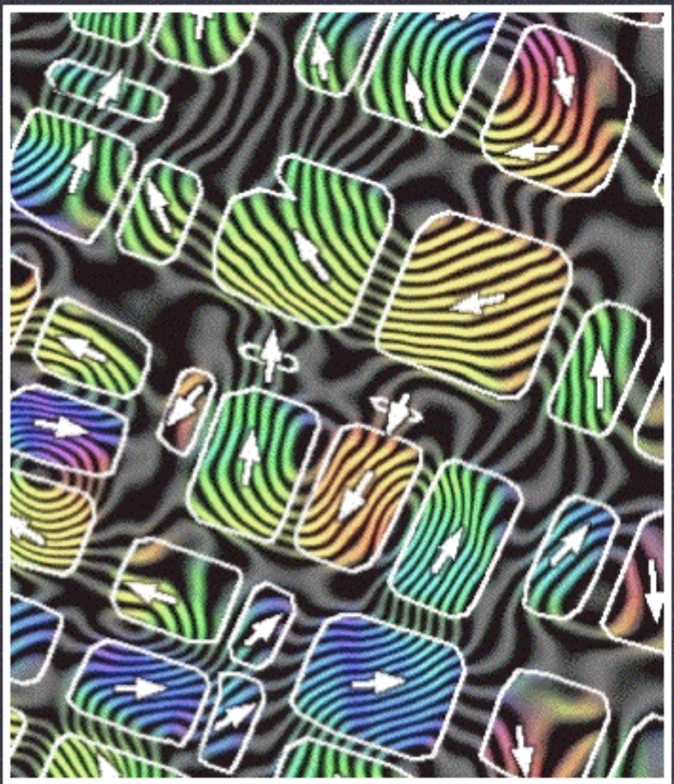
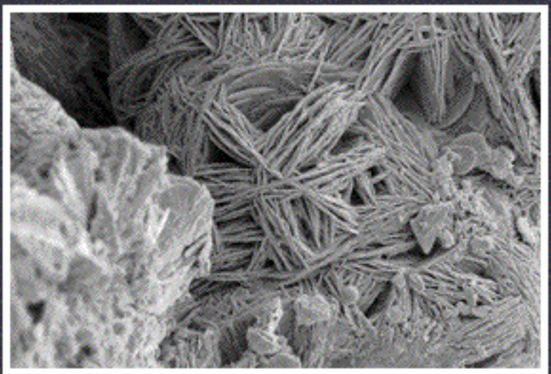
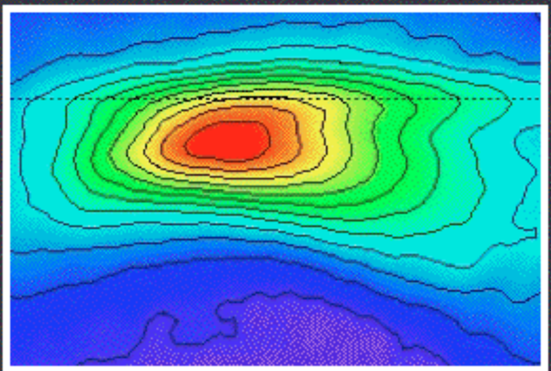






MAGNETIC INTERACTIONS 2014

8TH-9TH JANUARY
ST CATHARINE'S COLLEGE
CAMBRIDGE

2G AGICO ASC SCIENTIFIC BARTINGTON
LAKESHORE MAGNETIC MEASUREMENTS LTD
MINERAL PHYSICS GROUP

SPONSORS

This meeting is able to take place with the kind support of our sponsors listed below. This a not-for-profit meeting, with all donations going to make sure that student participation is free-of-charge, with any excess being used to help support student travel expenses for participating in the meeting. On behalf of the organising committee and all participants we'd like to thank all our sponsors for their generous support.

2G Enterprises

AGICO

ASC Scientific

Bartington® Instruments

LakeShore

magnetic measurements

mpg

MAGNETIC INTERACTIONS CONFERENCE
University of Cambridge
St. Catharine's College
McGrath Centre Auditorium
8-9 January 2014

SCHEDULE

Wednesday, 8 January

12:00-1:00 Welcome and registration, McGrath Centre Lobby
Lunch buffet, McGrath Centre Bar

1:20-1:30 Introductory remarks

1:30-4:30 Session: Fundamental and Applied Rock and Mineral Magnetism

1:30-2:00 Michael Carpenter, University of Cambridge
Magnetoelastic behaviour of materials from the perspectives of strain and elasticity

2:00-2:20 Trevor Almeida, Imperial College London
Oxidation of pseudo-single domain Fe_3O_4 particles and associated magnetic response examined by complementary environmental TEM, off-axis electron holography, Mössbauer spectroscopy and SuperSTEM analysis

2:20-2:40 Wyn Williams, University of Edinburgh
Effects of the core-shell structure on the magnetic properties of partially oxidized magnetite grain: Experimental and micromagnetic investigations

2:40-3:00 James Bryson, University of Cambridge
Synchrotron X-ray imaging of nanomagnetism in meteoritic metal

3:00-3:30 Coffee break, McGrath Centre Bar

3:30-3:50 Richard Harrison, University of Cambridge
FORCinel version 2.0: A practical guide to the VARIFORC method

3:50-4:10 Rabiu Abubakar, Imperial College London
Formation of magnetic minerals in hydrocarbon-generation conditions

4:10-4:30 Ioan Lascu, University of Cambridge
Speleothems as geomagnetic recorders

4:30-5:00 Break

5:00-7:30 **Poster session and drinks, McGrath Centre Bar**

7:30 Dinner, Senior Combination Room (SCR), St. Catharine's College

Thursday, 9 January

9:00-9:30 Tea and coffee, McGrath Centre Bar

9:30-12:30 **Session: Behaviour, Records, and Models of the Geomagnetic Field**

9:30-10:00 Maxwell Brown, GFZ
GEOMAGIA50 database for sediments

10:00-10:20 Andy Herries, La Trobe University
The palaeomagnetism of fossil bearing palaeokarst in South Africa

10:20-10:40 Laura Roberts-Artal, University of Liverpool
New palaeomagnetic results from outcrop and drill core samples of the 3.47 billion year old Komati Formation, Barberton Mountain Land, South Africa

10:40-11:00 Jay Shah, Imperial College London
Palaeomagnetic evidence for the persistence of the South-Atlantic geomagnetic anomaly

11:00-11:30 Coffee break, McGrath Centre Bar

11:30-11:50 Neil Suttie, University of Liverpool
New insights from old observations: The voyage of Alexander von Humboldt

11:50-12:10 John Piper, University of Liverpool
Palaeomagnetism and planetary tectonics

12:10-12:30 Antony Morris, Plymouth University
Recognizing detachment-mode seafloor spreading in the deep geological past

12:30-12:50 Andrew Biggin, University of Liverpool
Inferring changes in the palaeomagnetic dipole moment through geological time

POSTER PRESENTATIONS

Roberts Blukis, University of Cambridge
Computational study of the Fe-Ni phase diagram and investigation in nanoscale exsolution patterns in iron and stony-iron meteorites

Will Brown, University of Leeds
Jerks abound: Observations of geomagnetic jerks and implications for core dynamics

Grace Cox, University of Leeds
Dispersion and phase shifts of torsional waves in forward models

Stacy Emmerton (Adrian Muxworthy), Imperial College London
Dating hydrocarbon seeps – the Mupe Bay Mystery

Stacy Emmerton (Adrian Muxworthy), Imperial College London
Correlating biodegradation to magnetisation in oil bearing sedimentary rocks

Emma Hodgson, University of Liverpool
Thermoremanent behaviour in oxyexsolved titanomagnetite

Claire Lam, Imperial College London
Determining the magnetic signature of London's air pollution

Phil Livermore (Will Brown), University of Leeds
Core-flow constraints on extreme archeomagnetic intensity changes

Conall Mac Niocaill, University of Oxford
Oroclinal bending, distributed deformation, and Arabia–Eurasia convergence in NE Iran

Claire Nichols, University of Cambridge
Nanopaleomagnetism of meteorites: Evidence for a core dynamo in the pallasite parent body

Andreas Nilsson, University of Liverpool
An updated SW Pacific palaeointensity dataset and its influence on global Holocene geomagnetic field models

Owain Roberts, Imperial College London
High-latitude paleomagnetic and Ar-Ar study of 0-6 Ma lavas from eastern Iceland: Contribution to the time-averaged field initiative

