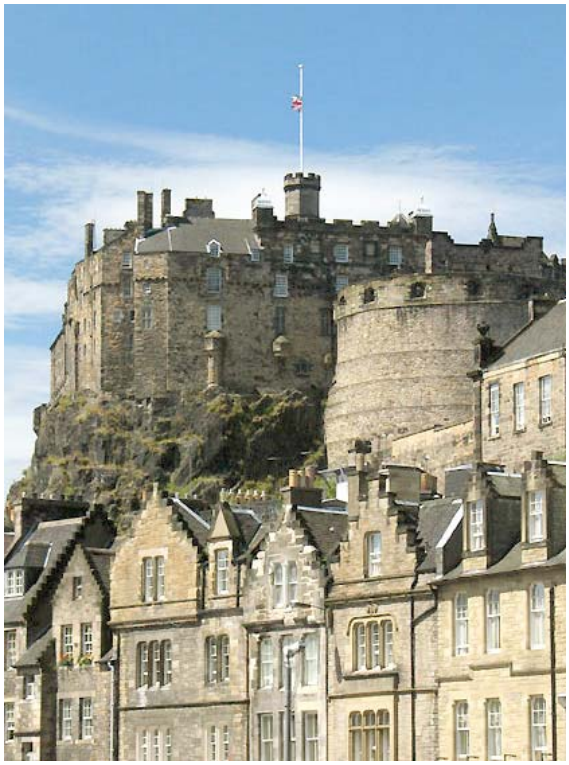
Magnetic Moments

8-9 January 2008
The University of Edinburgh
School of GeoSciences



Annual UK Magnetics meeting

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Programme

Tuesday 8 Jan

1200-1400	**Finger Buffet lunch in the Carstares Room, Old College**
1400-1410	Introduction and Welcome
1410-1425	**Overview of Palaeomagnetic Research in the UK (C. Mac Niocaill, Oxford)**
1425-1500	Palaeomagnetism posters: 5 minute oral presentations
1500-1520	**Coffee**
1520-1535	**Overview of Environmental Magnetic Research in the UK (J. Bloemendal, Liverpool)**
1535-1550	**Overview of Rock Magnetic Research in the UK (D. Krása, Edinburgh)**
1550-1635	Environmental, Rock, Geo- and Archaeomagnetism posters: 5 minute oral presentations
1635-1830	**Wine Reception and Poster Session**
1930-late	**Conference Dinner**

Wednesday 9 Jan

0845-0900	**Overview of Archaeomagnetic Research in the UK (M. Hill, Liverpool)**
0900-0915	At the Limits of Archaeomagnetic Data – the Church and the Mosque Point the Way? (A. Lodge, R. Holme, J. Ramm)
0915-0930	Origins of the Soils Magnetic Susceptibility Anomalies on the area of Poland (O. Polechonska)
0930-0945	Sediment dynamics in an upland temperate catchment: changing sediment sources, rates and deposition (R. Hatfield, B.A. Maher, J.M. Pates, P.A. Barker)
0945-1005	**Coffee**
1005-1020	**Overview of Geomagnetic Research in the UK (N. Pressling, Plymouth)**
1020-1035	Core Flow Modelling from Satellite-Derived 'Virtual Observatories' (C. Beggan, K. Whaler, S. Macmillan)
1035-1050	The Matuyama-Brunhes Reversal: a Global and Temporal Perspective (M. Brown, M.N. Gratton, R. Holme, J. Shaw)
1050-1105	A palaeomagnetic investigation of the Archean Pongola Supergroup, South Africa (C. Rowan, N.J. Beukes, J. Gutzmer)
1105-1120	Palaeomagnetic studies in the Kletno Old Uranium Mine (Sudety Mts, Poland) – preliminary results. (K. Sobien, J. Nawrocki)
1120-1140	**Coffee**
1140-1155	Off-axis electron holography of multi-domain magnetite below the Verwey transition (T. Kasama, N. Church, J.M. Feinberg, R. E. Dunin-Borkowski, R.J. Harrison)
1155-1210	A suite of synthetic titanomagnetites for electron holography: initial observations of magnetic properties in exsolved samples (N.S. Church, R.J. Harrison, R.E. Dunin-Borkowski)
1210-1225	FORCinel: An improved algorithm for calculating first-order reversal curve (FORC) distributions using locally-weighted regression smoothing (R.J. Harrison, J.M. Feinberg)
1230-1245	**Closing remarks**

Abstracts

The effect of nanoscale intergrowths on current palaeomagnetic interpretations

Louise Barron, Williams, W, Whaler, K, Muxworthy, A, Edinburgh.

Magnetic minerals are abundant within our Earth's crust and can retain, through one of a number of processes, a remanent magnetisation induced by the Earth's magnetic field. Analyses of palaeomagnetic samples have been used for the past fifty years to improve our understanding of many of the Earth's major processes. Recent studies utilising newly developed imaging techniques, namely holographic transmission electron microscopy (HTEM), have for the first time allowed direct observations of samples, used for palaeomagnetic interpretations, on a nanoscale. Further to this, HTEM allows the in-plane magnetic field of a sample to be observed. Observations of samples used for palaeomagnetic interpretations have shown that closely packed magnetic lamellae within a non-magnetic matrix often occur as a result of the chemical process of exsolution. However, the results of current micromagnetic models, generated to predict the magnetic field within such samples, are not in agreement with the direct observations. This lack of correlation indicates a gap in our present understanding of the physics of such features. The main aim of this research is to produce a predictive micromagnetic model with the capabilities to quantify and analyse the magnetostatic interactions prevalent within the previously mentioned samples. Through the use of such a micromagnetic model the reliability of palaeomagnetic samples can then be examined; in particular the effect of differing magnetic ordering of individual phases within the samples.

Core Flow Modelling from Satellite-Derived ‘Virtual Observatories’

Ciaran Beggan, Whaler, K., Macmillan, S., Edinburgh.

