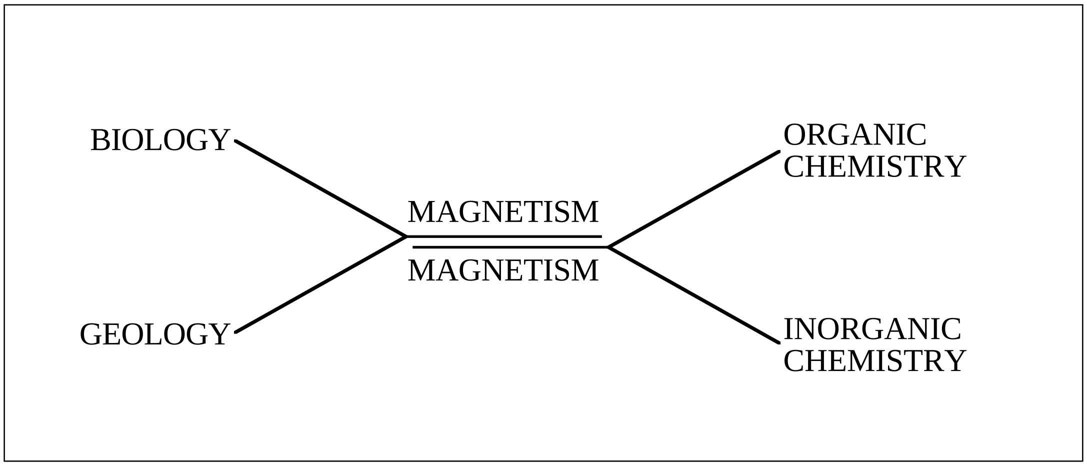
Previous measurements (hysteresis, ARM, IRM and thermoremanent analysis) revealed that the grain size and composition variations in the lake sediments are limited. However, the magnetic properties of the source material (basalts, soils) differ considerably from the lake sediments.

The main purpose of my visit to the *IRM* was to perform low temperature analysis in order to (1) explain the small variations in the rock magnetic properties of the lake sediments (possible effect of superparamagnetic grains) and (2) obtaining more insight in the magnetic differences between the basalts, soils and lake sediments of the Maar.

Therefore, I selected 11 lake sediment samples, representative of the different climate periods, 6 soil samples and 4 basalt samples. On all these samples I measured decay of low-temperature Mr on warming from 20 up to 300 K with the MPMS, hysteresis loops at 77 K as well as room temperature with the VSM and the frequency dependence of susceptibility at room temperature with the Lakeshore.

As analysis of these new rock-magnetic data is still underway, I will only provide some general results of these measurements. All the measured lake sediments showed similar low-temperature Mr curves as well as similar frequency dependences of susceptibilities, confirming the hypothesis that the rock magnetic changes in the lake sediments are limited. Also the differences between the hysteresis loops at 77 K and the room temperature hysteresis loops were fairly constant. These sediments showed a weak Verwey transition, indicating the presence of some pure magnetite grains. This observation agrees with the maximum unblocking temperature of 580°C in the thermomagnetic runs. Both the shape of the low-temperature Mr curve as well as the weak frequency dependance of the susceptibility (< 2 % between 400 and 4000 Hz) suggest that the amount of superparamagnetic grains in these sediments is limited.

For the soils and basalts the frequency dependence of the susceptibility is also weak. For the basalts, no Verwey transition was observed from the low-temperature Mr measurements. As the thermomagnetic curves of these basalts showed a blocking temperature of ~400°C, the absence of the Verwey transition is probably related to a higher Ti-content of the Ti-magnetites. Like the sediments, the soils also showed a weak Verwey transition. However, for the soils the total decrease in Mr between 20 and 300 K is generally larger than for the lake sediments. Presently I am working on the interpretation of the *IRM* results. In combination with the already existing rock magnetic data, these results will be a great help to understand the correlation between climate and rock magnetic character and the relation between source material and sediments.



The conference explored common ground for research in the disciplines diagrammed above at the interface between water and sediments from oceans, lakes, or soils.

...Workshop *continued from page 1*

Microbiology, 2) Sedimentary Biogeomagnetism and Chemical Stability, and 3) Analytical Techniques in Surface Chemistry and Geochemistry. Each session began with a lead speaker who gave a 30 minute talk on a central issue, followed by a period of discussion during which audience members were invited to take the podium and present their current research and ideas for future projects.