Samuel Taylor, Institut de Physique du Globe de Paris
Magnetic analysis of the Nussloch loess sequence: Implications for environmental & palaeomagnetic research

Megan Thomas, University of Liverpool
An archaeomagnetic study of a Roman bath in Southern France

Jessica Till, Université Pierre et Marie Curie, Paris
Experimental comparison of abiotic and microbial Fe-mineral transformations to identify pedogenic magnetic enhancement pathways

CONFERENCE PARTICIPANTS

Rabiu Abubakar, Imperial College London
Trevor Almeida, Imperial College London
George Beckmann
Andrew Biggin, University of Liverpool
Roberts Blukis, University of Cambridge
Mark Bourne, University of Southampton
Maxwell Brown, Deutsches GeoForschungsZentrum (GFZ) Potsdam
Will Brown, University of Leeds
James Bryson, University of Cambridge
Michael Carpenter, University of Cambridge
Nathan Church, Norwegian University of Science and Technology (NTNU) Trondheim
Pádraig Ó. Conbhuí, University of Edinburgh
Grace Cox, University of Leeds
Arne Døssing, Imperial College London
Richard Harrison, University of Cambridge
Andy Herries, La Trobe University
Emma Hodgson, University of Liverpool
Elliot Hurst, University of Liverpool
Claire Lam, Imperial College London
Ioan Lascu, University of Cambridge
Conall Mac Niocaill, University of Oxford
Matthew Meyer, Plymouth University
Antony Morris, Plymouth University
Adrian Muxworthy, Imperial College London
Lesleis Nagy, University of Edinburgh
Claire Nichols, University of Cambridge
Andreas Nilsson, University of Liverpool
Ahmed Omer, Plymouth University
John Piper, University of Liverpool
Owain Roberts, Imperial College London
Laura Roberts-Artal, University of Liverpool
Jay Shah, Imperial College London
Neil Suttie, University of Liverpool
Samuel Taylor, Institut de Physique du Globe de Paris
Megan Thomas, University of Liverpool
Jessica Till, Université Pierre et Marie Curie, Paris
Wyn Williams, University of Edinburgh
Chuang Xuan, University of Southampton

ABSTRACTS

Formation of magnetic minerals in hydrocarbon-generation conditions

Abubakar, R.[1], Muxworthy, A. R.[1], Sephton, M. A.[1], Southern, P.[2], Watson, J.[1], Fraser, A.J.[1], Almeida, T.P.[1]
[1]Department of Earth Science and Engineering, Imperial College London,
[2]Healthcare Biomagnetics Laboratory, University College London

The promotion of palaeomagnetism as a tool for the exploration of oil and gas has intensified in the last two decades; from the studies of aeromagnetic maps and soil samples above oil fields to experimental and thermodynamic models on the production of magnetic minerals due to burial and/or contact with migrating crude oils. In this paper, we report how three source rock samples from the Wessex Basin in Dorset southern England were pyrolysed at 150 °C, 200 °C, 250 °C, 300 °C and 320 °C in conditions similar to those found in the oil kitchen. Magnetic analysis of both the pyrolysed and the non-pyrolysed samples at room temperature and at 5 K coupled with transmission electron-microscopy and imaging and X-ray analysis revealed the formation of nanometre sized magnetic particles that varied across the rock samples analysed but more importantly across the pyrolysis temperature range. Magnetic measurements demonstrated the formation of magnetic minerals peaked at 250 °C for all rock samples and then decreased at 300 °C before peaking at 320 °C. The sizes of the magnetic minerals formed also indicated that it is possible for them to migrate together with the oil making partly responsible for the magnetic anomalies observed over oil fields and at various depths within oil fields.

Oxidation of pseudo-single domain Fe_3O_4 particles and associated magnetic response examined by complementary environmental TEM, off-axis electron holography, Mössbauer spectroscopy, and SuperSTEM analysis

Trevor P. Almeida[1], Adrian R. Muxworthy[1], Wyn Williams[2], Takeshi Kasama[3], Cathrine Frandsen[4], Rafal E. Dunin-Borkowski[5]
[1]Department of Earth Science and Engineering, Imperial College London, [2]School of GeoSciences, University of Edinburgh, [3]Centre for Electron Nanoscopy, Technical University of Denmark, [4]Department of Physics, Technical University of Denmark, [5]Ernst Ruska-Centre for Microscopy and Spectroscopy with Electrons and Peter Grünberg Institute, Forschungszentrum Jülich, Germany

In order to interpret palaeomagnetic measurements reliably, the mechanisms that induce and alter chemical remanent magnetisation (CRM) in naturally occurring magnetic recorders must be fully understood. Current models of CRM processes only exist for the smallest uniformly-magnetised single domain (SD) grains. However, magnetic signals from rocks are often dominated by larger grains that contain non-uniform pseudo-SD (PSD) magnetisation states. Magnetite (Fe_3O_4) is the most magnetic naturally occurring mineral on Earth, carrying the dominant magnetic signature in rocks and providing a critical tool in palaeomagnetism. The oxidation of Fe_3O_4 to other iron oxides, such as maghemite (γ-Fe_2O_3) and hematite (α-Fe_2O_3), is of particular interest as it influences the preservation of remanence of the Earth's magnetic field by Fe_3O_4. The complementary use of environmental transmission electron microscopy (ETEM) and off-axis electron holography techniques can be used to reveal local changes in magnetisation in minerals as they alter during in situ heating in a controlled oxidising atmosphere. Such experiments can provide direct information about the relationship between magnetic domain structure and chemical alteration features, phase boundaries and crystalline microstructure. In the present study, synthetic Fe_3O_4 particles with sizes in the PSD range (< 200 nm) were heated in situ in an ETEM under an oxygen atmosphere. Oxidation of the Fe_3O_4 particles was investigated using bright-field and dark-field imaging, electron diffraction and electron energy-loss spectroscopy. The associated alteration in CRM exhibited by individual Fe_3O_4 particles was investigated using off-axis electron holography, in the form of reconstructed magnetic induction maps. In addition to in situ investigations, the native PSD Fe_3O_4 particles were heated ex situ within a temperature controlled furnace under ambient pressure conditions. Complementary X-ray diffractometry and Mössbauer spectroscopy confirmed the progressive oxidation of the reaction products to γ-Fe_2O_3. Further, scanning TEM (STEM) facilities with ultra-high spatial and spectral resolution (SuperSTEM) were used to identify the presence of nano-scale γ-Fe_2O_3 surface layers on slightly oxidised Fe_3O_4 particles.

Inferring changes in the palaeomagnetic dipole moment through geological time

Biggin, A.[1], Suttie, N.[1], Paterson, G.A.[2], Aubert, J.[3], Holme, R.[1], Hurst, E.A.[1], Clarke, A.[1]
[1]School of Environmental Sciences, University of Liverpool, [2]Paleomagnetism and Geochronology Lab, Chinese Academy of Sciences, Beijing, [3]Institut de Physique du Globe de Paris

On timescales over which mantle convection may be affecting the geodynamo (10-100s of million years), magnetic reversal frequency is the best documented aspect of geomagnetic behaviour. Suitable, continuous recorders of this parameter become very sparse before a few hundreds of millions of years however presenting a major challenge to documenting and understanding geomagnetic variations on the timescale of even the most recent supercontinent cycle. It is hypothetically possible to measure the absolute geomagnetic palaeointensity from any geological material that has cooled from above the Curie Temperature of its constituent magnetic remanence carriers. Since igneous rocks are abundant in the geological record, estimates of dipole moment from these present a vital resource in documenting geomagnetic variations into deep time. In practice, a host of practical problems makes obtaining such measurements reliably from geological materials challenging. In order that even the existing record may be used to maximum effectiveness in characterising geomagnetic behaviour, two challenges must be met. 1. The variable reliability of individual measurements must be reasonably assessed; 2. The impact of the inhomogeneity of the distributions of dipole moment estimates in space and time must be assessed. Here, we will report efforts attempting to address these two challenges using novel approaches. A new set of quality criteria for palaeointensity data (QPI) has been applied to studies recently added to PINT. To address challenge 1, the idea, borrowed from a similar approach long-applied to palaeomagnetic poles, is that each published dipole moment estimate will eventually be given a QPI score indicating the number of these criteria fulfilled. To begin to address challenge 2, we take an approach using the outputs of numerical dynamo simulations. This involves subsampling synthetic global time series of full-vector magnetic field data, converting these into palaeomagnetic-like dipole moment estimates, and comparing these to the entire distribution to understand how well secular variation is averaged and characterised. Finally, the two approaches will be combined and datasets of real dipole moment estimates, filtered by QPI, will be compared to the synthetic distributions in order to present more robust characterisations of geomagnetic behaviour in different intervals than has previously been possible.