The Earth's large scale magnetic field is generated and sustained by dynamo action within the fluid outer core. The main field changes in both strength and shape over time, with the gradual decadal variation of the main field termed the secular variation (SV). The driving mechanism for the observed change is thought to arise from flow in the liquid outer core. Hence, it is conjectured that flow at the core-mantle boundary can be inferred from the SV observed at, or above, the surface of the planet. The strength and direction of the main field has traditionally been measured at the surface at a limited number of fixed ground observatories which are unevenly distributed across the globe. From these observations, temporally dependent magnetic field models can be derived. The last decade has seen a significant improvement in the capability to observe the global field at high spatial resolution. Several satellite missions have been launched, providing a rich new set of scalar and vector magnetic measurements from which to model the global field in detail. These data complement the existing record of ground-based observatories, which have continuous temporal coverage at a single point. We wish to exploit these new data to model the SV globally and improve the flow models that have been constructed to date. Using the approach developed by Mandea and Olsen (2006) we create a set of 648 evenly distributed `Virtual Observatories' (VO), at 400km above the Earth's surface, encompassing satellite measurements from the CHAMP satellite over five years (2001-2005). We invert the SV calculated at each VO to infer flow along the core-mantle boundary. In contrast to most other studies, we invert SV directly from observatory data - rather than spherical harmonic model coefficients - to calculate flow model coefficients. This allows a more rigorous test of flow assumptions to be made and the incorporation of realistic data uncertainties. Direct comparison of the SV generated by the flow model to the SV at individual VO can be made. Thus, the residual errors can be investigated in detail. We show comparisons of flow models from ground-based observatories and virtual observatories highlighting the similarities. We also show evidence in the residual distributions of the field and SV models derived from the VO, of signals that are consistent with unmodelled external field effects in the satellite data.

Geomagnetic Secular variation in the Cretaceous Normal Superchron and in the Jurassic

Andrew Biggin, van Hinsbergen, D., Langereis, C., Straathof, G, Haldan, M, Utrecht.

It is now widely thought that geomagnetic polarity reversals occur spontaneously as a result of normal dynamo action rather than being externally triggered. If this is the case, then we may expect that periods of time in which the geomagnetic reversal frequency was dramatically different were also characterised by different styles of secular variation. Two such periods were the Cretaceous Normal Superchron (CNS) when no reversals have been recorded for a period exceeding 30 Myr and the Jurassic period (144-200 Ma) where reversals occurred at an average rate of 4.7 Myr^-1. Here we analyse a new database of high quality palaeomagnetic directions from lavas emplaced during these periods in order to describe the palaeosecular variation (PSV) recorded in each. We then compare these records with one another and with that produced for the period 0-5 Ma (with average reversal frequency 4.0 Myr^-1). Our results are more equivocal than those obtained in a previous similar study which might be explained by the former study having been affected by artefacts introduced by the poor quality data that they were required to use. The usefulness of our Jurassic record is severely limited by the restricted palaeolatitudinal span of the available data. However, our record for the CNS does allow us to conclude that it was likely that secular variation was different then than in the 0-5 Ma period at least. This supports the hypothesis of a link between PSV and reversal frequency and therefore endorses PSV analysis as a first-order tool for determining geomagnetic stability in the past.

The Matuyama-Brunhes Reversal: a Global and Temporal Perspective

Maxwell Brown, Gratton, M. N., Holme, R., Shaw, J., Liverpool.

We present new palaeointensity and palaeodirectional results from the Matuyama-Brunhes geomagnetic field reversal. Dated volcanic sequences from four global locations: La Palma, Chile, Iceland and Guadeloupe, are investigated. These sections sample the Matuyama-Brunhes boundary, possible precursors, and fluctuations in the magnetic field prior to the main polarity reversal. Absolute palaeointensity values were determined using the 14 GHz microwave systems at the Geomagnetism Laboratory, University of Liverpool. New directional results (from thermal demagnetisation) and published directional data are combined with new microwave intensity data to define the full vector of the field during the reversal. We compare our data with 1) other published data for the Matuyama-Brunhes reversal and other reversal records that have both intensity and directional data; 2) a simple mathematical reversal model based upon CALS7K.2 (Brown et al., Geophys. J. Int, 168, 541-551, 2007); 3) the iterative Bayesian model of the Matuyama-Brunhes reversal, IMMAB4 (Leonhardt and Fabian, Earth Planet. Sci. Lett., 253, 172-195, 2007).

Magnetisation of the Lunar Crust

Ruth Carley, Whaler, K.A, Purucker, M.E, Edinburgh.

Since the Apollo missions it has been known that some areas of the lunar crust are remanently magnetised. The origins of the magnetic fields which produced this remanence are still under discussion, and theories include among many, an ancient lunar dynamo and enhancement of an ambient magnetic field as a result of impact. The nature, configuration and intensity of these ancient magnetising fields could have implications for the formation and evolutionary history of the Moon, conditions in the early solar system, and impact processes. The remanent magnetic fields have been measured from lunar orbit, directly at altitude with a magnetometer, and indirectly at the surface with electron reflectometry (ER). Identification of magnetised regions of the lunar crust, and information about their magnitudes and directions of magnetisation, provide information on surface or subsurface geological structures and processes such as the tectonic response to impacts. Global ER and magnetometer data at altitudes of ~100 km and ~30 km measured by Lunar Prospector (NASA, 1998), are being used to model the spatial extent, and magnitudes and directions of sources of magnetisation within the lunar crust. Modelling techniques are based on those developed for magnetisation models by data inversion for terrestrial and Martian data, invoking both equivalent source dipoles, and a continuously varying magnetisation distribution. Initial models utilise only the magnetometer data for selected regions of the lunar crust. Final models will combine magnetometer and ER data and will contribute to a 'comprehensive model' of the lunar magnetic field environment.

A suite of synthetic titanomagnetites for electron holography: initial observations of magnetic properties in exsolved samples

Nathan Stewart Church, Harrison, R. J., Dunin-Borkowski, R. E., Cambridge.

