and full hysteresis for well-defined natural and synthetic samples. Our numerical calculations and measured hysteresis provide fundamental basis in interpreting transient hysteresis and FORCs.

GP31A-03 0835h INVITED

The Other Iron Minerals: Magnetic Properties at Room and Low Temperature

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The magnetic properties of iron oxides and iron sulfides that are carriers of paleomagnetic fields have been well studied. Less is known about the magnetic properties of iron phases that are not common carriers of remanent magnetization, or those that are paramagnetic at room temperature. They include iron (oxy-)hydroxides, iron carbonates, iron phosphates and iron sulfates. Many of these phases are not easily identifiable with traditional X ray diffraction or spectroscopic methods, due to their poor crystallinity or low concentration in soils and sediments. Since they are important indicators of the environmental conditions under which they form and are preserved, alternative methods for their identification are of interest. AC and DC magnetometry are very sensitive in detecting low concentrations of magnetic phases. A short overview will be given on the magnetic properties of less-considered iron phases, including the iron (oxy-)hydroxides goethite, lepidocrocite and ferrihydrite; siderite, an iron carbonate; the iron phosphate vivianite; and iron sulfate, schwertmannite. Factors that influence the magnetic properties, such as cation substitution, grain size and particle interaction will be discussed, as well as the environmental conditions under which they form and are preserved.

GP31A-04 0855h

Magnetite dissolution in siliceous sediments

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Magnetite dissolution, and consequent loss of magnetization, is widely observed in reducing sedimentary environments, where the decrease in Eh-pH values with depth is driven by bacterially mediated degradation of organic carbon. We have observed low magnetizations in sediments with elevated porewater silica concentrations that arise from diagenesis of biogenic silica and/or silicic volcanic ash. These depletions in magnetization are greater than can be accounted for by dilution with magnetite-poor sediments and suggest that post-depositional destruction of magnetite has occurred. Biosiliceous sediments usually also contain elevated concentrations of organic carbon, which makes it difficult to separate organic-carbon-related magnetite dissolution from other possible mechanisms for magnetite dissolution. However, the extent of magnetite dissolution in the sedimentary sequences that we have studied is not obviously related to the redox-state of the environment. This suggests that other mechanisms might have given rise to magnetite dissolution in these siliceous sediments. Thermodynamic calculations indicate that magnetite is unstable under conditions of elevated dissolved silica concentrations (and appropriate Eh-pH conditions) and predict that magnetite will break down to produce iron-bearing smectite. A survey of magnetic susceptibility and pore water geochemical data from widely distributed Ocean Drilling Program sites supports this observed link between high dissolved silica concentrations and low magnetic susceptibilities. This observed link also holds for environments with low biogenic silica productivity (and low organic carbon content), but with high interstitial silica concentrations due to dissolution of silicic volcanic ashes. Dissolution of magnetite is therefore predicted to be a common feature of siliceous sedimentary environments.

GP31A-05 0910h INVITED

Bitter Patterns on Glass-Ceramic Magnetite: Links Among LEM States, Saturation Remanence, and Demagnetization Processes

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We have observed Bitter patterns on glass-ceramic magnetite particles in several states of magnetization induced at room temperature. Particle sizes range from 5 to 30 micrometers and most grains contain but a few (2-6) domains, placing them in the uppermost pseudosingle-domain to small multidomain ranges of size and behavior. Bitter patterns have been studied after the following treatments: (1) repeat demagnetizations in an alternating field (AF) with a peak amplitude of 500 Oe, (2) exposure to 25 kOe, resulting in saturation remanent magnetization (Mrs), (3) stepwise demagnetization of Mrs in back-fields of opposite polarity to the inducing field, and (4) stepwise AF demagnetization of Mrs. Similar to titanomagnetite and pyrrhotite, magnetite particles can occupy any one of a range of local energy minimum (LEM) domain states after each repeat AF treatment. However, the range of LEM states for most grains is quite narrow; for example, some grains fluctuate between only two states. Surprisingly, after AF demagnetization in a peak field of 500 Oe, some particles appear either to be saturated (no Bitter lines visible) or to contain only small, residual edge domains. Similar domain states also are observed when certain grains carry Mrs, and such saturated (or near-saturated) states can persist until demagnetization in hundreds of oersteds finally triggers nucleation of walls. The majority of particles do contain walls in states of Mrs. In these latter grains, both AF and back-field demagnetization drive three processes: wall motion, wall nucleation, and wall denucleation. Thus, remanence and demagnetization in small multidomain magnetite grains are not due to wall motion alone. Instead, these experiments suggest that, in magnetite, both the intensity of Mrs and the demagnetization of Mrs are crucially linked to LEM states and LEM-LEM transitions.