Computational study of the Fe-Ni phase diagram and investigation in nanoscale exsolution patterns in iron and stony-iron meteorites

Roberts Blukis, James Bryson, Richard Harrison
Department of Earth Sciences, University of Cambridge

Tetrataenite and Fe rich matrix exsolution patterns, also known as 'cloudy zones', are ubiquitous along kamacite-taenite grain boundaries in iron and stony iron meteorites. Despite being common their formation has not been thoroughly understood. Monte-Carlo methods were used to study the phase diagram of the Fe-Ni system in face centred cubic (FCC) phase and to explain the formation of 'cloudy zones'. The computational method used was capable of reproducing known information about tetrataenite phase and qualitatively reproduced observed cloudy zone patterns on a small scale. Software generated a cubic supercell consisting of 20x20x20 FCC unit cells containing 32000 atoms to which a Monte-Carlo algorithm was applied. Chemical and magnetic interactions between Fe-Fe, Ni-Ni and Fe-Ni atoms were taken into account in the algorithm. Simulations were run at different compositions with varying temperature. They predicted most likely composition of cloudy zones at ~0.37% Ni composition which is consistent with electron microprobe measurements of average chemical composition of 'cloudy zones'. The temperature of exsolution and 'cloudy zone' appearance of ~475 K was predicted which was lower than expected. The simulated exsolved structures consisted of islands of tetrataenite (FeNi) and matrix of ordered cubic Fe_3Ni phase. These simulations are going to be supplemented by free energy expressions and simulations of spinoidal structure to better understand the behaviour of the Fe-Ni system in the metastable FCC region. The research has shown an insight into development of 'cloudy zones' and could be used in more precise estimations of meteorite parent body cooling and magnetic history.

GEOMAGIA50 database for sediments

Maxwell C. Brown[1], Fabio Donadini[2], Ute Frank[1], Andreas Nilsson[3], Kimmo Korhonen[4], Monika Korte[1], Catherine G. Constable[5]

[1]Helmholtz-Zentrum Potsdam, Deutsches GeoForschungsZentrum, [2]Institut für Geophysik, ETH Zürich,
[3]School of Environmental Sciences, University of Liverpool, [4]Geological Survey of Finland,
[5]Scripps Institution of Oceanography, University of California, San Diego

The GEOMAGIA50 database is an international collaboration funded by the National Science Foundation (NSF) and German Research Foundation (DFG). Its aim is to provide easy access to published paleomagnetic and chronological data for the past 50 ka. We have expanded the database to include paleomagnetic, rock magnetic and chronological data obtained from sediments. Magnetic and chronological data recorded in sediments deposited over the last 50 ka can aid our understanding of past changes in the geomagnetic field, physical environments and climate. In addition, sediment data complement a wealth of archaeomagnetic and volcanic data covering the same period already stored in GEOMAGIA50. Data are housed on a server-side MySQL database and are accessed by users through a web-based interface. The interface allows rapid selection of data by age, geographic and data-type constraints. We will demonstrate the functionality of the database, showing examples of search and output options.

Jerks abound:
Observations of geomagnetic jerks and implications for core dynamics

Will Brown, Jon Mound, Phil Livermore

School of Earth and Environment, University of Leeds

The geomagnetic field is generated by the constant evolution of the fluid outer core. Geomagnetic jerks are rapid changes in the secular variation of Earth's magnetic field, the variation of the field at time scales on the order of months to decades, attributed primarily to changing flows near the surface of the outer core. Various generation mechanisms have been suggested for these rapid changes but none have conclusively explained the phenomena. Our recent study of geomagnetic jerks in observatory data over the period of 1957 to 2008 indicates that jerks are far more frequent an occurrence than previously suggested and perhaps part of the more rapid end of a spectrum of core dynamics. Whilst jerks are seen to be common, relative peaks in the global number of jerk occurrences are seen in 1968-71, 1973-74, 1977-79, 1983-85, 1989-93, 1995-98 and 2002-03 with the suggestion of further poorly sampled events in the early 1960s and late 2000s. We do not find consistent patterns in the spatial distributions of occurrences suggesting complex origins or the superposition of several discrete individual events. We observe that jerk amplitudes vary through time and their variations are potentially periodic in Europe and North America. These signals may be related to the 6-year periods detected independently in the secular variation and length-of-day, and thus may constrain the source of jerks in the core.

Synchrotron X-ray imaging of nanomagnetism in meteoritic metal

James Bryson[1], Claire Nichols[1], Julia Herrero Albillos[2], Florian Kronast[3], Tolek Tyliszczak[4], Gerrit van der Laan[5], Simon Redfern[1], Richard Harrison[1]
[1]Department of Earth Sciences, University of Cambridge, [2]Centro Universitario de la Defensa, Universidad de Zaragoza, [3]BESSY II, Helmholtz-Zentrum, Berlin, [4]Advanced Light Source, Berkeley, [5]Diamond Light Source, Didcot

It is becoming increasingly apparent that a wealth of paleomagnetic information is stored at the nanoscale within natural samples. To date, this nanopaleomagetism has been investigated using high-resolution magnetic microscopies, such as electron holography. Although unparalleled in its spatial resolution, electron holography produces images that are indirectly related to the magnetisation state of the sample, introducing ambiguity when interpreting magnetisation information. Holography also requires extensive off-line processing, making it unsuitable for studying dynamic processes, and the sample preparation negates the study of natural remanences. Here we demonstrate the capabilities of a new generation of nanomagnetic imaging methods using synchrotron X-ray radiation. X-rays tuned to an elemental absorption edge can display differing excitation probabilities depending on the orientation of an electron's magnetic moment relative to that of the X-ray beam. This is achieved by introducing an angular momentum to the photon through circular polarisation, resulting in an absorption signal that is proportional to the projection of the magnetic moment on to the X-ray beam direction. We introduce and compare two experimental set-ups capable of spatially resolving these signals to form a high-resolution magnetisation map: photoemission electron microscopy and scanning transmission electron microscopy. Both techniques provide measurements of magnetisation with 30-50 nm resolution and elemental specificity. Photoemission electron microscopy can be used also to create maps of all three of the spatial components of magnetisation and investigate dynamic magnetic switching processes. The full capabilities of X-ray imaging are demonstrated through the application of both of these techniques to meteoritic metal. We show that the 'cloudy zone' within iron meteorites contains nanoscale islands of tetrataenite (FeNi) that are populated equally by all three possible magnetic easy axes, suggesting that there were no stray fields (either magnetic or stress) effecting the magnetisation during cloudy zone formation. A further study on pallasitic metal displays an uneven population of the easy axes in its CZ, suggesting the sample was magnetised in a field. As the cloudy zone forms over 10-100 Ma, the magnetic signal across the pallasite CZ could relate to a relative measure of asteroid dynamo field direction and strength over this entire time period, which has the potential to revolutionise our understanding of dynamo processes and planetary formation.

Magnetoelastic behaviour of materials from the perspectives of strain and elasticity

Michael A. Carpenter
Department of Earth Sciences, University of Cambridge

Most phase transitions involving atomic displacements, development of electric dipoles or magnetic moments, changes in electronic structure, superconductivity, etc., also involve some distortion of the crystal structure and the resulting strain provides a pervasive influence on the static or dynamic properties of interest. If there is a change in strain state it is inevitable that there will also be changes in the elastic moduli and these can be described formally in terms of coupling between strain and the driving order parameter for the transition. There are two general consequences. Firstly, typical changes in strain of ~0.001-0.01 can result in changes of the elastic constants of 10s of %. Secondly, most phase transitions involve the development of some microstructure and this, too, can give rise to changes in elastic properties. In particular, under a dynamic stress ferroelastic twin walls can be mobile and their motion will give rise to characteristic patterns of acoustic attenuation. In some magnetic materials the twin walls have both magnetic and ferroelastic character. Magnetoelastic coupling is generally investigated from the perspective of magnetic measurements, but some changes in magnetic properties are understood to have been influenced by strain effects. The same magnetoelastic behaviour can also be examined from the perspective of elasticity, however, as this will highlight the strain relaxation behaviour more directly. Such strain-related phenomena have been investigated by Resonant Ultrasound Spectroscopy, which involves measurement of the acoustic resonant modes of mm-sized single crystal or polycrystalline samples at frequencies of ~0.1-2 MHz. Elastic and anelastic properties can be determined in the temperature range 5-1500 K, and it is possible also to apply a large magnetic field in the low temperature range. Examples of magnetic transitions investigated in this way include octahedral tilting transitions + antiferromagnetic ordering in the perovskite, $KMnF_3$, antiferromagnetic ordering + pseudoproper ferroelastic transition in wüstite, Fe_xO, and the paramagnetic – canted antiferromagnetic and spin flop transitions in hematite, Fe_2O_3. A new method for measuring elastic properties of fine powders has also been developed and will be illustrated for the case of the Verwey transition in magnetite, Fe_3O_4.