Natural titanomagnetites frequently exhibit exsolution structures, but the contribution to bulk magnetic properties of these assemblages of iron-rich ferrimagnetic titanomagnetites and titanium-rich paramagnetic ilmenite and ulvöspinel is poorly understood. To investigate the role of these two-phase systems, a suite of single-phase polycrystalline and single-crystal samples were synthesized from the magnetite-ulvöspinel solid solution. Samples from the polycrystalline suite were then resintered under oxidizing conditions to create two-phase systems of titanomagnetite and titanohematite. These exsolved systems exhibit a variety of geometries, including lamellar oxy-exsolution which mimics that found in natural assemblages. FORC distributions were measured for both the exsolved and single-phase samples to investigate the effect of the change in magnetic particle size and geometry on magnetic properties. These analyses show the influence of two distinct phases, and in some samples, the exchange interactions between them. The FORC measurements also reveal a dramatic increase in coercivity at low temperature in both single crystal and polycrystalline samples with compositions TM30-TM50.

Investigating the Geomagnetic Field in the British Iron Age

Sarah-Jane Clelland, Batt, C.M., Bradford.

The primary aim of this research is to use studies of the geomagnetic field, as recorded by archaeological and geological materials, to identify and characterise short (decadal) timescale changes in the Earth's magnetic field. The period of interest is the first millennium BC and the project will focus on data from the British Isles, as in Britain this period of time equates to the Iron Age, a period of important social and cultural changes (Haselgrove et al. 2001). This should improve the ability to define the chronology of the British Iron Age; something that is currently difficult to achieve with any precision that is applicable to anthropogenic timescales. Research is at a preliminary stage and this poster will present the aim, research questions and proposed methodology. This research will involve an evaluation of previous archaeomagnetic studies from this period in the UK leading to a redefinition of the direction of the geomagnetic field between 700BC and AD100. An initial survey of data within the current archaeomagnetic direction calibration curve (Zananiri et al. 2007), suggests that the associated median temporal placement for just over 100 data points fall within the period 700BC-AD100 but need re-evaluation. This project will also involve collecting new data from this period and investigating the potential to incorporate magnetic data from sedimentary sequences, given the different mechanisms of detrital and thermo remenant magnetisation recording. European secular variation records will also be utilised, predominately to determine to what extent changes in declination and inclination observed in this period are a Europe-wide phenomenon. Furthermore, the relationship between the geomagnetic field and the radiocarbon calibration curve in this period will be examined, possibly contributing to the debate on palaeoclimate. Ultimately it is anticipated that this research will improve the ability to define the chronology of the British Iron Age through directly dating the architecture associated with prehistoric pyrotechnology. This research has received a Natural Environment Research Council (NERC) PhD studentship.
References Haselgrove, C., Armit, I., Champion, T., Creighton, J., Gwilt, A., Hill, J.D., Hunter, F. and A. Woodward, 2001. Understanding the British Iron Age: An agenda for action. English Heritage and Historic Scotland. Zananiri, I., Batt, C.M., Lanos, Lh, Tarling, D.H. and P. Linford, 2007. Archaeomagnetic secular variation in the UK during the past 4000 years and its application to archaeomagnetic dating. Physics of the Earth and Planetary Interiors 160, 2: 97-107.

Assessing the Effects of Mineral Alteration on Palaeointensity Determinations

Ceri John Davies, Hill, M.J, Shaw, J, Prior, D, Liverpool.

We present an investigation into clarifying the authenticity of palaeointensities as determined from Late Cretaceous Madagascan basalt. An initial palaeomagnetic study (Riisager et al., 2001) produced 4 palaeointensities; mean 61.5 ± 5.5 μT. A large amount of lightning activity in the area and a high degree of thermochemical alteration during Curie point analysis resulted in only 6 samples being investigated for palaeointensity analysis. Here we re-analyse 67 sister samples, investigating their rock magnetic, microscopy and palaeointensity data. To be confident in palaeointensity determinations it is necessary to understand the processes that could affect the samples ability to record an accurate thermal remanent magnetisation, TRM. We show that Curie point analysis can not be relied upon as an indicator of low temperature alteration. We also highlight the significance of heterogeneity within a cooling unit. Two cooling history and magnetisation acquisition models are proposed for samples subjected to i) high temperature oxidation (Group A) and ii) low temperature oxidation (Group B).

FORCinel: An improved algorithm for calculating first-order reversal curve (FORC) distributions using locally-weighted regression smoothing

Richard Harrison, Feinberg, J.M., Cambridge.

First-order reversal curves (FORCs) are a powerful method for characterising the magnetic hysteresis properties of natural and synthetic materials, and are rapidly becoming a standard tool in rock magnetic and paleomagnetic investigations. Here we describe a modification to existing algorithms for the calculation of FORC diagrams using locally-weighted regression smoothing (often referred to as 'LOESS' smoothing). Like conventional smoothing algorithms, locally-weighted regression smoothing fits a second degree polynomial to the measured magnetisation data over a specified area in FORC space defined by a smoothing factor. This method differs from conventional algorithms in two ways: firstly the area of FORC space used for fitting is defined as a region of arbitrary shape encompassing N neighbouring data points; secondly, data inside the fit region are given a weight that depends on the distance of the data point from the point being evaluated: data closer to the point being evaluated have higher weights and have a greater affect on the fit. LOESS smoothing offers several advantages over current methods: 1. It allows the FORC distribution to be calculated using a constant smoothing factor all the way to the Hc = 0 axis, without the need for a 'reversible ridge' which can swamp the low-coercivity signal and introduce unwanted artifacts. 2. It allows finer control over the degree of smoothing, enabling a graphical method for automated selection of the optimum smoothing factor for a given FORC measurement. 3. It performs automated extrapolation across gaps or undefined regions of FORC space. This has two applications: a) bad curves or outlying data points caused by instrumental instabilities can be removed from the data, eliminating artefacts from the final FORC diagram; b) specific regions of interest in the FORC measurement can be masked out in order to investigate their contribution to the final FORC diagram. The new method has been implemented in a freely available software package "FORCinel" which can be downloaded from http://www.esc.cam.ac.uk/~rjh40/forcinel. FORCinel is a suit of functions with a graphical user interface written using Igor Pro by Wavemetrics. A fully functional demo version of Igor Pro for Macintosh and Windows can be downloaded from www.wavemetrics.com.

Sediment dynamics in an upland temperate catchment: changing sediment sources, rates and deposition.

