GP72A MCC: Hall C Sunday 1330h

Unblocking the Road to Paleointensity Determination Posters

(joint with P)

Presiding: **A Smirnov,** University of Rochester**; D J Dunlop,** University of Toronto

GP72A-0989 1330h POSTER

Paleomagnetic Analysis of Calcium-Aluminum Inclusions (CAIs) from the Allende Meteorite

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A preliminary study involving CalciumAluminum inclusions (CAIs) found within primitive chondrite meteorites was conducted using standard paleomagnetic methods to illustrate that paleomagnetism can be successfully applied to the study of CAIs, to show that the proposed project is viable. The objective of the project is to determine the strength of the early magnetic field, its development and intensity levels at the time of formation of the meteorite in our early solar system. Key anticipated milestones will be to derive a magnetic signature from CAIs determining the earliest known magnetic field to exist in our solar system, and to better understand the nature of the magnetic fields during the period of planet formation.

Slices of the Allende meteorite (CV3) provided the source of the CAIs. The meteorite has little or no shock features, is considered very fresh, hard and well consolidated. The CAIs have sharp boundaries and are whitish-grey with uniform color. Two are fine-grained with an irregular, contorted shape. The third is roughly spherical and blocky-course grained.

The preliminary study involved five samples. Three were CAIs incased in a magnetically inert material and two were blanks used for comparison. The magnetic signatures of the five samples were determined by using the Shaw method (Shaw, J., 1974). This method involves comparing two anhysteretic remanent magnetizations (ARMs) created before and after heating. The comparison allows selection of a coercive force region within which the heating has not changed the magnetic properties. The process produces four tables of AF demagnetization: NRM, ARM1, TRM and ARM2.

The results of the analysis show the CAIs found within the Allende meteorite contain a measurable magnetic signature of TRM origin, and therefore the project is viable. The paleofields for two of the specimens are 5.2E-07T (0.0052E-04T) and 5.4E-07T (0.0054E-04T) respectively. The preliminary paleomagnetic and rock magnetic experiments were performed at the Institute of Rock Magnetism.

Shaw,J., 1974. A New Method of Determining the Magnitude of the Palaeomagnetic Field; Application to five historic lavas and five archaeological samples. Geophys. J. R. Astr. Soc., V.39, pg 133-141.

GP72A-0990 1330h POSTER

Are ARM and TRM analogs? Thellier Analysis of ARM and Pseudo-Thellier Analysis of TRM

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We test the possibility of using the pseudo-Thellier method as a means of determining absolute paleointensity. Thellier analysis of anhysteretic remanent magnetization (ARM) and pseudo-Thellier analysis of thermoremanent magnetization (TRM) have been carried out on a large collection of sized synthetic magnetites and natural rocks. In all samples, the intensity of TRM is larger than that of ARM and the ratio R (=TRM/ARM) is strongly grain size dependent. The best-fit slope (b_{TA}) from pseudo-Thellier analysis of TRM shows a linear correlation with R. The ratio b_{TA}/R yielded approximately correct paleointensities, although uncertainties are larger than in typical Thellier-type determinations. For single-domain and multidomain magnetites, AF and thermal stabilities of ARM and TRM are fairly similar. However, for pseudo-single-domain grains, ARM is much less resistant to thermal demagnetization than TRM, resulting in severely non-linear Arai plots for Thellier analysis of ARM.

GP72A-0991 1330h POSTER

Past 5 Ma geomagnetic field intensities inferred from the paleomagnetism of the Society Islands, French Polynesia

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It has been believed that the time-averaged virtual dipole moment (VDM) and virtual axial dipole moment (VADM) for the last few million years are almost the same as the present geomagnetic dipole moment ($\sim 8 \times 10^{22}$ Am2) on the basis of the absolute paleointensities reported so far (e.g. Heller et al., 2002; Kono and Tanaka, 1995). This estimation is, however, questionable because a number of less reliable data is incorporated into the analysis (e.g. Juarez and Tauxe, 2000).

Therefore, we have performed absolute paleointensity measurements with volcanic rocks from the Society Islands, French Polynesia, in order to extract reliable geomagnetic dipole moments. According to our K-Ar dating on the selected samples from 52 sites, they range from 0.5 to 4.6 Ma. Since a magnetostratigraphy constructed from these ages and paleodirectional results are consistent with the geomagnetic polarity time scale (Yamamoto et al., 2002), these samples can provide reliable absolute paleointensities.