Dispersion and phase shifts of torsional waves in forward models

Grace Cox, Phil Livermore, Jon Mound
School of Earth and Environment, University of Leeds

Torsional Alfvén waves have been thought to exist in the Earth's core since their theoretical prediction by Braginsky in 1970. More recently, they have been inferred from observations of secular variation and length of day, and also observed in geodynamo simulations. These inferences from geophysical data have provided an important means of estimating core properties such as viscosity and internal magnetic field strength. We produce 1D forward models of torsional waves in the Earth's core, also known as torsional oscillations, and study their evolution in a cylinder, a full sphere and an equatorially symmetric spherical shell. The key features of torsional waves in our models are: geometric dispersion, phase shifts and internal reflections. In all three core geometries, we find that travelling torsional waves undergo significant geometric dispersion that increases with successive reflections from the boundaries such that an initial wave pulse becomes unidentifiable within three transits of the core. This dispersion partly arises due to low amplitude wakes trailing behind sharply defined pulses during propagation, a phenomenon that is linked to the failure of Huygens' principle in the geometric setting of torsional waves. We investigate the relationship between geometric dispersion and wavelength, concluding that long wavelength features are more dispersive than short wavelength features. This result is particularly important because torsional waves inferred from secular variation are relatively long wavelength, and are therefore likely to undergo significant dispersion within the Earth's core. Torsional waves in all three geometries are reflected at the equator of the core-mantle boundary with the same sign as the incident wave, but display more complicated behaviour at the rotation axis. In a cylindrical core, the analytic solutions to the torsional wave equation are known. We use these to derive an expression for the phase shift that torsional waves undergo upon reflection at the equator of the core-mantle-boundary and when passing through the rotation axis. Finally, we identify a weak reflection at the tangent cylinder due to geometric effects in an equatorially symmetric shell, and observe other internal reflections due to strong magnetic field gradients.

Dating hydrocarbon seeps: The Mupe Bay Mystery

Stacey Emmerton[1], Adrian Muxworthy[1], Mark Sephton[1], Wyn Williams[2]
[1]*Department of Earth Science & Engineering, Imperial College London,*
[2]*School of GeoSciences, University of Edinburgh*

An outcrop of Wealden beds at Mupe Bay (UK) is associated with a key piece of evidence for the timing of hydrocarbon migration in the Wessex Basin. A conglomeratic bed contains oil-stained clasts and matrix that appear different upon superficial observation. Conventional interpretations assign differences to the erosion and transport of oil-cemented clasts by Wealden rivers before their incorporation into a later stained conglomeratic bed. This scenario constrains the onset of oil migration in the basin to the Early Cretaceous, however, arguments have been put forward for single phase staining. Magnetic information may provide new ways to examine the Mupe Bay record of oil migration. Migrating fluids such as hydrocarbons have been shown to cause chemical conditions suitable for the alteration or formation of authigenic magnetite resulting in associated chemical remanent magnetization (CRM). Magnetic characterization re-veals both the matrix and clasts contain multi-domain magnetite but abundant hematite only exists within the clasts. Hysteresis parameters show the matrix has more multi-domain and likely larger magnetic grains than the clasts. Magnetic directions are different in the clasts and matrix supporting a two-phase oil-staining event. Moreover, paleomagnetic directions for the clasts after tilt correction are consistent with biodegradation processes in the Early Cretaceous. Consistent directions in separate clasts imply the biodegradation and magnetite formation took place following transportation and incorporation of the oil-cemented clasts into the conglomerate bed. Magnetic directions reveal that the Mupe Bay matrix has a viscous remanent magnetization (VRM) corresponding to today's magnetic field, confirming the matrix represents an active oil seep. This study represents an unprecedented use of magnetic data to date the onset of oil migration in a basin. The classic two-stage oil-staining scenario which constrains the onset in the Wessex Basin to the Early Cretaceous is supported by our data.

Correlating biodegradation to magnetisation in oil bearing sedimentary rocks

Stacey Emmerton[1], Adrian Muxworthy[1], Mark Sephton[1], Wyn Williams[2]
[1]Department of Earth Science & Engineering, Imperial College London,
[2]School of GeoSciences, University of Edinburgh

Relationships between magnetization and hydrocarbons have been alluded to in the past; here we report a study that identifies a definitive connection between magnetic mineralogy and biodegradation within oil-bearing rocks. Samples from Colombia, Canada Indonesia and the UK were collected and magnetically characterized. A distinct decrease in magnetic susceptibility was correlated to decreasing oil quality (loss of aliphatic hydrocarbons). Further magnetic characterization revealed that the high quality, low biodegradation oils from Colombia have a higher magnetic susceptibility (10^{-3}-10^{-4} m^3kg^{-1}) and are dominated by pseudo-single domain grains of magnetite. The lower quality oils i.e., the UK, Canadian and Indonesian samples, displayed decreased magnetic susceptibility (10^{-5}-10^{-6} m^3kg^{-1}) and pseudo-single domain to multidomain grains of magnetite and hematite. Magnetite and pyrrhotite framboidal material were found in all but the Canadian samples. Therefore, with decreasing oil quality there is a progressive dominance of multidomain magnetite as well as the appearance of hematite. The presence of hematite only within heavily biodegraded samples suggests a later stage of biodegradation at the surface due to oxidation of magnetite. We have identified a relationship between magnetization and the relative abundance of aliphatic organic compounds in oil. Biodegradation appears to remove both aliphatic hydrocarbons and magnetic susceptibility owing to influence of bacterial metabolic activity that uses ferric iron minerals as electron acceptors. These findings rein- force the importance of bacteria within petroleum systems as well as providing a platform for the use of magnetization as a hydrocarbon migration proxy and as an inexpensive and simple method to determine oil quality.

FORCinel version 2.0: A practical guide to the VARIFORC method

Richard J. Harrison
Department of Earth Sciences, University of Cambridge

The latest version of FORCinel (version 2.0) includes some new features that significantly change (and hopefully improve) the way in which FORC diagrams are processed and analysed. The most significant new feature in version 2.0 is the addition of Ramon Egli's VARIFORC smoothing method (Egli 2013). This method brings dramatic improvements to the processing of FORC data, by enabling the smoothing factor used at any given point to vary across the diagram, and by allowing different smoothing factors to be defined in the horizontal (i.e. coercivity) and vertical (i.e. interaction field) directions. This approach yields general improvements to all FORC processing, but is especially useful for high-resolution FORC diagrams, where typically there are regions where small smoothing factors are needed in order to observe very narrow features (such as the central ridge associated with non-interacting single domain grains) and other regions where very large smoothing factors are needed in order to distinguish weak, broad signals from the background noise. The VARIFORC (VARIable FORC smoothing) protocol is based on weighted polynomial regression of rectangular arrays of measurement points whose size is determined by the local properties of the FORC function (i.e. small arrays where high-resolution is needed and vice-versa). The resulting FORC diagram is characterised by improved signal-to-noise ratios, which pass significance tests over much larger domains. With data that has been processed by VARIFORC smoothing, it is now possible to add a contour that defines the threshold of statistical significance (Heslop and Roberts 2012). Data falling inside this contour have a signal-to-noise ratio above the threshold, and can be considered part of the FORC signal. Data falling outside this contour can be treated as noise.

References

Egli, R. (2013) VARIFORC: An optimized protocol for the calculation of non-regular first-order reversal curve (FORC) diagrams. Global and Planetary Change, doi:10.1016/j.gloplacha.2013.08.003.

Heslop, D., Roberts, A.P. (2012), Estimation of significance levels and confidence intervals for first-order reversal curve distributions. Geochemistry, Geophysics, Geosystems, doi:10.1029/2012GC004115.