Robert Hatfield, Maher, B.A., Pates, J.M., Barker, P.A., Lancaster.

Robust identification of catchment suspended sediment sources is a prerequisite both for understanding sediment delivery processes and targeting of effective mitigation measures. Fine sediment delivery can pose universal management problems, especially with regard to nutrient run-off and lake siltation. In this study, suspended sediment samplers were located within the three main tributary inflows to Lake Bassenthwaite, a key but vulnerable site of special scientific interest, which suffers water quality problems linked to accelerated delivery of fine sediment. Magnetic properties of contemporary suspended sediments, collected on a monthly basis, were measured on a particle size-specific basis and compared to the lake sediment core-tops. Ferrimagnetic grain size and magnetic 'hardness' vary significantly between the suspended sediments collected from the different tributaries, with the 8-31 μm and 31-63 μm clastic grain fractions displaying greatest magnetic contrasts. Post-depositional formation of bacterial magnetosomes is evident in the 2 – 8 μm and < 2 μm fractions of the lake sediments. As magnetic properties are strongly particle size dependant, we use only the detrital, clastic fractions, 8-31 μm and 31-63 μm for comparison with the potential source suspended sediments. Dating and analysis of the sedimentary records of nine one meter cores from Bassenthwaite identifies variable sedimentation rates across the deep lake basin. Mineral magnetic techniques, supported by independent geochemical analyses, identify significant variations both in sediment source and flux over the last ~ 2500 years. Using a quantitative fuzzy clustering technique, we show that between ~2500 years BP and ~1700 AD sediment fluxes to the lake were low and dominated by material sourced from within the River Derwent sub-catchment (providing 80% of the hydraulic load at the present day). Post-1700 AD, the lake sediments became dominantly sourced from Newlands Beck (presently providing ~10% of the lake's hydraulic load). Three successive, major pulses of erosion and increased sediment flux appear linked to specific activities within the catchment, specifically; mining activities and associated deforestation in the mid – late 19th century, agricultural intensification in the mid- 20th century and, within the last decade, the additional impact of climate change. We also begin to discuss a longer term record spanning ~6000 years obtained from a 3 meter core of the lake. This radiocarbon and paleomagnetic dated record aids evaluation of the long term natural variability within the lake and starts to build up some context to the recent human impact in the catchment. These results are important for all upland areas as modifications in climate are progressively superimposed upon the effects of previous and/or ongoing anthropogenic catchment disturbance.

A comparison of palaeointensity results obtained using the microwave technique and LTD-DHT Shaw method on basalts from the Auckland volcanic field, New Zealand

Mimi Hill, Cassidy, J, Liverpool.

Samples from five monogenetic volcanoes in the Quaternary Auckland volcanic field that record the same geomagnetic excursion have been investigated using the microwave palaeointensity technique. Both the perpendicular applied field method and Coe version of the Thellier technique were carried out, with sister sub samples being run in many cases to check for consistency. The experiments were performed using the Liverpool microwave systems operating at 14 GHz. A total of 52 samples gave results ranging from 1 to 24 microT. Mochizuki et al (2006 Phys. Earth Planet. Int., 154, 168-179) previously studied samples from three of the five volcanoes using the LTD-DHT Shaw palaeointensity method. Their results from 17 samples showed greater consistency both between and within volcanoes.. Despite the differences, the overall mean palaeointensity determined from each study are statistically indistinguishable and show that the geomagnetic field was reduced to about 2 x 10^22 Am^2 for this Auckland excursion.

Off-axis electron holography of multi-domain magnetite below the Verwey transition

Takeshi Kasama, Church, N., Feinberg, J.M., Dunin-Borkowski, R.E., Harrison, R.J., Cambridge.

The Verwey transition has an enormous impact on the magnetic properties of magnetite at low temperatures – the magnetocrystalline anisotropy increases by an order of magnitude and the magnetic easy axis switches from the <111> directions of the cubic phase to the [001] direction of the monoclinic phase. On cooling through the transition, the [001] easy axis of the monoclinic phase may be chosen to lie along any one of three <100> directions of the parent cubic phase, resulting in the development of transformation twinning. Numerous studies have proposed that a strong interaction exists between the ferroelastic twin walls and the ferrimagnetic domain walls in magnetite. Nevertheless, the nature of this interaction remains highly controversial. Key questions include: i) what kinds of magnetic domains are common?, ii) are magnetic domain walls strongly pinned by the twin walls or can they be moved independently? and iii) how does the twin microstructure that develops on cooling through the transition depend on the magnetic microstructure that exists above the transition, and vice versa? Here, we use off-axis electron holography in the transmission electron microscope to study the magnetic domain structures in synthetic multi-domain magnetite, both below and above the Verwey transition. Electron holography allows magnetic structures to be imaged quantitatively at a nanometer scale. Lorentz electron microscopy is employed to make dynamical observations of the nucleation and translation of transformation twins and magnetic domain walls as the sample was repeatedly cycled through the phase transition. All TEM observations were performed at 300 kV using a Philips CM300ST field emission gun TEM. The distribution of magnetic domains above and below the transition was generally very different. The cubic phase is characterised by a low density of magnetic domain walls, whereas the monoclinic phase contains a higher density of closely-spaced lamellar domains. In contrast to previous studies, magnetic closure domains within the monoclinic phase were also observed to be relatively common. Regions showing a clear interaction between magnetic domain walls and twin domain walls were observed. A typical feature is the presence of irregular twin boundaries formed by the impingement of monoclinic domains that nucleated in different parts of the crystal. The monoclinic domains on either side of the boundary contain much finer scale needle-like twins, with the orientation of needles switching through 90° across the boundary. The magnetisation in each monoclinic domain is perpendicular to the needle twins, and, except in rare cases, does not appear to be greatly affected by the needle twins themselves. In one case, however, a zigzag magnetic domain structure coincident with the needle twinning was observed, suggesting that different classes of needle twins are present: some which leave the easy axis untouched and other that cause the easy axis to change direction. The irregular boundaries between monoclinic domains are shown to be 90° magnetic domain walls. Both conventional and 'divergent' 90° walls are observed using Lorentz microscopy. Micromagnetic models show that a conventional 90° wall is converted to a divergent wall by passage of a 180° Bloch wall through the adjacent monoclinic domain. The irregular boundaries are immobile, except at temperatures very close to the Verwey transition, where lateral migration of the boundary prior to the transition was observed on heating.