GP31A-06 0930h

The Dependence of Anhysteretic Remanent Magnetization on Alternating Field Decay Rate: Fundamental Origin and Paleomagnetic Applications

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We have measured the intensity of anhysteretic remanent magnetization (ARM) as a function of alternating field (AF) decay rate. For synthetic and natural single-domain (SD) and pseudo-single-domain (PSD) magnetites, ARM intensity increases as decay rate decreases. Multidomain (MD) magnetites have the opposite response, ARM increasing as the decay rate increases. These are identical to the SD/PSD and MD dependences of thermoremanent magnetization on cooling rate. For all grain sizes and domain structures, ARM intensity increases as the AF decay rate used to achieve an initial demagnetized state decreases. Decay-rate differences in ARM intensity are a property of low- and medium-coercivity grains, as shown by annealing and by stepwise AF demagnetizing samples. We interpret the SD results to mean that increased AF exposure time permits a closer approach to equilibrium magnetization. An approximate thermal activation theory based on Neel [1949] and an exact theory by Egli and Lowrie [2002] predict 6-11% increases in ARM for an order-of-magnitude decrease in decay rate, in reasonable accord with the observed 12% increase for 65 nm SD grains. For MD grains, we hypothesize that increased exposure time (slower decay) permits more efficient self-demagnetization, reducing ARM. Low-coercivity grains experience the largest self-demagnetizing fields and therefore have the largest decay-rate response. Initial-state decay-rate response is attributed to longer exposure times leaving domain walls more strongly pinned in deeper potential wells (the net self-demagnetizing field is zero in the demagnetized state). Acquisition decay-rate, annealing, and initial-state responses of PSD grains are a blend of SD and MD responses. Because ARM is the most frequently used normalizer in relative paleointensity determination, it is important either to use a standard decay rate or else to remove the decay-rate dependence by demagnetizing the ARM to about 30% of its initial value (ARM0.3). A standard demagnetization level for the normalizing ARM is particularly important when comparing paleointensity records from different laboratories.

GP31A-07 0945h

Stable Remanence from Crystallographically Oriented Magnetite Inclusions in Clinopyroxene

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The unusually stable remanent magnetization found in many gabbroic rocks actually comes from clinopyroxene crystals. While not magnetic itself, clinopyroxene acts as a crystallographic host to two arrays of magnetite inclusions, formed during slow cooling by exsolution. In the cone-sheet samples studied (Messum, Namibia), this exsolution takes place at $850^\circ \pm 50^\circ$C. The typical size of a magnetite inclusion in each array is $1\mu m$ x $2\mu m$ x $50\mu m$. Even with such extreme shape anisotropy, these inclusions are too large to expect single domain behavior. However, alternating field and thermal demagnetization, hysteresis, and FORC experiments all show stable remanence behavior, significantly in excess of that predicted for single domain magnetite (e.g. mean destructive field > 80 mT). When viewed with a magnetic force microscope (MFM), the magnetite inclusions from both arrays display a regular (and fixed) internal segmentation of domains. This segmentation was the result of a second stage of exsolution, in which the oxide has segregated into two phases: one a nearly pure magnetite, and the other a Ti-rich ulvöspinel. This internal oxide exsolution was crystallographically coherent (both minerals have almost identical inverse spinel crystal structure) and has generated regularly spaced septa of ulvöspinel along {100} of magnetite. Three-dimensionally, the ulvöspinel has isolated the magnetite into rectangular boxes of approximately 50nm x 100nm x 200nm. The long dimension of each nanobox is nearly perpendicular to the magnetite inclusion length. Each box is a single domain, usually of opposite polarity to its adjacent neighbors. The domain walls are fixed in position with nonmagnetic spinel dividers. Multidomain features such as Bloch (or Neél) walls have not been observed. Thus each magnetite inclusion is an aggregate of $\sim 10^5$ closely packed magnetite nanoboxes, separated by continuous walls of ulvöspinel. The factors that control the orientation and dimensions of the magnetite boxes and ulvöspinel septa, appear to be related to the crystallographic parameters and cooling history of the clinopyroxene host. This host-dictated form of the magnetite boxes also controls the anisotropy of remanence and hysteresis, which is dipolar (not linear or double dipolar). The origin of the anomalously high coercivity appears to be the strong magnetic exchange coupling between adjacent, single domain magnetite nanoboxes. In summary, the clinopyroxene has provided an architectural framework upon which a second (internal oxide) exsolution built a coherent set of single-domain magnetites with fixed domain walls. It is this nanostructured assembly that has unusually stable remanence.

GP31B MCC: Level 2 Wednesday 0830h

Fundamental and Applied Rock Magnetism II Posters *(joint with MR)*

Presiding: **S L Halgedahl,** University of Utah; **A J Newell,** University of California, Santa Barbara

GP31B-0744 0830h POSTER

The Effect of Grain Shape on the Magnetic Properties of Magnetite: A Finite Element Approach