The measurements were mainly done by the double heating technique of the Shaw method combined with the low temperature demagnetization (LTD-DHT Shaw method; Tsunakawa et al., 1997; Tsunakawa and Yamamoto, 1999). Various rock magnetic properties were also measured to assess the data qualities. As a result, 194 out of 357 samples yielded successful paleointensities. Some of them were crosschecked by additional results obtained by the Coe's version of the Thellier method. The selected 26 site-mean paleointensities, which satisfy that the mean is determined from more than 3 individual results and that the standard deviation is less than 20%, gave a mean VDM of $3.51 \pm 1.96 \times 10^{22}$ Am2 and a mean VADM of $3.63 \pm 1.95 \times 10^{22}$ Am2. This is consistent with the equatorial Pacific sedimentary record (VADM= $3.9 \pm 1.9 \times 10^{22}$ Am2; Valet and Meynadier, 1993), but is about 50% lower than the previous estimation. This suggests that the present-day field is very intensive and thus it may not be representative of the geomagnetic field.

GP72A-0992 1330h INVITED POSTER

On Paleointensity Estimates From Saturation Isothermal Remanent Magnetization Normalization.

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The ratio of Natural Remanent Magnetization (NRM) to saturation Isothermal Remanent Magnetization (IRMs) of a rock is dependent upon the magnetic material in it, the mechanism of magnetization, and the field in which the rock is magnetized. In calibration experiments, a variety of rocks given Thermal Remanent Magnetization (TRM) in a field of order 0.01 mT gave ratios of NRM:IRMs of order 0.01, when the NRM and IRMs were demagnetized to 20mT to eliminate the effect of very soft multidomain material. The method was initially used with lunar samples because standard methods that involved heating the samples proved impossible, whereas many analyses had presented the critical values of NRM and IRMs after 20mT. In this case, to know the field to an order of magnitude was important and led to the notion that there was a strong field on the moon, comparable with the geomagnetic field, from about 3.9 to 3.6 Gyr (Cisowski and Fuller 1986). Similarly, it is useful to know the martian field in which NRM was acquired by ALH84001 at 4.0 Gyr was one order less than the geomagnetic field, as has been suggested by studies of that meteorite. Clearly, the method is a simple normalization and should not be relied upon as anything more.

GP72A-0993 1330h INVITED POSTER

Nonlinear and Multivectorial Paleointensity Data: Problems and Opportunities

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Nonlinear paleointensity data on an Arai plot are usually symptomatic of chemical alteration during heating. Multidomain (MD) and pseudo-single-domain (PSD) grains, however, give persistent curved characteristics in both the Thellier and pseudo-Thellier methods even when no alteration is occurring. The main reasons for this nonlinearity are low-temperature and high-temperature tails in the unblocking temperature spectrum f(Tub). The tails are particularly evident in partial thermoremanent magnetization (TRM) acquired in narrow intervals of blocking temperature Tb. It often happens that the average Tub of a narrow-band partial TRM approximates Tb; this may be the key to a reliable paleointensity method for MD and PSD grains. A different problem is extracting two paleofield estimates from the same rock, one for the primary TRM and the other for a younger partial TRM overprint. Multivectorial TRMs of this type are frequent in orogenic belts and in metamorphic rocks generally. Because thermal overprinting often occurs long after primary magnetization, the difference in directions can be considerable and conventional scalar Arai plots are unsuitable. We will present a case-history for the Cordova Gabbro of the Precambrian Grenville Province in Ontario, where the primary and overprint vectors are at a large angle, and also model studies for multivectors at a variety of angles, including overprinting following field reversal.

GP72A-0994 1330h INVITED POSTER

An Inverse Thellier Method of Paleointensity Determination

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Inverse thermoremanent magnetization (ITRM) is produced when magnetite warms from below the Verwey transition at 120 K to room temperature in a magnetic field H. ITRM could be acquired by magnetite-bearing meteorites if their interiors remain below 120 K at the time of impact and they subsequently warm in the Earth's field. ITRM might possibly be distinguished from genuine extraterrestrial remanence by the recorded field intensity H, since the present field is well mapped over the Earth. To test this idea, we have invented an "inverse Thellier" paleointensity method using double cooling-warming steps below 300 K in place of double heating-cooling steps above 300 K. We used as the "NRM" a total ITRM produced by warming natural samples and sized synthetic magnetites from 30 K to 300 K. The field H was either 0.1 or 0.2 mT (in some experiments, total ITRM was produced in one of these fields and partial ITRMs in the other). The first cooling-warming step, usually to 200 K, was in zero field. Remanence measured after this step gives the loss in NRM. The second cooling-warming step was in field H. The difference in remanence between the second and first steps gives the partial ITRM gained. NRM losses and partial ITRM gains in further steps to 150, 130, 120, 110, 100 and 90 K, generate an "inverse Arai plot", whose slope is the ratio between the ITRM and partial ITRM fields. We tested magnetites with sizes of 0.065, 0.2, 0.6, 1.0, 1.1, 3, 6, 9, 17 and 135 micrometers, both unannealed and annealed, and two samples of the Tudor Gabbro containing elongated single-domain magnetite. The results are discouraging. Despite a variety of shapes of cooling-warming cycles, most inverse Arai plots have the convex-down form typical of Arai plots for TRM in multidomain grains. More ITRM is lost in early zero-field steps than is regained as partial ITRM in in-field steps, even for grains that are single-domain or nearly so. The only quasi-linear plots were for the two gabbros, which also gave the correct slopes when H was varied. It is disappointing that the inverse Thellier method, which eliminates chemical alteration due to heating, fails for as yet unknown physical reasons.