The palaeomagnetism of fossil bearing palaeokarst in South Africa

Andy I.R. Herries
Australian Archaeomagnetism Laboratory, La Trobe University, Australia

The palaeomagnetic analysis of palaeocave deposits containing human and other vertebrate fossils in South Africa over the last 14 years has identified a number of short geomagnetic field reversals in early Pleistocene speleothem including the Réunion Event (~2.2 Ma), Huckleberry Ridge Event (~2.05-2.02 Ma), and Punaruu Event (~1.11 Ma) and perhaps the Pre_Olduvai Event (~1.98 Ma). Other speleothems have been shown to contain other reversals such as the Brunhes-Matuyama Boundary (780 ka) and Gauss-Matuyama Boundary (2.58 Ma) and most recently the base of the Olduvai Event (1.95 Ma). The Uranium-Lead dating of the speleothems has shown that these reversals and events occur in speleothems in multiple caves and suggest that other reversals likely exist in speleothems that are yet to be studied palaeomagnetically, including the end of the Olduvai Event (1.78 Ma) and perhaps the Gilsa and Gardar Events. Moreover, the study of a recent thick late Pliocene speleothem potentially identifies an as yet un-noted excursion/event. The relationship between speleothems and reversals in South African caves is curious and potential reasons for this association will be explored as will the potential mechanisms for remanence acquisition.

Thermoremanent behaviour in oxyexsolved titanomagnetite

Emma Hodgson, Andy Biggin
School of Environmental Sciences, University of Liverpool

Palaeointensity measurements of the magnetic field are important in constraining thermodynamics of the deep Earth. The scarcity of ideal rocks containing single domain magnetite grains in isolation make it necessary to understand the behaviour of larger multi domain (MD) and interacting single domain (ISD) grain sizes during palaeointensity experiments. Subaerial basalts commonly contain grains of titanomagnetite that have undergone oxyexolution. This process effectively subdivides titanomagnetite grains into iron rich regions separated by iron poor lamellae. This process may progress to create essentially single domain structures interspersed with non magnetic lamellae, the close proximity of which causes them to interact magnetostatically with one another. Rocks containing such grains are commonly used to measure palaeointensity but little is known about the degree of non ideal behaviour they exhibit. Non ideal curvature in the Arai plot can be caused by a number of reasons that must be identified so as not to collect misleading results. By comparing controlled experiments using synthetic samples of known grainsize, the curvature caused by non ideal behaviour due to domain or grain size can be isolated. This study compares the behaviour of themoremanence acquisition and loss in synthetic samples of magnetite and oxyexolved titanomagnetite. A number of controlled experiments were designed to identify any grain size dependency. These include different methods of pTRM (partial thermoremanent magnetisation) acquisition, the iterative effects of multiple heating steps, the magnitude of pTRM tails acquired from different thermal histories and the overall behaviour during simulated Thellier palaeointensity experiments.

Determining the magnetic signature of London's air pollution

Claire Lam[1], Owain Roberts[1], Adrian Muxworthy[1], Dave Green[2]
[1]*Department of Earth Science and Engineering, Imperial College London,*
[2]*Environmental Research Group, King's College London*

The magnetic signature of three sets of daily sampled particulate matter (PM) collected in London, were examined and compared to variations in other pollution data and meteorological data using principal component analysis. The magnetic signature arising from the magnetic minerals in the PM was examined via measurement on a highly sensitive Alternating Gradient Magnetometer. This is the first study of its kind of London's PM. It was found that the variations in the mass- dependent magnetic parameters displayed a complicated relationship governed by both the meteorological conditions and the PM loading rate, whereas mineralogy/grain-size-dependent magnetic parameters displayed little variation. The signal was found to be dominated by magnetite-like grains less than 100 nm in diameter which is thought to be derived primarily from vehicles. Such small grains are known to be particularly dangerous to humans. There was also evidence to suggest from magnetic stability parameters that the magnetite-like grains were covered with an oxidised rim.

Speleothems as geomagnetic recorders

Ioan Lascu
Department of Earth Sciences, University of Cambridge

Speleothems are a relatively untapped reservoir of paleomagnetic and rock magnetic information. Speleothems have immense potential for archiving high quality, high resolution geomagnetic records, and can be dated with supreme precision using radiometric techniques. The recently resurrected research field of speleothem magnetism investigates the fundamental processes involved in natural remanence acquisition in speleothems using rock magnetic and microscopic imaging techniques, and establishes chronological constraints for recorded geomagnetic and environmental magnetic events. Recent instrumental progress provides the sensitivity and sample handling capabilities needed to collect a rich variety of magnetic measurements from speleothems, at an unprecedented spatial resolution. Precisely dated paleomagnetic records from speleothems may contribute to constraining time-dependent, global geomagnetic field models. An additional benefit of having detailed, high-precision chronologies of paleomagnetic variations is that the chronological information can be transferred to existing deposits with correlatable paleomagnetic records, but with less constrained age models. Moreover, high-resolution geomagnetic fluctuations recovered from speleothems may contribute valuable information to geodynamo models that focus on small-scale core flow dynamics. Finally, the environmental magnetic records of speleothems can bridge the gap that exists between climatic and environmental interpretations from traditional speleothem measurements such as oxygen isotopes, and the environmental magnetic records of other depositional environments. As an example of application of speleothem magnetism, I will discuss a record of the Laschamp geomagnetic excursion preserved in a stalagmite from Crevice Cave, Missouri, USA. The Laschamp excursion was the first geomagnetic excursion described in the paleomagnetic record, and remains the most studied geomagnetic event of its kind. However, the exact age and duration of the event are still a matter of debate. The most accurate assessment of the timing of the occurrence of the Laschamp excursion comes from the radiometric analysis of volcanic rocks. Singer et al. (2009) and Laj et al. (2014) used K-Ar and Ar-Ar methods to determine mean ages for the Laschamp of 40.7 ± 1.0 ka and 41.3 ± 0.6 ka, respectively. Our speleothem sample from Crevice Cave grew continuously during Marine Isotope Stages 3 and 4, at a rate < 20 mm/ka. A 19-cm slab from the Crevice stalagmite was cut into discrete samples with volumes of ~0.5 cm^3. The NRM measurements show a directional excursion 2-4 cm from the top of the sample, expressed as an inclination departure of ~50°, and a declination departure of ~140° from the normal range of secular variation. The sample has been dated using the ^{230}Th method, with age errors an order of magnitude lower than previous determinations. The excursion is bracketed by ages of 42.2 ± 0.1 ka and 39.2 ± 0.1 ka, confirming it is the Laschamp. Annual band counting from confocal micrographs, corroborate a maximum duration of 3000 years for the Laschamp excursion in our sample.

Core-flow constraints on extreme archeomagnetic intensity changes

Phil Livermore[1], Alex Fournier[2], Yves Gallet[2]
[1]*School of Earth and Environment, University of Leeds,*
[2]*Institut de Physique du Globe de Paris*

In the recent literature there have been reported certain events of very rapidly changing intensity in the archeomagnetic field, termed archeomagnetic spikes. These spikes have rates of change of intensity much larger than values typical of the present-day, by up to 40-50 times. This large discrepancy prompts us to question whether such rapid changes in the magnetic field are plausible. I summarise a new study in which we investigated models of Earth's core – the source of the magnetic field – that are designed to give maximal values of intensity change. These provide the end-member cases of largest possible field variation, and can be used to judge the reported archeomagnetic spikes. I will discuss the results, their impact on the archeointensity observations, and what it might tell us about the dynamics of the core.

Oroclinal bending, distributed deformation, and Arabia–Eurasia convergence in NE Iran

Conall Mac Niocaill[1], Habib Alimohammadian[2], Richard Walker[1], James Hollingsworth[3]
[1]Department of Earth Sciences, University of Oxford, [2]Geological Survey of Iran, [3]CNRS, France

The collision of Arabia with Eurasia has produced significant region shortening across wide areas of Iran. These plates converge in a N-S direction at about 25 mm/yr, and virtually the entire active collision zone is contained with the geographical and political boundaries of the country. Many features of continental tectonics are well preserved within the region, such as the partitioning of oblique motions onto parallel strike-slip and thrust faults, the concentration of deformation around the boundaries of rigid blocks, and the rotations of tectonic blocks around vertical axes. The collision zone terminates abruptly in the NE of the country, with active deformation trending N-S along the border with Afghanistan, and this is converted into shortening in the Kopeh Dagh and Alborz mountains. There mountain ranges changing from a NW-SE trend along the border with Turkmenistan to an E-W trend in Northern Iran. In the eastern Alborz mountains, the overall pattern of N-S shortening is accommodated on major thrust systems bounding the eastern branch of the Alborz (east of 57 °E), Sabzevar, andKuh-e-Sorkh mountain ranges, which lie south of the Kopeh Dagh mountains. This shortening has resulted in significant crustal thickening, forming peaks up to 3000 m high. To the west of 57 °E much of the convergence seems to be accommodated on large left-lateral strike-slip faults. Active shortening dies out eastward into Afghanistan, which is thought to belong to stable Eurasia. This change in deformation style has given rise to a significant curvature of the eastern Alborz, and a major issue of contention is whether this curvature reflects a component of oroclinal bending of an originally linear mountain belt that has been rotated to its present configuration of whether the motion is purely translational. We present new palaeomagnetic data from Neogene sediments, distributed across NE Iran that provide new constraints on the deformation of the region. A complex pattern of both clockwise and anti-clockwise rotations is preserved, but the overall pattern does not match present-day GPS measurements of crustal motions. These datasets suggest that the major phase of oroclinal bending predates the magnetisation of the late Neogene Units.