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Most micromagnetic models in rock magnetism use a regular grid of cells to construct the geometry of a magnetic grain. This has the advantage of allowing rapid evaluation of demagnetising fields using fast Fourier transforms, but means that significant modelling errors are introduced for non-cuboid shaped

grains. Micromagnetic solutions for magnetite have usually predicted values of saturation remanence far lower than those observed experimentally. Although there are many possible reasons for this discrepancy, the inability of regular grids to model realistic grain geometries is a major drawback of this type of model. Since most naturally occurring magnetic minerals have irregular grain shapes a different approach is needed to produce a more realistic model. We will present a finite element (FE) micromagnetic model, allowing the definition of an arbitrary geometry for grain (or grains) of magnetite. The FE approach allows far more flexibility when modelling irregular grain shapes, and when modelling interacting grains of different geometries. The details of the different micromagnetic approaches will be examined, and the validity of different convergence criterion for the models will be discussed. In particular the suitability of energy minimisation versus a dynamic solution of the Landau-Lifshitz-Gilbert equation will be examined. The advantages of the finite element model will be illustrated by modelling cubic and spherical grains of magnetite. The FE model holds great promise for modelling multidomain grains, which is of particular importance to rock and palaeomagnetism. We will discuss how the current FE methods can be extended to model such grains.

GP31B-0745 0830h POSTER

New Observations and Theory of Single-Domain Magnetic Moments and Their Implications

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The magnetic moment of a uniaxial single-domain particle is generally assumed to be oriented in one of only two possible stable positions, either closely parallel or anti-parallel to the particle long (easy) axis. However, we demonstrate that it can actually have several quantifiable stable orientations within the same nominally uniaxial particle. A new model gives quantitative predictions verified by experiments. The results have major implications for rock magnetism, palaeomagnetism, and magnetic materials research. For instance, deflections of the natural remanence vector and computations of the ancient field vector and palaeointensity are not only controlled by the shape and distribution of the particles, but also by the possible stable orientations of the moments within single-domain particles. Furthermore, the model quantitatively accounts for several previously unexplained diverse phenomena exhibited by acicular single-domain particles, namely field-impressed anisotropies, gyroremanences, and transverse components of remanence. These phenomena are theoretically impossible in idealised uniaxial single-domain particles, and could be used to quantify the deviation from such ideal behaviour. The model may also be useful for other single-domain particle morphologies and crystal structures.

GP31B-0746 0830h POSTER

Observations From Magnetic Force Microscopy on Crystallographically Oriented Magnetite Inclusions in Clinopyroxenes

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Crystallographically oriented magnetite inclusions in pyroxenes are a product of subsolidus exsolution during slow cooling and are common features in gabbroic and granulite facies rocks. These elongate inclusions often record a stable component of the direction and intensity of the Earth's magnetic field and consequently, are of significant interest to paleomagnetism. However, the high coercivities sometimes found in these inclusions, which average > 80 mT, cannot be wholly explained by their extreme shape anisotropy. In this study, we visually evaluate the microstructure within crystallographically oriented magnetite inclusions in clinopyroxene crystals from the Messum Volcanic Complex using atomic force microscopy (AFM) and magnetic force microscopy (MFM). Both techniques measure the deflection of a flexible silicon cantilever probe as it is scanned over a sample surface. The probe can be scanned at varying heights above the sample allowing for the measurement of either near-surface forces related to sample topography (a proxy for mineralogy) or stray electromagnetic forces dominant farther from the sample surface. The topography and magnetic domain state within individual magnetite inclusions varied significantly between samples, but all inclusions fall within two broadly defined categories: segmented and non-segmented inclusions. The more common segmented inclusions contain a second, nonmagnetic phase forming walls parallel to {100} of magnetite which partition the remaining magnetite into orthogonal parallelepipeds with sides 50-200 nm long, creating a boxwork texture. This nonmagnetic phase was independently observed using an analytical transmission electron microscope and is rich in Fe, Ti, and Cr and has a spinel structure. The segmented inclusions are the product of a second stage of exsolution occurring during continued cooling of the host rock. The temperature and duration over which this oxide exsolution event occurred are poorly constrained and dependent on factors such as clinopyroxene composition, *f*O2, and cooling rate. A unique kind of highly stable magnetic domain state is produced in the segmented inclusions, whereby individual boxes of magnetite act as single domains whose directions are influenced by neighboring boxes and fixed in the surrounding nonmagnetic phase. The vertical components of magnetization of adjacent magnetite boxes are often oriented antiparallel to one another. The stability of this distribution of magnetic single domains was tested by gathering MFM images of segmented inclusions before, during, and after the application of a 72.5 mT DC field. Only 12% of the magnetite boxes changed polarity in the presence of this applied field, indicating that the boxwork texture is highly stable. Less common in occurrence, non-segmented inclusions show topographically (i.e., mineralogically) homogenous interiors with long magnetic domains running lengthwise down the inclusions. The lengthwise domain boundaries are diffuse, possibly indicating a vortex arrangement of direction. Crystals containing non-segmented inclusions were observed to change their magnetic directions when exposed to fields of <10 mT. Thus, crystallographically oriented magnetite inclusions in clinopyroxenes can have a wide range of coercivities. A full understanding of the inclusions' paragenesis and their mutual interactions is necessary before they can be viewed as faithful recorders of the Earth's magnetic field.