GP72A-0995 1330h POSTER

Geomagnetic Intensity Variation in Hawaii Over the Past 30ky, Using the Microwave Technique

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A sequence of 176 lava flows from the SOH1 borehole on Kilauea, Hawaii has been investigated using the microwave palaeointensity technique, resulting in a high-resolution record of absolute palaeointensity over the past 30ky. As a result of using this technique (using two microwave systems operating at frequencies of 8.2 and 14GHz), a high success rate of palaeointensity determinations has been achieved (over 90%). Results show significant variations in intensity, ranging from 18 to 62 microTesla, with an average of 26 microTesla for the time period studied. Comparisons with previously published Thellier data from the same core are made. Spectral analysis has been performed on the record so far, and an attempt to determine any links between geomagnetic field intensity and orbital precession is discussed. Extension of the record back to 45ka is currently in progress.

GP72A-0996 1330h POSTER

Microwave Palaeointensity Study of two Geomagnetic Reversals Recorded in Lava Sequences From the Waianae Volcano, Hawaii

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Sequences of lava from the Waianae volcano, Oahu, have recorded the Earths magnetic field from 3.9-2.9 Ma. They provide an ideal opportunity to study the behaviour of the geomagnetic field leading up to, during and after successive field reversals. Here we present results from a microwave palaeointensity study (including rock magnetic analysis) through two sequences, the Puu Heleakala section leading up to and including the Gilbert Gauss reversal and the Puu Paheehee section containing the Lower Mammoth event. The Heleakala section contains 35 lava flows and two samples per flow were studied. Unfortunately many samples were affected by lightning so only 37 samples from 21 flows were suitable for microwave palaeointensity analysis. The mean intensity of is 21 +/- 5 microtesla. The Paheehee section consists of 28 flows, and three samples per flow were studied. The average intensity pre reversal is 5.8 +/- 0.9 microtesla and post reversal is 16.9 +/- 6.1 microtesla.

GP72A-0997 1330h POSTER

Trying to Make Sense of Multidomain Arai Diagrams

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Variable contributions from specimen to specimen of two types of multidomain (MD) tail can explain the concave-up, concave-down, and S-shaped Arai diagrams exhibited by samples of the 1915 Mount Lassen dacite treated by Thellier's method. The slope of the line joining the endpoints of each Arai diagram gives a good estimate of the known geomagnetic field intensity for the Mount Lassen region during the 1915 eruption. In other words, the NRM divided by the total TRM gives the correct slope for the Thellier experiment, a feature long recognized as characteristic of MD remanence that is stable to heating. Fabian (2001) has demonstrated very elegantly that the common concave-up shape of MD Arai diagrams can be well accounted for by the low-T tail of each pTRM segment acquired during cooling from the Curie point in the earth's field. By low-T tail we mean that part of the pTRM with the unblocking temperature less than blocking temperature. However, concave-down and more complex shapes cannot be explained by Fabian's phenomenological theory of TRM. We suggest that the reason is its inability to incorporated the experimentally observed tail of pTRM*, that is, the tail with unblocking temperature greater than the blocking temperature of the pTRM produced during each Thellier step by heating to an intermediate temperature and cooling back down to room temperature in the laboratory field. If the pTRM* tail is systematically greater than the corresponding low-T pTRM tail, the Arai diagram will be concave-down, whereas if it is systematically smaller the shape will be concave up. If the two tails always make equal contributions, the Arai diagram will yield the ideal straight line with slope corresponding to the correct paleointensity. Such could occur if the non-ideal MD remanence were distributed symmetrically about the T-unblocking = T-blocking line of Fabian (2001). Finally, if one tail is greater than the other tail at low temperatures and greater at high temperatures, the Arai diagram will be S-shaped.