Modelling the hysteresis of interacting pseudo-single-domain magnetite particles

David Krása, Williams, W., Edinburgh.

Recent studies have shown that inclusions or fine exsolution structures of crystallographically oriented magnetite particles can be important remanence carriers in igneous rocks. These structures often take the form of arrays of tightly spaced individual grains straddling the single domain (SD) to pseudo-single-domain (PSD) threshold. Due to the proximity of neighbouring particles, magnetostatic interactions are expected to play an important role for the magnetic properties of these particle assemblages. We have used an unconstrained, fully three dimensional finite element (FE) micromagnetic model to calculate hysteresis curves of 3x3 arrays of magnetite particles with aligned easy axes with grain sizes r between 50 and 200nm and grain spacings d between 0 and 3·r. The calculations show that the domain state of individual particles is not only dependent on their respective grain size but also on the grain separation. Closer spacing generally leads to an increased SD-PSD size threshold. Associated with that is a characteristic change in magnetic stability as witnessed by coercive force Hc and the squareness ratio Mrs/Ms: For particle spacings below approximately 50nm, Mrs/Ms decreases sharply for all modelled grain sizes. This decrease is related to the appearance of supervortex structures at zero external field. Our modelling approach allowed us to observe the formation of these supervortices in the course of a hysteresis cycle. As expected, SD sized particles retain a uniform particle magnetisation throughout the whole hysteresis cycle. The particle arrays, however, form intermediate supervortex structures even for relatively large interparticle spacings because the individual particle's magnetisation cannot collapse into a vortex state to reduce its magnetic stray field. Only when the spacing increases to 150nm (i. e. d=3·r), does the magnetisation of all particles in the array rotate coherently. In contrast, PSD particle arrays generally reverse their magnetisation by spin curling and the formation of individual vortex states at zero field. For almost touching particles, though, an SD like magnetisation structure of individual grains is maintained throughout the hysteresis cycle by forming supervortex states. The individual vortex state, however, is energetically more favourable as soon as the interparticle spacing is only slightly increased. The poster discusses the influence of particle size and spacing on magnetisation reversal modes and magnetic grain size determinations.

First Order Reversal Curve Measurements of Self-assembled Iron Oxides Nanostructures

Julia Linke, Driscoll, JL, Harrison, RJ, Kursumovic, A, Cambridge.

The first order reversal curve (FORC) method is an experimental tool to characterise hysteretic processes in samples containing mixtures of magnetic phases or grain sizes. It has only become available with recent advancements in the automation of vibrating-sample and alternating-gradient magnetometers. Until the 1990's major hysteresis loops, which present bulk averages, were most widely used for magnetic characterisation. By contrast, the FORC method is based on a set of minor partial hysteresis loops below and up to saturation. From this data the distribution of switching fields and local interaction fields between particles or grains can be determined, which allows modelling of more complex magnetic interactions in nanomaterials. We used the FORC method to investigate the magnetic properties of synthetic alpha-Fe2O3 and Fe3O4 nanostructures. The thin films were deposited on silicon from aqueous and ethanolic FeCl3 solutions by ultrasonic aerosol assisted chemical vapour deposition (UAA CVD). With increasing deposition temperature the FORC distributions change from single domain to pseudo-single-domain and multi-domain distributions due to changes in the oxidation state of iron and the crystallinity of the nanostructures. The coercivities for alpha-Fe2O3 samples range from 400 to 600 Oe, and for Fe3O4 containing samples from 150 to 250 Oe. Iron oxide nanostructures are considered important building blocks for magnetic sensors and biomedical devices.

At the Limits of Archaeomagnetic Data – the Church and the Mosque Point the Way?

Alexandra Lodge, Holme, R., Ramm, J., Liverpool.

The standard archaeomagnetic dating procedure compares archaeomagnetic directions (declination D and inclination I) and intensities (F) (or just one of these components) from samples of unknown age to well-dated reference curves constructed for a particular geographic region. We are currently developing a new approach to archaeomagnetic dating in Europe using global geomagnetic field modelling. This technique produces curves that are not controlled solely by data within a 500 km radius of the curve and therefore, new data anywhere in Europe will help to improve our global model and therefore the reference curves at any location in Europe. Many data used to construct these curves and to be dated come from burnt material such as hearths, pottery, bricks and tiles, which contain a record of the Earth's magnetic field at the time the material was last heated. However, there is a more unusual and potentially untapped resource of declination data; the orientation of religious buildings. In Christianity, churches are built E-W: if the orientation was determined using a magnetic compass with no correction for declination and we know the date the church was built, then we can determine the declination at that time. Earlier studies have proved inconclusive (e.g. Searle, 1974; Hoare and Sweet, 2000); however, given the advance in global models and reference curves since then, a re-evaluation is appropriate. In addition to churches, we consider the orientation of mosques. In Islam, all mosques have a qibla wall which one must face in order to face Mecca for prayer. If the orientation of the qibla wall is determined using a magnetic compass, again without correction for declination, then if the date of construction is known, we can determine the declination at that time. From our investigations so far, mosques seem more likely than churches to be oriented accurately, due to the advanced mathematics and astronomy of the medieval age in Islamic states, coupled with the vital importance of facing Mecca as part of the Islamic faith. The earliest known documented evidence of the use of the magnetic compass for determining the qibla direction comes from two sources, the first is by the Yemeni Sultan al-Ashraf (ca. 1290) and the second by the Cairene astronomer Ibn Simcū (ca. 1300) (Schmidl, 1996-1997). An earlier study of Turkish mosques by Barmore (1985), suggests that some, although not all appear to have been oriented using a magnetic compass. We now have access to the full database from this study, which includes 333 independent determinations of the orientation of 298 Turkish structures (mosques, chapels and prayer courts) and are currently in the process of evaluating whether the mosques were oriented using a magnetic compass. Here we present the current state of the global database, where, when and how many data are available; this clearly highlights for example why new Turkish data is vital. We then show the preliminary results so far for the orientations of both churches and mosques. References: Barmore, F., 1985, Turkish mosque orientation and the secular variation of the magnetic declination, J. Near Eastern Studies, 44, 81-98. Hoare, P. G., & Sweet, C. S., 2000, The orientation of early medieval churches in England, J. Historical Geography, 26, 162-173. Schmidl, P. G., 1996-97, Two early Arabic sources on the magnetic compass, J. Arabic and Islamic Studies, 1, 81-132. Searle, S., 1974. The Church points the Way, New Scientist, 61, 10-13.