GP31B-0747 0830h POSTER

Thermoremanence and Stable Memory in Multidomain Hematite

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Thermal demagnetization of thermoremanence (TRM) imparted parallel to the (0001) basal plane of a large natural single crystal of hematite revealed very high unblocking temperatures. Most demagnetization occurs between 670 C and the Neel temperature. In contrast, the decay curve of 1-mT TRM drops exponentially with increasing alternating field, characteristic multidomain (MD) behaviour. Such exponential decay is due to hematite's weak spontaneous magnetization and self-demagnetizing field. Domain walls in MD hematite move almost unhindered to their limiting positions and the TRM intensity approaches to the saturation remanence. This also explains the observed high Mtrm = 1.1 kA/m. The TRM memory recovered after low-temperature cycling (LTC) is parallel to the original TRM and equally resistant to thermal demagnetization. The surviving thermoremanence after LTC is about 30 percent of the original remanence, very similar to single-domain hematites with grain sizes 0.12-0.42 micrometer. Stable TRM and memory with very high unblocking temperatures are due to hard spin-canted ferromagnetism, not to defect ferromagnetism. However, the defect moment seems to couple to the spin-canted moment and renucleate memory in warming through the Morin transition.

GP31B-0748 0830h POSTER

FORCs, SORCs and Stoner-Wohlfarth Theory

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The Preisach model is an abstract model of hysteresis, applicable to many kinds of physical phenomena. The Stoner-Wohlfarth model is a physical model of magnetic hysteresis in single-domain ferromagnets. If the Preisach model can be applied to magnets, it can predict the magnetization for an arbitrary sequence of fields. In the "classical" Preisach model the hysteresis is determined by the Preisach density $\mu(H_a, H_b)$, where H_a and H_b are extrema in the field. This density can be estimated by measuring the magnetization $M(H_a, H_b)$ in a series of first-order reversal curves (FORCs). However, Mayergoyz and Friedman [IEEE Trans. Magn. **24**, 212, 1988] showed that the classical Preisach model cannot represent the hysteresis predicted by the Stoner-Wohlfarth theory. To fill the gap, they developed a "nonlinear" Preisach model with a three-parameter density $\mu(H_a, H_b, H)$. To determine the density, one must measure second-order reversal curves (SORCs) - an enormous task. Now many researchers use FORCs to parametrize hysteresis without attempting to make predictions, allowing them to relax the restrictions on the classical Preisach model. They use a modified density $\rho(H_c, H_u) = 2\mu(H_a, H_b)$, where $H_c = (H_b - H_a)/2$ and $H_u = (H_b + H_a)/2$. Classical and nonlinear Preisach densities are calculated for a Stoner-Wohlfarth system of randomly oriented particles with uniaxial anisotropy. High precision is achieved by closed-form integration of single-curve densities. In classical Preisach theory, the density $\rho(H_c, H_u)$ would be an even function of H_u, but here it is only nonzero for negative H_u. It is concentrated near portions of the H_c and H_u axes, approaching positive infinity as H_u goes to zero and negative infinity as H_c goes to zero. The asymptotes exist because, in a single particle, the slope of the magnetization curve approaches a limit of infinity at the switching field. In addition, there is a delta function along part of the H_u axis associated with the jump at the switching field. This distribution is very difficult to model using numerical simulations. The switching fields range from $0.5H_K$ to H_K, where H_K is determined by the anisotropy, but half of the remanence is lost between $0.5H_K$ and $0.524H_K$ (the coercivity of remanence). Thus, at a typical modeling resolution much of the density is concentrated within two or three grid points. The delta function can only be obtained by modifying the procedure for calculating the density to take jumps into account. Adaptive quadrature is used to calculate magnetization curves for Stoner-Wohlfarth theory given an arbitrary sequence of input fields. In particular, FORCs and SORCs can be calculated to several digits of precision. This algorithm is used to demonstrate nonlinear features of Stoner-Wohlfarth hysteresis such as nonlocality.

GP31B-0749 0830h POSTER

Unravelling Magnetic Mixtures Using First-Order-Reversal-Curve (FORC) Diagrams: Linear Additivity and Interaction Effects.

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First-order-reversal-curve (FORC) diagrams for mixtures of different magnetic phases and bi-model distributions have been measured to examine the efficiency of the FORC method for unravelling complex magnetic signals. Mixtures of various magnetic minerals were considered; magnetite, maghemite, hematite and goethite, and the linear additivity of their FORC distributions assessed. For mixtures containing only hard magnetic minerals like hematite or goethite, which have relatively small spontaneous magnetisations (M_s) and large magnetocrystalline anisotropies, there is virtually no magnetostatic interactions between the phases. Because of this, FORC diagrams for mixed assemblages of hard minerals can be adequately describe by a linear addition of the two end-members. Softer minerals, i.e., relatively larger M_ss and smaller anisotropy like magnetite and maghemite, are more susceptible to interactions and the behaviour of soft mineral mixtures is non-linear. Discriminating between two end-members is difficult. When a magnetically weak phase like hematite is mixed with a stronger phase like magnetite, it can still be identified using the FORC technique when it could not by more standard magnetic hysteresis measurements. When the weaker phase can be identified then weak-strong mixes add linearly, however, beyond a certain critical concentration the stronger mineral swamps the magnetic signal and this linearity breaks. It is suggested that the FORC method is highly suitable for identifying small traces of hard magnetic minerals like hematite and goethite in the presence of stronger minerals such as magnetite.