Ken Nealson from the Center for Great Lakes Studies began session one with a discussion of the iron and manganese cycles in lakes and how the metal cycles are strongly coupled to the carbon and sulfur cycles. He also described some laboratory experimental results on the dissolution and reduction of magnetite by strains of the bacterium *Shewanella putrefaciens*. Audience members had numerous questions concerning the stability of iron minerals and the rate of iron mineral dissolution. Questions were raised as to how much of sedimentary magnetite is intracellular vs. extracellular, and how does the topology of a bacterium influence the grain-size and grain shape of BMM. Tadashi Matsunaga, Steve Lund, Stefan Spring, Dennis Bazylinski, John Peck, and Richard Frankel led the ensuing discussion period. Data were presented on various species of bacteria such as RS-1 (Matsunaga), a sulfur reducer which can produce both intracellular magnetite and extracellular sulfides, and *M. bavaricum* (Spring) a bacterium in which magnetite magnetosomes are observed to co-exist with elemental sulfur globular structures in the cell. Several researchers debated the importance of trace heavy metals in magnetite and greigite (Bazylinski, Peck, Schueler), and whether the absence of heavy metals can be used as an indicator of biogenically produced minerals. Frankel and Spring discussed the possibility of using DNA probes on sediments to identify both living and dead biomineralizing bacteria. Steve Lund questioned the fate of biomineralizing bacteria and BMM in cores which are stored in laboratories whose chemical environments are much different from lacustrine and ocean environments.

John King began the second session with a discussion of rock-magnetic parameters which are used to determine magnetic granulometry in sediments. He then reviewed some recent studies which correlate these parameters with processes such as climate change (wind direction, wind strength), reduction diagenesis, and determination of paleoredox boundary. Audience members were interested in how to use rock-magnetic parameters to identify BMM, and in particular, can magnetite produced by iron dissimilatory bacteria be recognized. In addition, audience members were concerned with recognition of diagenesis. John Tarduno, Andrew Roberts, Mark Dekkers, Frank Oldfield, and Michael Singer led the discussion period.

Day two of the workshop was led by chemists William Bleam and Emi Ito. Dr. Bleam discussed several X-ray spectroscopy techniques as well as nuclear magnetic resonance (NMR) and electron paramagnetic resonance (EPR). Applications of these techniques include detection of light elements (P,S) detection of Cr, Ti, and determination of the oxidation state of iron. These techniques may also be used to determine whether iron minerals are trapped inside phyllosillicates or adhere to the surface of phyllosillicates.

Dr. Ito spoke about using stable isotope analyses to distinguish biomineralized magnetite from detrital magnetite. In theory, biomineralized magnetite should bear the isotopic signature of its biomineralizing organism in much the same way that plants have distinct $d^{13}C$ signatures. Detrital magnetite would be expected to have much more chemical variation and impurities. In theory one could examine $d^{18}O/d^{16}O$ in biomineralized magnetite in an attempt to determine the chemical environment in which the organism lived. However, it is not known if the magnetite is in equilibrium with the pore-water oxygen. In addition, the source of the oxygen could be dissolved oxygen, sulfate or nitrate. The process by which the organism utilizes oxygen could impose additional fractionation. Chemistry aside, gathering a sufficient amount of biogenic magnetite from which to extract oxygen would be quite a challenge.

Richard Frankel and Subir Banerjee led the wrap-up session. Each workshop participant had the opportunity to state what he/she perceived to be the most pressing issue in sedimentary biogeomagnetism and to suggest topics for future collaborative research. In addition, the ideas and discussion which grew out of this workshop will be used to assess urgent needs in instrumentation and funding of magnetics research.

The Metaphysical Corner

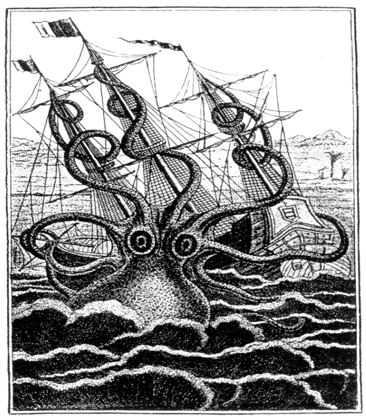
"I cannot satisfy myself that, when one is added to one, the one to which the addition is made becomes two, or that the two units added together become two by reason of the addition. I cannot understand how when separated from the other, each of them was one and not two, and now, when they are brought together, the mere juxtaposition or meeting of them should be the cause of their becoming two"

-Socrates, in the *Phaedo* of Plato

Quoted in *The History of Mathematics*, by Carl B. Boyer

IRM Student Wins High-T_c SQUID

Smithsonian Report, 1916.—Bartsch. PLATE 9.



REPRODUCTION OF A PAINTING IN THE CHAPEL OF ST. THOMAS AT ST. MALOS, FRANCE.