Modelling and Interpreting Lithospheric Magnetic Field Anomalies over the Atlantic, Using CHAMP Satellite Data

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A GIS-based forward modelling technique has been adopted to predict intermediate wavelength magnetic anomalies over the Atlantic Ocean and allow separate assessment of the contribution of both induced and remanent magnetisation to the potential field. Magnetic anomalies due to remanent magnetisation are computed from vertically integrated magnetisation (VIM) and palaeofield unit vectors, both of which are age-dependent and implement the latest digital isochron age map provided by the Earthbyte group at Sydney University. VIM assumes a simple three-layer crustal thickness model, exponential decay of thermo-remanence and acquisition of chemical remanence. Calculation of palaeofield unit vectors requires spreading centre palaeopositions for the ocean floor; these are obtained by performing finite rotations within a moving hotspot reference frame. Palaeomagnetic field direction is approximated by a geocentric axial dipole. Magnetic anomalies due to induced magnetisation are computed from vertically integrated susceptibility (VIS); this assumes a three-layer crustal thickness model and associated standard susceptibilities. Comparisons have been made between magnetic anomalies predicted by the present work, by Hemant and Maus (2005) and with observations (MF5) at satellite altitude; these suggest that the correct application of finite rotations and the use of an updated palaeo-reconstruction model has improved model accuracy for Atlantic regions. The next stage in the present work is to use heat flow modelling to constrain Curie temperature depth, and thus magnetic crustal thickness in the Atlantic. Palaeofield unit vectors will also be computed for all other oceanic regions in the digital age map, allowing the eventual prediction of global oceanic magnetic anomalies.

Biomagnetic monitoring of pollution

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Exposure to and inhalation of particles below 10μm are strongly associated with adverse health effects. Biomagnetic monitoring using tree leaves is an effective method for providing high spatial resolution data sets for pollution assessment. Here we use magnetic analyses of kerbside tree eaves to examine levels of pollution around Lancaster, Lancashire. SIRM values indicate a majority presence of magnetically soft magnetite-based materials, with a small component of magnetically \'hard\' haematite-like minerals. Coercivity values indicate a dominant ferrimagnetic grainsize of ~0.1 to 2.5 μm. Analysis of samples from 08/10/07 and 09/10/07 indicate that at most locations leaf magnetic remanence was reduced significantly during rainfall occurring between the two sampling days. Sampling height also has a significant effect on leaf PM loading, with up to 100% increase from 1.5-2m to 0.3 meters, indicating that small children are particularly vulnerable to PM exposure. These results are then compared with data from an atmospheric dispersion modelling system (ADMS) devised for the Lancaster region. Compared with the model data trends, the leaf magnetic data show greater PM loading at junctions and traffic lights, and reduced PM loading with distance from vehicle sources at locations where rows of trees extend back from the road. These results indicate that trees in leaf have a significant protective effect and should be accounted for in ADMS in order to achieve more realistic simulations.

Origins of the Soils Magnetic Susceptibility Anomalies on the area of Poland

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Magnetic iron minerals, whose presence in soils can easily be detected by magnetic susceptibility measurements, are components of numerous industrial dusts. Beckwith et al. (1986) demonstrated that there is a linear dependence between magnetic particles content and content of heavy metals like: Cu, Fe, Pb and Zn (in urban dusts). A similar dependence was observed in atmospheric dusts (for Pb, Cu, Zn, and Cd) by Hunt et al. (1984). If the origin of magnetic particles and a considerable part of heavy metals permeating into soils as a result of industrial emission or imission is the same, the application of magnetic susceptibility measurements for the detection of potential high risk-areas is possible. For the area of Poland, the map of magnetic susceptibility of soils was evaluated by Magiera (2002). The presentation shows supplemental information gathered for the subsoil samples (at the depth 40 – 60 cm). On the base of differential map of topsoils and subsoils magnetic susceptibility, possible causes of abnormal values will be considered. Three main natural origins of magnetic susceptibility anomalies were pointed: soils developed on loess, on moraines and on the magmatic and metamorphic rocks of the Sudety Mountains. Within the borders of those areas the stronger, local anomalies appeared. Some of them are the focus of attention of further investigation. Two polish ironworks: Ostrovia (Ostrowiec Świętokrzyski, NE margin of Holycross Mts.) and Andrzej (Zawadzkie, N Upper Silesia) were chosen for the case study. Lateral and vertical extension of soils pollution are studied and compared with several parameters like type of soil, prevailing directions of winds. Increased concentrations of heavy metals are expected at a distance up to 3 km from the ironworks. Two soils profiles were taken from the polluted areas. Vertical migration of heavy metals were determined by further petromagnetic and geochemical analysis of profile samples, taken with 5 cm step. In the Ostrovia case magnetic susceptibility decreases rapidly from the top level to 15 cm where it stabilizes at the level characteristic for natural podzols and sands. It is confirmed by geochemical analysis, showing decrease of Fe as well as Zn and Pb content at the same depth distance. More complicated results were obtained in the Zawadzkie case. Fe content stabilizes at the 50 cm depth, which correspond with magnetic susceptibility profile. It can be caused by longer history of factory, different methodology and many other aspects. SEM images shows that there are numerous Fe spherules in top samples of both profiles. They have miscellaneous structures, usually with empty space inside. References: Magiera T., Lis J., Nawrocki J., Strzyszcz Z., 2002 – Magnetic Susceptibility of Soils in Poland, ISBN 83-86986-64-6, IPIŚ PAN, Zabrze Beckwith P.R., Ellis J.B., Revitt D. M., Oldfield F., 1986 – Heavy metal and magnetic relationships for urban source sediments. Phys. Earth Planet Interiors, 42: 67-75 Hunt A., Jones J., Oldfield F., 1985 – Magnetic measurements of heavy metals in atmospheric particulates of anthropogenic origin. Sc. Total Environ., 33: 129-139