GP31B-0750 0830h POSTER

First-order reversal curve (FORC) diagrams of elongated single-domain grains at high and low temperatures

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First-order reversal curve (FORC) diagrams were measured on elongated single-domain maghemite particles at temperatures ranging from 20 K to 853 K (580^{o}C). Below room temperature, the FORC distribution is almost temperature invariant because both FORC variables, coercivity H_c and interaction field H_i, are proportional to spontaneous magnetization M_s, which changes only 15% from 20-300 K. Above room temperature, the FORC distribution contracts along both axes above 430^{0}C and the bulk coercive force $< H_c >$ decreases rapidly. These features are caused by the increasing thermal activation of single-domain moments pinned by shape anisotropy. A profile f(H_c) through the FORC peak along the H_c axis can be integrated to give a synthetic alternating field demagnetization curve or isothermal remanence curve. The synthesized curves match measured curves quite well at different temperatures, and the FORC median H_c varies approximately in proportion to $< H_c > (T)$. A profile g(H_u) through the FORC peak parallel to the H_u axis contracts with heating approximately as $M_S(T)$, and the half-width of g(H_u) is similar to independent measures of local interaction fields H_i. These properties support the interpretations of FORC variables H_c and H_u as being equivalent to microcoercivity H_c, and interaction field H_i, respectively.

GP31B-0751 0830h POSTER

FORC Diagrams of Synthetic Magnetic Minerals at Ambient and High Temperatures

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FORC diagrams provide a new tool for probing the magnetic structure of natural and synthetic materials. In order to interpret the FORC diagrams of natural samples properly, diagrams for well-characterized synthetic samples must be cataloged. We have obtained FORC diagrams for synthetic samples of pure magnetite, hematite, maghemite, goethite and pyrrhotite, each of which was also studied using Mössbauer spectroscopy. The FORC diagram for each mineral has distinct features that can form the basis for magnetic mineral identification. However, due to the large saturation magnetization of magnetite, even a small impurity of that mineral in a sample leads to its dominance in the FORC diagram. Traditionally, heating of samples above the Curie temperature of magnetite (580^{o}C) has been used to detect the presence of hematite in mineralogically mixed systems. We have found that for mixtures of magnetite and hematite, FORC diagrams obtained above the Curie point for magnetite can not only detect the presence of hematite but can provide information about its grain-size distribution and about magnetic interactions as well

GP31B-0752 0830h POSTER

N-type self-reversal of remanent magnetization above and below room temperature carried by titanomaghemite in submarine basalts

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The possibility that cation-deficient titanomagnetite (titanomaghemite) could display Néel's classic N-type thermomagnetic behavior has been discussed in the literature since the late 1950's. Yet, few natural samples with this behavior have been reported. However, we recently noted partial self-reversals of natural remanent magnetization (NRM) carried by titanomaghemite in highly oxidized lavas from several sites on Detroit Seamount (northwestern Pacific Ocean, Ocean Drilling Project Sites 883, 1203 and 1204). These samples also showed the self-reversal of a partial thermoremanent magnetization (pTRM) given in a 40 μT laboratory field in the temperature range 250 − 350 ^{o}C. To test for N-type behavior in these seamount rocks, hysteresis loops were measured versus temperature at the Institute for Rock Magnetism. Through the temperature dependencies of saturation magnetization (Ms), we observed that samples that did not show pTRM self-reversal had broad N-type minima, with compensation temperature below 0 ^{o}C. One of these samples showed a N-type self-reversal of saturation isothermal remanent magnetization at low temperature. In Ms(T) curves of samples which showed the self-reversal of pTRM we observed even broader N-type minima with compensation points distributed above and below room temperature. We believe that N-type grains of titanomaghemite with compensation points above room temperature in these rocks are responsible for the partial self-reversals of pTRM we have observed. This explanation is further supported by the observation that the blocking temperatures of the self-reversed pTRM are lower than those that characterize the initial stages of titanomaghemite inversion. Further rock magnetic and compositional data, together with a comparison with theoretical calculations will be discussed.

GP31B-0753 0830h POSTER

The Hysteresis Properties of Multidomain Magnetite and Titanomagnetite/-maghemite in Mid Ocean Ridge Basalts

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Hysteresis measurements have been carried out on a suite of ocean-floor basalts with ages ranging from Quaternary to Cretaceous. Approximately linear, yet separate, relationships between coercivity (Bc) and the ratio of saturation remanence /saturation magnetization (Mrs/ Ms) are observed for massive doleritic basalts with low-Ti magnetite and for pillow basalts with multi-domain titanomagnetites (with x = 0.6). Even when the MORB has undergone low-temperature oxidation resulting in titanomaghemite, the parameters are still distinguishable, although offset from the trend for unoxidized multidomain titanomagnetite. The parameters for these iron-oxides with different titanium content reveal contrasting trends that can be explained by the different saturation magnetizations of the mineral types. This plot provides a previously underutilized and non-destructive method to detect the occurrence of low-titanium magnetite in igneous rocks, notably MORB.