Doctoral student Stefanie Brachfeld has won a competition sponsored by Conductus Inc., a San Diego-based SQUID manufacturer, to design a research project using their high-Tc sensor. Stefanie's proposed study of the lock-in of remanence in sediments was judged to be sufficiently innovative and substantive to merit the award of a Conductus iMAG SQUID sensor with which to carry out the proposed research. The competition was announced in *Physics Today*, and was open to researchers in any field, so the IRM is very proud of Stefanie's achievement.

The winning proposal involved both laboratory simulations with controlled material properties and field behavior, and measurements of natural sediment cores from Yellowstone and Jackson Lakes (Wyoming). The planned research requires two orthogonal sensors, and a second iMAG high-Tc SQUID will be purchased by the IRM to enable Stefanie to carry out the study as planned. ■

IRM Has New Manager

Mike Jackson has returned to the IRM as the new Facilities Manager, replacing Chris Hunt, who has relocated to the green pastures of Brattleboro, Vermont. Mike previously spent four years here (1987-1991) doing postdoctoral research on the magnetic signatures of deformation and diagenesis, and then began a stint at the ill-fated US Bureau of Mines, working on seismic and radar imaging of underground mine sites. Appropriately, Mike's return coincided with the University's Homecoming Week. He is pleased to be back among friends, and hopes to maintain (with occasional blatant lapses) the high managerial and journalistic standards established by Chris. ■

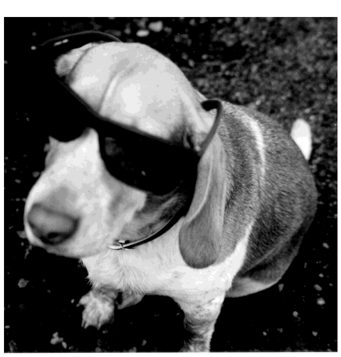


Photo by Patrick Jackson.

New IRM Facilities Manager, Quarterly Editor, and General Factotum.

IRM Events

TAUXE LECTURES

Lisa Tauxe presented a series of lectures during a two-week visit to the IRM in October. In addition to unraveling the mysteries of bootstrap statistics and their use in both paleomagnetism and anisotropy, Lisa described her recent efforts in numerical modeling of the hysteresis behavior of mixtures of superparamagnetic and stable single-domain magnetite. Finally, in the Geology Department's weekly guest lecture, Lisa discussed the issue of magnetic lock-in depth in deep-sea sediments and how it bears on the age of the Matuyama-Bruhes geomagnetic field reversal.

NEW VSM ARRIVES

A new high-temperature VSM, manufactured by Princeton Measurements Corporation, has recently been installed at the IRM. The new instrument features high sensitivity and a heating system enabling measurements up to 800 C, and it will be used for Curie point determinations and measurements of hysteresis properties as a function of temperature. Look for more details in a future issue of the *Quarterly*. ■

Tidings of Joy!

On November 12, Bruce Moskowitz and B. J. Wanamaker became the proud parents of a beautiful daughter, Irene. Mother and daughter are doing fine, but Bruce is a wreck! Irene is the 6th "daughter of the IRM", following Diana Lu, Mary Kelso, Marketa Kletetschka, Amy Sun, and Rachel Housen. ■

The *Institute for Rock Magnetism* is dedicated to providing state-of-the-art facilities and technical expertise free of charge to any interested researcher who applies and is accepted as a Visiting Fellow. Short proposals are accepted semi-annually in spring and fall for work to be done in a 10-day period during the following half year. Shorter, less formal visits are arranged on an individual basis through the Facilities Manager.

The *IRM* staff consists of Subir Banerjee, Professor/Director; Bruce Moskowitz, Assistant Professor/Associate Director; Jim Marvin, Senior Scientist; and Mike Jackson, Senior Scientist/Facilities Manager.

Funding for the *IRM* is provided by the W. M. Keck Foundation, the National Science Foundation, and the UNIVERSITY OF MINNESOTA.

The *IRM Quarterly* is published four times a year by the staff of the *IRM*. If you or someone you know would like to be on our mailing list, if you have something you would like to contribute (*e.g.*, titles plus abstracts of papers in press), or if you have any suggestions to improve the newsletter, please notify the editor:

Mike Jackson
Institute for Rock Magnetism
University of Minnesota
291 Shepherd Laboratories
100 Union Street S. E.
Minneapolis, MN 55455–0128
phone: (612) 624-5274
fax: (612) 625-7502
e-mail: irm@geolab.geo.umn.edu
web: http://www.geo.umn.edu/orgs/irm/irm.html

I R M
Institute for Rock Magnetism