Palaeomagnetic Constraints on Tectonic Rotation During the Evolution of the Atlantis Massif Oceanic Core Complex

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Integrated Ocean Drilling Program (IODP) Expedition 304/305 sampled exhumed lower oceanic crust at Atlantis Massif, located on the western flank of the Mid-Atlantic Ridge (MAR) at 30°N. The corrugated, striated central portion of the massif displays morphological and geophysical characteristics inferred to be representative of an oceanic core complex exposed by long-lived detachment faulting. Palaeomagnetic analyses on gabbros from hole U1309D, which penetrated 1.4km into the central dome of the detachment footwall, reveal three characteristic types of magnetic remanence: (i) samples with a single, high temperature reversed component of magnetisation, R1; (ii) samples with R1 and a lower temperature normal polarity overprint, N1; and (iii) samples with R1 and N1 components, plus an additional low temperature reversed polarity overprint, R2. The transition between the distinct components occurs over very narrow and consistent temperature intervals, illustrated on Zijderveld diagrams as sharp breaks in slope. This provides strong evidence for a thermal origin of magnetic remanence. However, no obvious relationship is seen between remanence structure and igneous stratigraphy, suggesting that overprints were not produced by partial thermal resetting of earlier remanences by later intrusions during subsequent geomagnetic chrons. Instead the data suggest progressive cooling of the sampled section over a protracted period that includes two polarity reversals (with remanence structure controlled by variations in blocking temperature spectra). Analysis of the unique suite of three-component samples allows us to determine relative magnetic directions, thereby overcoming the inherent lack of magnetic declination data in rotary drilled cores. Systematic differences in the direction of the youngest reversed (R2), and older normal (N1) and reversed (R1) polarity components can be explained by a c. 36° tectonic rotation during polarity chron C1r.1r (0.99-0.78 Ma) about a ridge-parallel axis trending 015°. These palaeomagnetic data provide the first direct evidence for the rotation axis, amount and timing of a phase of tectonic tilting during the development of an oceanic core complex. They are most compatible with a model involving flexural shallowing of an initially steep detachment fault during a period when plate divergence across the MAR was accommodated predominantly by amagmatic extension.

A palaeomagnetic investigation of the Archean Pongola Supergroup, South Africa

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Late Archean (3.0-2.5 billion yr) sediments and lavas of the Pongola Supergroup in South Africa represent one of the oldest-known cratonic cover sequences. Despite their age, these sequences have been subjected to only mild deformation and thermal metamorphism. Preliminary paleomagnetic results from these rocks indicate that despite strong thermal overprinting, these sequences may indeed carry a primary magnetic signal, which would provide important insights into tectonic processes and the geomagnetic field on the early Earth.

A new Automated Microwave Demagnetiser/Remagnetiser System for Palaeointensity Studies

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It has been established that applying high frequency microwaves is directly equivalent to heating the sample in terms of demagnetisation and remagnetisation. Samples are small (5mm diameter) and not easily oriented and so currently microwaves are only used to demagnetise/remagnetise samples in palaeointensity determinations (e.g. Hill et al 1999,2000,2002. ,Pressling et al 2007) These experiments were limited by the sensitivity of the magnetometer used. A new third generation automated microwave system has been designed and built around an innovative small bore cryocooled SQUID magnetometer. The magnetometer (designed by Tristan Technologies) is not filled with liquid helium but uses an advanced cryocooler to lower the temperature of the SQUID sensors to below the liquification temperature of helium. It is only necessary to attach a bottle of high purity helium gas. The new system is designed to take 5mm diameter samples but with an optical alignment system for palaeomagnetic directional studies. Samples are held in place by air pressure using a small vacuum pump. This novel system eliminates the use of glue and therefore reduces microwave absorption in the glue and possible magnetic contamination that could affect the measurements.

Palaeomagnetic studies in the Kletno Old Uranium Mine (Sudety Mts, Poland) – preliminary results.

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The Kletno ore deposits are located along the NNW-SSE tectonic zone known as Kletno Fold, (in south-eastern part of Sudety Mts., Poland). Main ore body, of thickness up to 5 meters, occurs above the marble footwall under the hanging wall of gneisses. Detailed description of ore deposits structure and its genesis is presented in papers of Banaś (e.g. 1965). He distinguished three mineral associations: magnetite, polymetallic and quartz-fluorite-sulphide. Magnetite mineralization is taught to be the oldest one, connected with Variscan regional metamorphism of syngenetic Fe-deposits together with contact metamorphism of the Śnieżnik gneiss intrusion. Polymetallic and fluorite (probably late Alpine in age) stages are taught to be a result of several low-temperature hydrothermal phases related to the deep-seated, post-magmatic or metamorphic source. Magnetite and polymetallic-fluorite mineralization is connected also with the oxide uranium mineralization. Main uranium ore mineral is pitchblende, forming with fluorite the largest uranium accumulations. Fifteen independently oriented hand samples were collected in the Kletno Old Uranium Mine, from the abandoned part of a tunnel, rendered accessible for touring. Sampled were quartz veins with fluorite and calcite, as well as skarned rocks with magnetite and gneisses with visible hematite occurrences. During thermal and AF demagnetization processes samples indicated two distinct components of different polarities. One of normal polarity based on magnetite and fine hematite and the second one with reversed polarity preserved in coarse grained hematite. Directions isolated in magnetite and hematite does not differ in the limits of error. It must have been the same mineralization process, but multistage and time extended, which led to magnetite and hematite genesis. Comparison of the obtained directions with the apparent polar wander path for Mesozoic Europe resulted in estimation of oxide mineralization age for Early Cretaceous up to Tertiary. Results of these preliminary studies are partially in agreement with works connecting mineralization with post-Variscan or Alpine processes. Legierski (e.g.1976) noticed significant time gap between Variscan granitoids and the polymetallic deposits using lead isotopic composition from the Bohemian Massive metallogenic zones. According to Jerzmański (1976) Sudetic polymetallic, fluorite and barite mineralization belong to one early Cimmerian mineralization cycle, originated due to renewal of deeper crust structures. Moreover, after Przeniosło and Sylwestrzak (1971) hematite mineralization is taught to be of genetic origin with quartz-fluorite-calcite processes probably late Alpine in age. Wide-ranging, detailed studies are essential for better understanding of the mineralization processes and precise age estimations in the Kletno region. References BANAS M. (1965) - Signs of mineralization in the metamorphic complex of Śnieżnik Kłodzki (Sudetes Mts). Polish Acad. of Sci. Geological Transactions 27, Warsaw (in Polish with English summary). JERZMAŃSKI J. (1976) – Barite and fluorite mineralization and its position in the metallogenic development of the Lower Silesia area. In: The current metallogenic problems of Central Europe, Geological Institute, Warsaw: 227-250. LEGIERSKI J. (1976) – Pb-Pb and U-Pb dating of the ore deposits of the Bohemian Massif. In: The current metallogenic problems of Central Europe, Geological Institute, Warsaw: 111- 114. PRZENIOSŁO S. and SYLWESTRZAK H. (1971) – Fluorite mineralization on the eastern slopes of the Śnieżnik Kłodzki Mt. (in Polish with English summary). Kwartalnik Geologiczny, 15(2): 251-261.