GP31B-0754 0830h POSTER

Rock Magnetic Investigation of Felsic Hydrothermal Vent System: Results from ODP Leg 193 to Eastern Manus Basin, Papua New Guinea

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In November-December, 2000, an active hydrothermal vent field in the Eastern Manus back-arc basin, Papua New Guinea, known as the PACMANUS vent field, was drilled during ODP Leg 193. This vent field has been considered as a modern-day analog of massive volcanogenic sulfide deposits within felsic volcanic sequence. The recovery was generally low due to fragility of rocks. Detailed paleomagnetic and rock magnetic analyses were performed on rock samples recovered from three major sites (Sites 1188, 1189 and 1191). Site 1188, a low-temperature diffused venting region, was drilled to 370 mbsf utilizing a combination of RCB, Hammer Drill, ADCB and casing, and Site 1189, a black smoker region, was drilled to a depth of 200 mbsf using RCB. Paleomagnetic analysis shows that recovered rock samples have inclination close to the present-day Earth field. The top 35 m of PACMANUS vent field consists of fresh to moderately altered dacite-rhyodacite and exhibits moderately high natural remanent magnetization (< 6 A/m). Although there are small intervals of markedly less intensive alteration, the region below this extrusive layer is largely comprised of pervasively altered rocks with little evidence of sulfide deposit and exhibits as a whole a low magnetization intensity. However, two intervals with high remanent magnetization (> 6 A/m) were recognized below the upper extrusive layer at Site 1188 (135-211 mbsf and 280-370 mbsf) and one interval at Site 1189 (137-190 mbsf). In particular, the samples between 135-211-mbsf interval at Site 1188 have extremely high remanence with intensities ranging up to 300-500 A/m. Although pockets of magnetite are not uncommon in the ancient hydrothermal ore bodies, they have seldom been documented in modern-day system, and little is known about the physical and chemical condition that allows the magnetite to form in hydrothermal systems. Two possibilities of magnetite formation and its apparent alignment with the Earth field are explored: one that these magnetites precipitated from magnetite-rich fluid as it cooled from above the Curie temperature (TRM) and the other that magnetization was acquired by the growth of magnetite grains below the Curie temperature (CRM). Understanding the origin and behavior of these magnetic mineral assemblages may in turn provide a valuable constraint on the physical and chemical conditions of subseafloor hydrothermal systems, which are very poorly known at the moment.

GP31B-0755 0830h POSTER

A new pre-treatment pTRM Method for Paleointensity Determination: Application to Cretaceous Volcanic Rock Samples from China and Pacific Ocean

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We present a pre-treatment Thellier method which involves partial alternating field (AF) demagnetization prior to regular Thellier heating steps. Our method can help improve the experimental scheme in the Thellier paleointensity method and extract paleointensity information from many samples that contain pseudo-single domain (PSD) and multidomain (MD) grains. Although Néel's theory satisfactorily explains the magnetic properties of single-domain (SD) grains, which are ideal recorders of both direction and intensity of the past geomagnetic field, numerous subsequent paleomagnetic research, coming from both continents and oceans, showed that only rarely the magnetic carriers in rocks are pure SD grains. In most cases, samples contain PSD and MD particles as remanence carriers. Theoretical and experimental studies have shown that the law of additivity of partial TRM (pTRM) required in the Thellier paleointensity method is no longer valid for MD particles, as well as for PSD particles that contain more MD-like grains. We have developed a technique that combines BEI photo observation and AF pre-treatments to make sample remanence more SD-like. We found that mild AF pre-cleaning is effective to erase the MD spectrum, leaving the SD-like spectrum untouched. We estimate the paleointensity of samples based on comparison of their pTRM blocking temperature spectra and NRM unblocking temperature spectra. We have applied our technique to several Cretaceous aged rock samples from China and the Pacific Ocean. Preliminary results show that these samples can be pretreated by AF demagnetization to render them more useful for paleointensity studies.

GP31B-0756 0830h POSTER

On Curie (Neel) Temperature Determination Using Magnetic Susceptibility

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Until recently, temperature dependence of induced magnetization was used practically exclusively in order to determine Curie (Neel) temperature of minerals. In theory, Curie temperature (Tc) is defined as temperature at which spontaneous alignment of atomic magnetic moments vanishes. In practice, several approximations have been used, mostly based on linear fit(s) to section(s) of magnetization decay. This method is strongly limited by sensitivity of the instrument used, because at temperatures close to Tc magnetization values are very low. Recently, newly developed instruments enabled also the use of temperature dependence of magnetic susceptibility. However, despite completely different physical basis, in many cases the same methods for determining Tc have been used as in the previous instance. In our contribution we show that this approach may result in significant error, even more than 100degC. We will demonstrate the importance of Curie-Weiss paramagnetic law and the use of paramagnetic

G
P

Curie temperature when using temperature dependence of magnetic susceptibility for the Curie (Neel) temperature determination.