Recognizing detachment-mode seafloor spreading in the deep geological past

Antony Morris, Marco Maffione, Mark W. Anderson
School of Geography, Earth, and Environmental Sciences, Plymouth University

Large-offset oceanic detachment faults are a characteristic of slow- and ultraslow-spreading ridges, leading to the formation of oceanic core complexes (OCCs) that expose upper mantle and lower crustal rocks on the seafloor. The lithospheric extension accommodated by these structures is now recognized as a fundamentally distinct “detachment-mode” of seafloor spreading compared to classical magmatic accretion. Paleomagnetic analyses of OCC footwall sections sampled by scientific ocean drilling along the Mid-Atlantic Ridge have demonstrated that unroofing during detachment faulting is characteristically accommodated by tectonic rotation around ridge-parallel, shallowly plunging axes, consistent with flexural, isostatic rolling-hinge deformation. However, recognition of this signature in the deep geological past in ancient ophiolites requires separation of seafloor spreading and emplacement-related tectonic signatures and analysis of rotation in an original seafloor frame of reference. We illustrate this approach using an example of a fossil OCC in the Mirdita ophiolite of Albania. This is a slice of Jurassic oceanic lithosphere, consisting of a partially serpentinized lherzolitic mantle sequence (containing discrete gabbro intrusions) overlain tectonically by an upper crustal sequence of sheeted dikes and lavas. The contact between mantle and upper crustal rocks in the region of the Puka Massif is locally marked by mylonitic shear zones in amphibole-bearing peridotites. These field relationships may result from either (a) detachment-mode spreading and associated mantle exhumation (as seen in modern OCCs) or (b) local tectonic excision of the lower crustal section during ophiolite obduction or post-emplacement deformation. These alternatives may be resolved by paleomagnetic detection of OCC-type relative rotation of detachment footwall and hanging wall sections around a ridge-parallel axis, as seen in in situ OCCs. We show that footwall and hanging wall blocks either side of the inferred Mirdita detachment have significantly different magnetizations that can only be explained by relative rotation during seafloor spreading. By combining these data with field structural data from the Mirdita sheeted dike complex, we show that the style of rotation across the detachment is identical to examples of rolling hinge footwall rotation documented recently in OCCs in the Atlantic, confirming that detachment-mode spreading operated at least as far back as the Jurassic.

Nanopaleomagnetism of meteorites: Evidence for a core dynamo in the pallasite parent body

Claire Nichols[1], James Bryson[1], Richard Harrison[1], Julia Herrero Albillos[2], Florian Kronast[3], Gerrit van der Laan[4]
[1]Department of Earth Sciences, University of Cambridge, [2]Centro Universitario de la Defensa, Universidad de Zaragoza, [3]BESSY II, Helmholtz-Zentrum, Berlin, [4]Diamond Light Source, Didcot

Meteoritic Fe-Ni metal contains nanostructures with a unique capability to reveal information about the early solar system. Here, we examine the Esquel and Imilac pallasites with the intention of uncovering more about the accretion and subsequent cooling of the main group pallasite parent body as well as furthering ideas as to how pallasites formed. The pallasites consist of olivine crystals embedded in an Fe-Ni matrix; the matrix consists of a complex series of microstructures including the cloudy zone. The cloudy zone is formed by spinodal decomposition, forming nanoscale tetrataenite islands in an Fe-rich matrix. These tetrataenite islands have extremely high coercivity, > 2 T, enabling them to record some of the earliest magnetic fields in the solar system. The cloudy zone was analysed using X-ray photoemission electron microscopy (X-PEEM) and X-ray magnetic circular dichroism (XMCD); electrons are excited from the sample surface using an intense beam of circularly polarised synchrotron X-rays. The intensity of the emitted electrons is dependent upon the direction of surface magnetisation relative to the direction of the X-ray beam. These techniques allow the surface magnetisation to be measured with a resolution of up to 30 nm for a field of view of 5-70 µm. The tetrataenite islands have the $L1_0$ superstructure, with magnetic easy axis parallel to the c axis, which may be oriented in any of six <100> directions. If no external field is present, the magnetisation will be equally proportioned in each of the six orientations. If an external field is present, the proportions vary; this can be simulated using a computer model of the cloudy zone in order to establish the intensity and direction of an external magnetic field. The Esquel and Imilac both experienced external magnetic fields, with a minimum intensity of > 2-5 µT respectively. Ruling out stray fields, these are attributed to a core dynamo in the pallasite parent body. This information would help to improve constraints on cooling and accretion models for the pallasite parent body. It also suggests that the pallasites did not form at the core-mantle boundary; since the cloudy zone forms at T < 400 °C it must have formed at a shallower depth since the core was still molten at this time.

An updated SW Pacific palaeointensity dataset and its influence on global Holocene geomagnetic field models

Andreas Nilsson, Mimi J. Hill, Richard T. Holme
School of Environmental Sciences, University of Liverpool

It is well known that the majority of palaeomagnetic data have been obtained from the Northern Hemisphere. In order to help address this imbalance on the centennial and millennial timescales a campaign of measurements is in progress. Focussing on determining palaeointensity (primarily using the microwave method) a mix of burnt archaeological and geological material from the SW Pacific region are being investigated. Here we report an update of results from Australia, New Zealand and the SW Pacific Islands. The influence of the new data on constraining global geomagnetic field models in the region is demonstrated and discussed.

Palaeomagnetism and planetary tectonics

John Piper
School of Environmental Sciences, University of Liverpool

The on-going search for exoplanets has located Earth-like planetary bodies and more will no doubt be located in the future. This search has stimulated investigations into critical conditions required for Plate Tectonic to initiate and mobilise planetary lithospheres. Models have become progressively more sophisticated in recent years and predict three behaviour comprising (i) stagnant lids covering the whole planetary surface punctuated by high volume volcanic activity; (ii) episodic lids interchanging between static and mobile and causing periodic overturn as seen on Venus and (iii) mobile lids in constant motion able to generate zones of subduction and spreading (Plate Tectonics). The second style is seen on Mars where stripe magnetic anomalies are latitudinally-oriented and record motion of the whole lithosphere over a hotspot frame. The palaeomagnetic record from Earth's continental crust provides a means of testing for tectonic style throughout the history of the crust. Plate Tectonics (iii) is difficult to test in the remote geological past and requires extreme pole selection. In contrast regimes (i) and (ii) are easy to test because they predict conformity of palaeomagnetic poles to a single position, a demanding requirement readily identified. In the event poles closely conform to a single position over very long intervals of geological time (2.7-2.2 Ga, 1.5-1.25 Ga and 0.75-0.6 Ga) employing a reconstruction requiring only peripheral adjustment and comprising a symmetrical supercontinent constrained to a single hemisphere on the globe like Phanerozoic Pangaea. This shows that Lid Tectonics dominated the behaviour of the Earth's lithosphere throughout most of its history. A rapid 90° reconfiguration of crust and mantle followed the long 2.7-2.2 Ga quasi-static interval and is the closest terrestrial analogy to the resurfacing of Venus. Although signatures of Plate Tectonics achieve an orogenic scale from Mesoproteroozoic times onwards, this style of tectonism only became comprehensive and global in its effects following break-up of the continental lid at 0.6 Ga. This is the defining distinction between the Precambrian and Phanerozoic eons of Geological Time.