The palaeomagnitic characteristics of the Holocene deposits in the Chirchik river basin.

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Palaeomagnetic reversal stratigraphy, widely used for dating and correlation of fluvial sediment. We researched fairly complete and thick stratigraphic sections of the whole Holocene in the region Chirchik river basin. In this region the Holocene deposits characterize by sediments of the riverbed and first and second river terraces. The resulting field and laboratory data provide the basis for this paper. Palaeomagnetical data were taken from the seven sections of the Holocene deposits. Descriptive information of sections included: sediment texture, colour, internal structures, nature of bedding contacts and lateral variation. Many units were traced laterally between sections. The determination of a primary magnetization and its stability has been made by laboratory processes employing the magnetic cleaning by means of a conventional technique. Three or four palaeomagnetic samples with regular vertical intervals to 0.1-0.2 m. were taken at each sites of sections. Palaeomagnetical investigations are determined the small magnetic parameters of the samples. Magnetic susceptibility (χ) are changed from 18.0*10-6 SGS to 28.0*10-6 SGS, and the mean value of χ equally 21.3*10-6 SGS. Natural remaining magnetization (In) are changed from 0.3*10-6 SGS to 12.0*10-6 SGS, and the mean value of In equally 4.6*10-6 SGS. An analysis of In and χ along sections, from the base upwards, show that In decrease from 12.0*10-6 SGS to 3.6*10-6 SGS and χ increase from 18.0*10-6 SGS to 45.0*10-6 SGS. Increasing of magnetic susceptibility is explained by fortification of the faction of the ferromagnetic minerals. The viscous magnetization of the simples does not exceed 35% In. The sediments of first terrace in the studied sections are magnetized on direction of the modern magnetic field (Dav=50; Iav=580). The study of the magnetic characteristics are showed that sediments of second terrace in Chirchik river basin are magnetized on direction of the modern magnetic field (Dav=350; Iav=580). However in upper part of terrace is determined a short excurse (Dav=1780; Iav=380). Moreover in the zone of direct polarity is determined two event of a reversed magnetization (Dav=1800; Iav=-580; and Dav=1860; Iav=-520). Palaeomagnetical results is shown that the decrease a tension of the magnetic field at moment of the manifestation of the event of a reversed magnetization. Conversely, the tension of the magnetic field does not change at moment of the manifestation of the short excurse. According to these data, all the formations of the holocene time in the Chirchik river basin are of a normal magnetization and belong, therefore, to the Brunhes epoch, and in these sediments are determined two event of a reversed magnetization and an short excurse.

Low latitude glaciations during the Neoproterozoic: clues from the African cratons

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Geological observations from Neoproterozoic rocks have build up evidence for marine glaciers in equatorial latitudes, suggesting a period of extreme global climate conditions. One popular model used to describe these observations is the Snowball Earth Hypothesis. This model involves global glaciation with glaciers extending from polar to tropical regions and has been a hot topic of debate for the last decade. Opposing models dispute the reliability of the model by questioning the distribution of continents during these periods, the cause of the freeze and thaw that started and ended the snowball events, the characteristics of the ice sheet and the glacial origin and supposed synchronicity of the sediments. In order to better understand and constrain these periods of apparent extreme climate conditions a multidisciplinary approach will combine palaeomagnetism with chemostratigraphy, sedimentology and radiometric dating. This will provide more clues to the distribution and movement of continents at these periods and it will help us to better understand the environmental setting of the deposits that are associated with the snowball periods. The research will focus on central and western African cratons which include famous deposits that are associated with a snowball event. During the summer of 2007 we sampled the Western Congo Group, a Neoproterozoic succession containing the supposedly glacio-marine Lower and Upper Mixtite Formations. The successions will be correlated to other Neoproterozoic successions using stable isotope curves and petrological characteristics. Palaeomagnetic results will hopefully constrain the depositional latitude of the formations which will give us the opportunity to test the equatorial origin of glacial deposits.

Determining archaeointesity from anisotropic ceramics

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Archaeological ceramics can be useful for determing the changes in the past magnetic field strength. They are often well-dated and frequently have suitable magnetic remanence carriers for archaeointensity determination. Anisotropy, usually as a result of the manufacturing process, can be a problem. This can be corrected for by measuring the tensor of anisotropy but if the laboratory field is applied in such a direction as to reproduce the original NRM, no correction should be needed. Finding the appropriate direction requires precise measurement of the laboratory TRM and control of the applied field directions. At the University of Liverpool the microwave system uses a automated sample carriage, triple axis field coils and a small bore SQUID magnetometer allowing such precision. We demonsterate how this can be used to obtain reliable archaeointensity results from highly anisotropic ceramics.