GP31B-0757 0830h POSTER

The Magnetics Information Consortium (MagIC)

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The Magnetics Information Consortium (MagIC) is a multi-user facility to establish and maintain a state-of-the-art relational database and digital archive for rock and paleomagnetic data. The goal of MagIC is to make such data generally available and to provide an information technology infrastructure for these and other research-oriented databases run by the international community. As its name implies, MagIC will not be restricted to paleomagnetic or rock magnetic data only, although MagIC will focus on these kinds of information during its setup phase. MagIC will be hosted under EarthRef.org at http://earthref.org/MAGIC/ where two "integrated" web portals will be developed, one for paleomagnetism (currently functional as a prototype that can be explored via the http://earthref.org/databases/PMAG/ link) and one for rock magnetism. The MagIC database will store all measurements and their derived properties for studies of paleomagnetic directions (inclination, declination) and their intensities, and for rock magnetic experiments (hysteresis, remanence, susceptibility, anisotropy). Ultimately, this database will allow researchers to study "on the internet" and to download important data sets that display paleo-secular variations in the intensity of the Earth's magnetic field over geological time, or that display magnetic data in typical Zijderveld, hysteresis/FORC and various magnetization/remanence diagrams. The MagIC database is completely integrated in the EarthRef.org relational database structure and thus benefits significantly from already-existing common database components, such as the EarthRef Reference Database (ERR) and Address Book (ERAB). The ERR allows researchers to find complete sets of literature resources as used in GERM (Geochemical Earth Reference Model), REM (Reference Earth Model) and MagIC. The ERAB contains addresses for all contributors to the EarthRef.org databases, and also for those who participated in data collection, archiving and analysis in the magnetic studies. Integration with these existing components will guarantee direct traceability to the original sources of the MagIC data and metadata. The MagIC database design focuses around the general workflow that results in the determination of typical paleomagnetic and rock magnetic analyses. This ensures that individual data points can be traced between the actual measurements and their associated specimen, sample, site, rock formation and locality. This permits a distinction between original and derived data, where the actual measurements are performed at the specimen level, and data at the sample level and higher are then derived products in the database. These relations will also allow recalculation of derived properties, such as site means, when new data becomes available for a specific locality. Data contribution to the MagIC database is critical in achieving a useful research tool. We have developed a standard data and metadata template that can be used to provide all data at the same time as publication. Software tools are provided to facilitate easy population of these templates. The tools allow for the import/export of data files in a delimited text format, and they provide some advanced functionality to validate data and to check internal coherence of the data in the template. During and after publication these standardized MagIC templates will be stored in the ERR database of EarthRef.org from where they can be downloaded at all times. Finally, the contents of these template files will be automatically parsed into the online relational database.

URL: http://earthref.org/MAGIC/

GP31C MCC: Level 2 Wednesday 0830h

Magnetic Petrology and Its Applications to Tectonics, Remote Sensing, and the Martian Climate Posters *(joint with P, T, V)*

Presiding: **T C Onstott,** Princeton University**; R A Duncan,** Oregon State University

GP31C-0758 0830h INVITED POSTER

The Paleomagnetic Effects of Reheating the Ecstall Pluton, British Columbia

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Current interpretations of paleomagnetic data of plutons from the western Canadian Cordillera vary from thousands of kilometers of cross-latitudinal transport, to in situ tilting, to post-intrusion folding. The Ecstall pluton of British Columbia is ilmenohematite-bearing, and it has a progressive steepening of inclination of magnetic remanence vectors from 16o to 81o [1] between 24 and 12 km west of a thermal boundary with the Coast Mountains batholith (CMB). The CMB was at 700-800oC between 60 and 52 Ma. Our heat flow calculations show that the thermal effects of the CMB on the adjacent 91 Ma Ecstall pluton were enough to reset the thermal chemical remanent magnetisation (TCRM), which occurs at less than 390oC [2]. Reheating to the temperatures necessary for TCRM is supported by K/Ar and Ar/Ar cooling dates on hornblende and biotite. Thus, the progressive shallowing of NRM vectors is attributed to reheating of the Ecstall pluton by the Coast Mountains batholith, following post-solidification cross-latitudinal transport of the pluton. Much of the controversy concerning the amount of translational displacement of the coastal terranes of British Columbia prior to 60 Ma hinges on the interpretation of discordant magnetizations from plutons that may have cooled slowly after emplacement in the mid to lower crust, as was the case for the Ecstall pluton. Many of these plutons contain ilmenohematite as an accessory magnetic phase. Our interpretation for the acquisition of NRM in the Ecstall pluton may have far-reaching implications for understanding of the enigmatic discordant paleomagnetic directions reported from plutons of the western Canadian Cordillera.