Fabian, K., 2001, A theoretical treatment of paleointensity determination experiments on rocks containing pseudo-single or multidomain magnetic particles, Earth Planet. Sci. Lett. 188, 45-55.

GP72A-0998 1330h INVITED POSTER

Effects of Cooling Rate on Blocking Temperature and Paleointensity, Revisited: Old and New Results

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Recent years have witnessed a renaissance in experiments to determine paleointensities. Some of the most notable studies have focused on the rapidly chilled margins of oceanic pillow basalts; other studies have yielded paleointensities from single domain magnetite within parent crystals which cooled slowly within an igneous body. Yet, work by several authors has shown theoretically that cooling rate can affect the blocking temperature and the intensity of weak-field thermoremanent magnetization (TRM) acquired by single domain (SD) grains. If the natural cooling rate was sufficiently slow, a Thellier-Thellier paleointensity experiment can yield an ancient field value that is several tens of percent higher than the true field in which the particles originally cooled. In this talk, the theory of this effect is reviewed for SD magnetite. New calculations are presented, which account for a range of grain volumes and aspect ratios in SD magnetite particles, as well as for different sizes and shapes of the cooling body. These results are discussed in light of time variations in the virtual dipole moment and secular variation in direction of the earths field.

GP72A-0999 1330h POSTER

Absolute Paleointensity of Oligocene Lava Flows From the Kerguelen Archipelago (Southern Indian Ocean)

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In order to define more accurately the geodynamo behavior, numerous paleomagnetic investigations are needed. The aim is to increase both temporal and spatial resolution of paleomagnetic records. For the last 30 Ma, there is a lack of paleointensity results in the southern hemisphere, especially at high latitudes.

Located in the southern hemisphere at 49^{o} latitude (northern part of the Kerguelen-Gaussberg plateau), this study will present new paleointensity results on Oligocene Kerguelen flood basalts (24-30Ma). The 57 lava flows of Monts des Ruches, Temptes and Rabouillre sections are thermally or AF demagnetized. Looking at the viscosity index, NRM scatter and principal component analysis, 32 flows were suitable for a pilot paleointensity experiment and 12 were totally analysed using Thellier-Thellier method.

Application of strict a posteriori criteria make us confident about the quality of the 12 new mean-flow determinations, which are the first reliable data available for the Kerguelen Archipelago. Compilation of these results with a selection of the 2002 updated IAGA palaeointensity database lead to a higher Oligocene mean VDM than previously reported. However, these Kerguelen palaeointensity estimates represent half of the reliable Oligocene determinations and thus a bias toward higher values.

Nonetheless, the new estimates reported here strengthen the conclusion that the recent geomagnetic field strength is anomalously high compared to that older than 0.3 Ma.

GP72A-1000 1330h POSTER

Magnetization of ALH84001: Inferences for the Martian Magnetic Anomalies.

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The magnetization of ALH84001 and the origin of its magnetic carriers have implications for the martian dynamo and the crustal anomalies on Mars. It is now evident that the magnetization of ALH84001 is predominantly carried by single domain magnetite, which formed by thermal decomposition of siderite at elevated temperature in a major impact event at about 4.0 Gyr. Saturation remanent magnetization normalization of the intensity of magnetization of ALH84001 suggests that the ambient field at 4.0 Gyr, in which NRM was acquired, was one order of magnitude weaker than the present geomagnetic field. Since the generating volume for the martian field is smaller than that of the earth, it is unlikely that the field was ever orders of magnitude greater than the geomagnetic field, or even substantially greater than the value interpreted at 4.0 Gyr. Surprisingly, the measured martian anomalies are an order of magnitude larger than anomalies observed on earth at comparable satellite altitudes. This implies that the martian crust contains substantial volumes of source rock more strongly magnetized than found in comparable volumes on earth. The most potent plausible magnetic phase is single domain (SD) magnetite of which about 1 part in 100 in source regions would suffice. We suggest that SD magnetite formed as a result of thermal decomposition of siderite in altered iron rich basaltic rocks. Experiments and theory show that siderite is a major product of percolation and evaporation of brines generated under pressures of more than 0.1bar of carbon dioxide. This is the preferred explanation for the carbonate in nakhlites, as well as in ALH84001. Thermal decomposition of siderite may result from deep burial, magmatic heat sources, or impact heating. The model predicts that conditions in the northern hemisphere of Mars precluded the formation of SD magnetite by the decomposition of siderite, and for this reason the stronger anomalies are confined to the southern highlands.