High-latitude paleomagnetic and Ar-Ar study of 0-6 Ma lavas from eastern Iceland: Contribution to the time-averaged field initiative

Owain Roberts[1], Arne Døssing[1], Conall Mac Niocaill[2], Adrian Muxworthy[1]
[1]*Department of Earth Science and Engineering, Imperial College London,* [2]*Department of Earth Sciences, University of Oxford*

Statistical analyses of paleomagnetic data from sequential lava flows allow us to study the geomagnetic field behavior on kyr to Myr timescales. Previous paleomagnetic studies have lacked high-latitude, high-quality measurements and resolution necessary to investigate the persistence of high-latitude geomagnetic field anomalies observed in the recent and historical field records, and replicated in some numerical geodynamo simulations. As part of the Time-Averaged Field Initiative (TAFI) project, the lava sequences found in Nordurdalur (by Fljótsdalur) and Jökuldalur in eastern Iceland provide an excellent opportunity to improve high-latitude data suitable for investigating the 0–5 Ma TAF and paleosecular variation. These adjacent valleys, separated by 40 km, are known to comprise a fairly continuous record of lava flows erupted from the Northern Rift Zone between 0.5 and 5-7 Ma. During a five weeks field campaign in summer 2013, we collected a total of ~1900 cores (10–16 cores/site; mean = ~13 cores/site) from ~140 separate lava flows (165 in total) along eight stratigraphic profiles in Nordurdalur and Jökuldalur. In addition, hand samples were collected from ~70 sites to deliver ~40 new $^{40}Ar/^{39}Ar$ radiometric age measurements. We present a preliminary composite magnetostratigraphic interpretation of the exposed volcanic pile in Nordurdalur and Jökuldalur. The new data will be compared and contrasted with previously published paleomagnetic and geochronological results. In addition, determinations of the anisotropy of the magnetic susceptibility of individual lava flows is sought to deliver fossil lava flow directions. The aim of the study is ultimately to present a high-quality study of paleomagnetic directions and intensities from Iceland spanning the past 6–7 Myr. The new Fjlotsdalur and Jökuldalur data will be combined with previously published paleomagnetic results.

New palaeomagnetic results from outcrop and drill core samples of the 3.47 billion year old Komati Formation, Barberton Mountain Land, South Africa

Laura Roberts-Artal[1], Andrew Biggin[1], Conall MacNiocaill[2], Maarten de Wit[3], Cor Langereis[4], Allan Wilson[5], Nick Arndt[6]

[1]School of Environmental Sciences, University of Liverpool, [2]Department of Earth Sciences, Oxford University, [3]Department of Geosciences, Nelson Mandela Metropolitan University, [4]Paleomagnetic Laboratory, Fort Hoofddijk, Utrecht University, [5]School of Geosciences, University of the Witwatersrand, [6]Université Joseph Fourier

Palaeomagnetic results obtained in the 1980s and 1990s from the Komati Formation in the Palaeoarchaean Onverwacht Group in the Barberton Greenstone Belt constitute the world's oldest unrefuted palaeomagnetic pole. This pole has been crucial in arguing for the existence of a viable geomagnetic field early in the Earth's history but does not yet have the support of rigorous field tests in constraining its age and viability. Here we will present new palaeomagnetic data from a hitherto unexamined locality where these komatiites crop out along the Komati River and where two 400 m drill cores have recently been extracted by an International Continental Drilling Programme (ICDP) project. Oriented samples have been taken from both of the deep drill cores and also from surface outcrops allowing detailed comparisons to take place between the new and old datasets. The implications of these new results for our understanding of the early Earth's geomagnetic field will be discussed.

Palaeomagnetic evidence for the persistence of the South-Atlantic geomagnetic anomaly

Jay Shah[1], Marko Leitner[2], Michael O. McWilliams[3,4], Roman Leonhardt[5], Adrian R. Muxworthy[1], Christoph Heunemann[2], Valerian Bachtadse[2], Jack A.D. Ashley[1], Jürgen Matzka[6]

[1]Department of Earth Science and Engineering, Imperial College London, [2]Geo- and Environmental Sciences, Ludwig-Maximilians Universität, Munich, [3]Department of Geological and Environmental Sciences, Stanford University, [4]CSIRO Earth Science and Resource Engineering Division, Perth, [5]Central Institute for Meteorology and Geodynamics, CONRAD Observatorium, Vienna, [6]National Space Institute, Technical University of Denmark

In this study we have carried out a full-vector palaeomagnetic analysis for lavas from Tristan da Cunha, an island situated in the South Atlantic Ocean. For the last 400 years, the geomagnetic field has displayed a persistent negative anomaly in the south Atlantic, a phenomenon known as the South Atlantic geomagnetic Anomaly (SAA). The current day geomagnetic field intensity in this region is approximately 25 μT, compared to the expected range of > 35 μT. The origin of the SAA and its behaviour on geological timescales is currently poorly understood, which is partly due to poor data coverage from the South Atlantic to sufficiently constrain mathematical models. Palaeomagnetic directional analysis and $^{40}Ar/^{39}Ar$ dating suggest the studied lavas were quickly extruded 70-81 ka. Palaeointensity estimations of the lava flows were made using the Thellier method, with an average of 19 ± 6 μT, and average VADM of $3.3 \pm 1.1 \times 10^{22}$ Am^2. These weaker intensities are comparable to the present day SAA, and the VADM of the lavas is similarly weaker than the time averaged VADM of the SINT-800. Findings indicate the SAA is a persistent feature of the geomagnetic field up to 81 ka.

New insights from old observations: The voyage of Alexander von Humboldt

Neil Suttie, Richard Holme

School of Environmental Sciences, University of Liverpool

Prior to 1840 there was no capability to measure absolute magnetic field strength and the field intensity must be inferred from archaeomagnetic analyses. There is no consensus as to what the strength of the field was even as late as 1800, with some workers finding evidence for rapid fluctuations, while others prefer a model of continuing linear decay. Here we re-examine this controversy in light of a series of relative magnetic field intensities measured by the explorer and naturalist Alexander von Humboldt during his voyage to South America in the years 1798 to 1803. Although these can only give the field strength relative to the couple exerted on a magnetised needle of unknown moment, they are shown to be consistent with field models for the period. We argue that variations in intensity inferred from archaeomagnetic data cannot be reconciled with this model.

Magnetic analysis of the Nussloch loess sequence:
Implications for environmental & palaeomagnetic research

Samuel Taylor, France Lagroix
Institut de Physique du Globe de Paris

This study involves an extensive rock magnetic analysis of the Nussloch loess-palaeosols sequences (Rhine Valley in Germany, 49°18’59’’N; 8°43’54’’E). A 17 m section of the P8 sequence sub-sampled at a 5 cm resolution, continuously as bulk material and discreetly in oriented cubes, is investigated. The P8 (present – 65 kyrs) sequence overlaps and extends further in time the previously studied P4 (18 – 35 kyrs) sequence. The main objectives of this study are two-fold: first to characterise the mineral magnetic response of these loess-palaeosols deposits to environmental and climatic changes occurring in Western Europe. Second, to evaluate the efficiency of the deposit as a palaeomagnetic field recorder. The bulk magnetic parameters of the newly sampled P8 profile compare favourably with those of the previous P4 profile attesting at least, to a regional response of the loess-palaeosols magnetism to environmental change. Gleyed horizons are characterised by an overall decrease in degree of anisotropy (trend with depth) and the deviation of the principal axes from the aeolian sedimentary fabric observed in some P8 loess intervals. The ‘weaker’ gleys found up profile do not show large variations in their magnetic fabrics with respect to surrounding loess, corraborating with environmental magnetism results in this area for weakening gley-induced diagenesis upsection. Preliminary tests have shown that there is a stable component of remanence throughout the Nussloch sequence. Further work will involve the extraction and evaluation of both a relative palaeointensity scale and secular variation curve with AMS, bulk magnetic parameters and an understaning of acqusition mechanisms used as constraints.