GP31C-0759 0830h POSTER

Low-Temperature Magnetometry of Synthetic Titanohematite (y = 0.7): A Way to Get Closer to Resolving the Mechanism of rTRM?

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Rob Hargraves once referred to self-reversed magnetizations as "skeletons in paleomagnetists' closets" and devoted part of his career to understanding this phenomena. He and colleagues (Lawson et al., Science, 213,1372-1374, 1981) were the first to observe by transmission electron microscopy (TEM) the cation ordered and disordered antiphase domains and boundaries in high titanium titanohematites (yFeTiO3·1-yFe2O3). But the mechanism enabling titanohematite to acquire a reversed thermoremanence (rTRM) remains to the present day somewhat elusive. Following the first observation of rTRM in natural rocks in the early 1950's, numerous models have been proposed for the reversal mechanism. Concepts common to all models are: 1) microstructurally, the grain is composed of at least one cation ordered and one cation disordered phase, 2) the phase superexchange coupled to the cation ordered domain generating the rTRM is more Fe-enriched and therefore has a higher blocking temperature than the cation ordered domain. The model dependent concept is whether the phase superexchange coupled to the cation ordered domain generating rTRM is cation ordered and ferrimagnetic (Ishikawa, J. Phys. Soc. Jap., 13(8), 828-837, 1958; Prévot et al., PEPI, 126, 75-92, 2001) or cation disordered and antiferromagnetic (AF) (Hoffman, JGR, 97(B7), 10883-10895, 1992; Nord and Lawson, JGR, 97(B7), 10897-10910, 1992). We attempt to provide experimental validation to these currently proposed models for rTRM by analyzing the magnetic behavior of synthetic titanohematite samples, y = 0.7 (Tc $\approx$ 330 K), that have been annealed and quenched at various temperatures above and below the cation disorder - order transition. Our preliminary results, from remanent and induced magnetization experiments in weak and strong fields and across the temperature range of 3 K to 400 K, clearly show that 370 K is a critical temperature, when approached from above, at which superexchange interactions with the ordered domains commences. Moreover, on cooling through 370 K, magnetic susceptibility increases one order of magnitude in a 30 K interval or less depending on the sample. The larger the cation ordered domains, the sharper and greater is the increase in magnetic susceptibility. The magnetic moment measured in a strong field from 10 K to 400 K linearly decreases by one order of magnitude in the temperature range of 10 K to 400 K, showing no break in the slope at 370 K. This suggests that a low value of the anisotropy energy in the cation ordered domains is associated with the onset of superexchange interactions and critical to the rTRM. The increase in coercivity of remanence, the shape of hysteresis loops and the low values of remanent magnetization and magnetic susceptibility above 370 K suggest that an AF phase with a small parasitic moment is superexchange coupled to the cation ordered domains. This is in greater agreement with the cation disordered AF models proposed by Hoffman, Nord and Lawson.

GP31C-0760 0830h POSTER

Paleomagnetism and Monazite Dating of Grenville Rocks, Adirondack Mountains, NY

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Paleomagnetic studies on three rock units from the Adirondack Highlands, New York State yield stable magnetic directions. Electron microprobe monazite geochronology suggests a strong ca. 1050 Ma signature, corresponding to Ottawan granulite-facies metamorphism. Remnants of older (ca. 1130-1190 Ma) monazite, consistent with early-Grenville tectonomagmatic events are also documented. There is no evidence of younger (< 1050 Ma) events with the exception of partial alteration (with Ca-enrichment) of some monazite. Sillimanite-microcline gneisses (gms) of the far-western Highlands, associated with negative aeromagnetic anomalies, exhibit strong stable magnetization dominated by titanohematite with abundant exsolutions of ilmenite, pyrophanite, rutile and spinel. Mean magnetic directions for 14 sites are I-62.8, D=289.2 and a-95=7.6. Sampled in the central Highlands is the post-orogenic fayalite ferro-hedenbergite Wanakena Granite. Samples contain magnetite with ilmenite oxy-exsolution, occurring as discrete grains and inclusions in silicates. Directions from the Wanakena are steeply negative with westerly declinations (I=-76.4, D=296.7, a-95=4.4, N=7). The Marcy meta-anorthosite was sampled in the central and eastern Highlands, although many of these sites proved unstable. Stable results were combined with unpublished data from Rob Hargraves for 13 sites (I=-64.4, D=286.2, a-95=9.1). Over half of the anorthosites and one gms site have normal directions; all Wanakena sites are reversed. Combined anorthosites and gms units give a pole position of 20S/151E; the Wanakena pole is at -29S/132E. Both poles fall in the southern extent of the Grenville loop. The thermodynamically constrained equilibrium phase diagram for ilm-hem predicts that very fine exsolution, most likely responsible for the stable magnetization of the gms rocks, starts to form around 390C, well below the conditions of granulite grade metamorphism. The abundant lamellae provide a stable NRM through the formation of lamellar magnetism acquired at a late stage in the orogen. Using monazite ages for an upper limit and published age data for the Adirondacks produces a cooling curve yielding 920-900 Ma as time of magnetization acquisition for gms.