An archaeomagnetic study of a Roman bath in Southern France

Megan Thomas[1], Philippe Lanos[2,3], Mimi Hill[1], Fabien Colleoni[4]
[1]*School of Environmental Sciences, University of Liverpool,* [2]*Université Bordeaux-3,*
[3]*Université de Rennes-1,* [4]*Université Rennes-2*

Archaeomagnetism has a dual importance: firstly in providing well-dated, geologically recent, geomagnetic field information in order to better understand short timescale variations of the field and secondly, in aiding the archaeological interpretation of an archaeological site. Presented here is an example of the latter which can be achieved in a variety of ways; be it through providing dates, determining the maximum temperature reached of burnt material, determining the firing orientation of pots and so on. Here we present the first archaeomagnetic data from the Roman-aged Saint-Jean Poutge archaeological site, situated near Auch in Southern France. The data set is comprised of 89 archaeointensity estimates and 20 directional determinations. A traditional Thellier-Thellier intensity experiment with pTRM checks was conducted and the results were corrected for cooling rate and anisotropy. The percentage of accepted palaeointensity results for the number of samples studied ranged from 23% (for sandstone/ conglomeratic material) to 74% for tile samples. This difference in acceptance rate between samples from the site reinforces the suitability of certain materials (in this case tiles) for archaeomagnetic study. The measured samples are from two separate building phases (the first thought to be in the 2nd Century AD and the second in the 3rd century AD). This difference in age is confirmed by the archaeointensity results with the samples from the 2nd Century AD having, on average, intensity values 14 µT lower than the samples from the 3rd Century AD. Results range from 33 µT to 91 µT with averages of 53 ± 7 µT in the 2nd century AD and 68 ± 10 µT in the 3rd century. This is within the error envelopes for the current global field models (Arch3K and Cals3K3). This archaeomagnetic study demonstrates the potential of archaeomagnetism to support or refute the existing archaeological interpretation of a site. The difference in measured archaeointensity between samples from different contexts supports the archaeological interpretation that the site underwent a rebuilding phase and the samples we took were from two discreet construction phases.

Experimental comparison of abiotic and microbial Fe-mineral transformations to identify pedogenic magnetic enhancement pathways

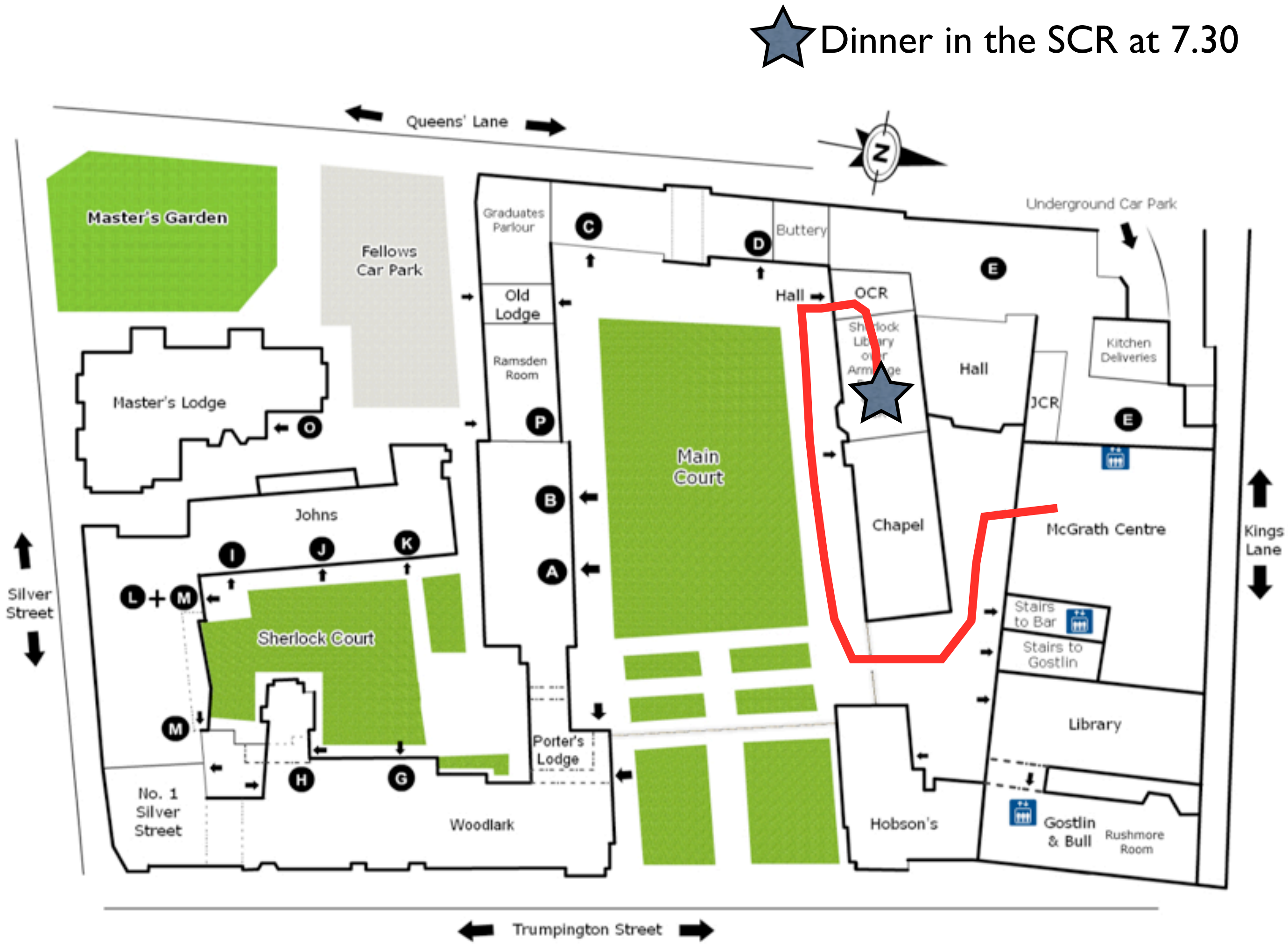
J. Till[1,2], Y. Guyodo[1], G. Ona-Nguema[1], F. Lagroix[2], G. Morin[1]
[1]IMPMC, Université Pierre et Marie Curie, Paris, [2]Institut de Physique du Globe de Paris

We will present an overview of results from an interdisciplinary experimental study of possible pathways of magnetic enhancement during pedogenesis of loess-derived soils. Metastable Fe-oxyhydroxides have been proposed as candidates for weakly-magnetic precursor phases that alter to form more strongly magnetic Fe-oxides during soil formation. Alteration experiments on synthetic oxyhydroxides including goethite, ferrihydrite, and lepidocrocite were performed by either heating in a controlled atmosphere, or through bioreduction by the dissimilatory Fe-reducing bacteria *Shewanella putrefaciens*. Magnetic properties, microstructure, and morphology of the reaction products were characterized by low-temperature magnetic measurements, high-resolution TEM microscopy, X-ray diffraction, and synchrotron spectroscopy. Heating-induced dehydration of lepidocrocite produces a topotactic reaction that forms pseudo-morphed superparamagnetic maghemite or magnetite, representing a direct inorganic pathway for formation of magnetic nanoparticles. Fe-oxides produced by dehydration of both lepidocrocite and nanogoethite have distinctive nanostructures characterized by abundant defects. However, reduction-heating of dehydrated nanogoethite produces magnetite with many characteristics of biogenic magnetite. Bacterially-mediated remineralization of lepidocrocite and ferrihydrite rapidly produces abundant, highly crystalline magnetite with a broad grain size range. This study is working toward the identification of magnetic and non-magnetic biosignatures in Fe-oxides that may help elucidate the origins of magnetic minerals in soils, sediments, and other planetary settings.

Effects of the core-shell structure on the magnetic properties of partially oxidized magnetite grain: Experimental and micromagnetic investigations

Wyn Williams[1], Kunpeng Ge[2], Qingsong Liu[2], Yongjae Yu[3]
[1]University of Edinburgh, [2]Chinese Academy of Sciences, [3]Chungnam National University

The relationship between hysteresis parameters and oxidation of ultrafine magnetic particles is determined though a series of experimental measurements and micromagnetic simulations, as a function of gradual oxidation of magnetite. In the experiment, both coercivity (B_c) and the ratio of saturation remanence to saturation magnetization (M_{rs}/M_s) versus oxidation parameter z display similar trends, which slowly increase before z = 0.9, ranging from ~17 mT to ~21 mT and ~0.22 to ~0.28, respectively. But thereafter both parameters are seen to decrease sharply before magnetite becomes completely oxidized. Numerical simulations using a micromagnetic model with a simple core-shell geometry exhibit good agreement with the experimental observations. The numerical simulations show three broad categories of behavior. Firstly, uniformly magnetitzed single domain (SD) size particles become increasingly unstable as the oxidation degree grows, but that their remanence remains almost unchanged. Secondly, slightly larger grains near the boundary between SD grains and pseudo-single-domain (PSD) sized particles, the coercivity initially decreases before growing again with increasing oxidation before finally decreasing sharply upon complete transformation to maghemite. Finally, larger PSD grains demonstrate far less sensitivity to the oxidation and do not show any clear trend. These results can be interpreted as the partially oxidized magnetic grains being controlled by both the oxidized shell and un-oxidized core as well as the effects of exchange and magnetostatic coupling.



St. Catharine's College site map showing way between the McGrath Centre and Senior Combination Room (SCR). Entrance to the main court is on Trumpington Street.