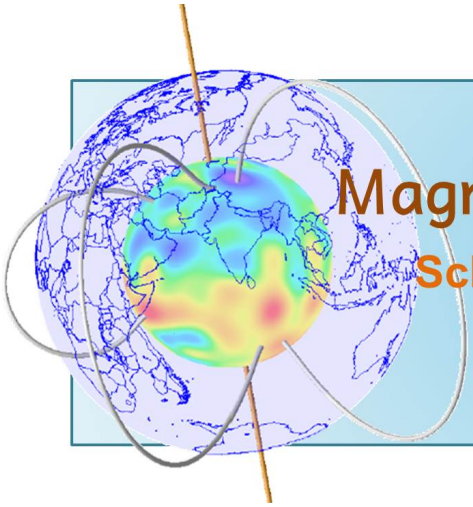


Magnetic Interactions 2015

School of Earth & Environment

University of Leeds

Wednesday 7th & Thursday 8th January 2015

Conference Programme

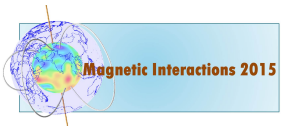
UNIVERSITY OF LEEDS

BGA British Geophysical Association

Bartington® Instruments

MINERALOGICAL SOCIETY

magnetic measurements



UNIVERSITY OF LEEDS

Conference Programme

Wednesday 7th January 2015

11.30	Arrival	
12.00	Lunch & Welcoming speech *(School of Earth & Environment Foyer)*	
13.00	Ioan Lascu *University of Cambridge*	High-resolution magnetic imaging of geologic samples using scanning magnetic tunnel junction microscopy
13.20	Miguel Valdez Grijalva *Imperial College London*	Micromagnetics of individual greigite SD and PSD grains
13.40	Jay Shah *Imperial College London*	A micro-CT approach to the paleomagnetic conglomerate test
14.00	Mark Bourne *University of Minnesota*	Long-term changes in precipitation recorded by magnetic minerals in a speleothem
14.20	Greg McIntosh *Canterbury Christchurch University*	Superparamagnetism in atmospheric particles
14.40	Coffee and Posters *(School of Earth & Environment Foyer)*	
15.40	Anita Di Chiara *University of Sao Paulo*	Palaeointensity of Proterozoic magmatic rocks from South America using the Preisach method, preliminary results
16.00	Adrian Muxworthy *Imperial College London*	Observing remanence structures in sub-micron magnetite at high-temperatures
16.20	Josh Einsle *University of Cambridge*	A 3D nanoscale approach to nebular paleomagnetism in the Semarkona LL3.0 ordinary chondrite
16.40	Claire Nichols *University of Cambridge*	Pallasite Paleomagnetism: A Quest for Quiescence of the Core Dynamo
17.00	James Bryson *University of Cambridge*	A time-resolved record of magnetic acitivity on the IVA iron meteorite parent body
17.20	Coffee and Posters *(School of Earth & Environment Foyer)*	
18.45	Move towards dinner venue	
19.00	Conference Dinner *(University House, University of Leeds)*	

Thursday 8th January 2015

09.30	Megan Hammond *University of Liverpool*	Bronze age archaeointensity data from the Levant and Anatolia and its impact of archaeomagnetic jerk and geomagnetic spike theory
09.50	Mimi Hill *University of Liverpool*	New archaeointensity data from the SW Pacific
10.10	Phil Livermore *University of Leeds*	Independent testing of extreme archeomagnetic change
10.30	Coffee *(School of Earth & Environment Foyer)*	
11.00	Ted Evans *University of Alberta*	Palaeogeomagnetism of Brunhes-age sediments in Alaska
11.20	Jon Mound *University of Leeds*	Geomagnetic Implications of Inner Core Translation
11.40	Antony Morris *Plymouth University*	Multipolarity Remanences in Lower Oceanic Crustal Gabbros Recovered By Drilling at Hess Deep (Integrated Ocean Drilling Program Expedition 345)
12.00	Business Meeting & Farewell	

Posters

Dominika Baliklov ***Imperial College London***	The age of the Morrison Formation (Western Interior, USA): A Magnetostratigraphic Approach
Ciaran Beggan ***British Geological Survey***	The International Geomagnetic Reference Field (IGRF) version 12: The BGS candidate and final model
Thomas Berndt ***Imperial College London***	Temperature and grain size dependence of the attempt time \tau_{0} for fine magnetic particles
Robert Blukis ***University of Cambridge***	Scanning magnetic microscopy studies of plessite region in iron and stony-iron meteorites
William Brown ***University of Leeds***	Model Jerks: Insights from Observations and Synthetic Models
Richard Harrison ***University of Cambridge***	FORCulator: a micromagnetic tool for simulating first-order reversal curve diagrams
Louise Hawkins ***University of Liverpool***	Long-term geomagnetic field variation and it's relation to whole-mantle convection: hypothesis testing using new palaeomagnetic data from the Devonian.
Matthew Meyer ***Plymouth University***	New Paleomagnetic Data from the Wadi Abyad Crustal Section and their Implications for the Rotation History of the Oman Ophiolite
Antony Morris ***Plymouth University***	IODP Expedition 351 Izu-Bonin-Mariana Arc Origins: Age Model for Site U1438
Joy Muraszko ***University of Cambridge***	Characterisation of biogenic magnetite from sediments of the SW Iberian Margin using FORCs and principle component analysis.
Greig Patterson ***Institute of Geology & Geophysics, Chinese Academy of Sciences***	Simulating paleointensity data from multidomain specimens
Radchagrit Supakulopas ***Imperial College London***	The magnetic properties and palaeodirections of basalts in Iceland: preparation to test the geocentric axial dipole hypothesis (GAD)
Tim van Peer ***University of Southampton***	Oligocene-Miocene Transition
Chuang Xuan ***University of Southampton***	Restoring Detailed Geomagnetic and Environmental Information from Continuous Sediment Palaeomagnetic Measurement through Optimised Deconvolution

Abstracts for oral presentations

Wednesday 7th January

High-resolution magnetic imaging of geologic samples using scanning magnetic tunnel junction microscopy

Ioan Lascu ***University of Cambridge***

In this talk we describe a magnetic tunnel junction (MTJ) scanning microscope custom-built for analysing geologic specimens. MTJ sensors contain a thin film multilayer structure, whose core consists of two ferromagnetic electrodes, separated by an insulating layer. One of the electrodes is magnetically pinned via exchange bias to an antiferromagnetic layer, while the other is free to react to an external magnetic field. The magnetization of the pinned layer is fixed in a perpendicular direction, so this ferromagnetic junction can be used as a low-field magnetic sensor. When a bias voltage is applied across the layered structure, electrons traverse the insulating barrier via quantum mechanical tunneling. The magnetoresistance of the junction is dependent on the magnetic orientation of the electrodes, and is quantified as the percent change between the low and high resistance states. The higher its value, the more sensitive the device is, which makes MTJ sensors (with magnetoresistance exceeding 200%) particularly attractive for detecting small-scale magnetic structures. MTJ sensors do not require the use of cryogens, enabling straightforward, low-cost operation of the microscope. The lack of cryogen technology means the sensor can be brought close to the sample surface, routinely allowing for sample-to-sensor distances of 15-20 µm. Scan height depends on factors such as scanning mode (if using a static or vibrating stage), sample surface configuration, or sensor configuration (i.e., proximity of the sensor to the tip of the die). This renders the MTJ microscope capable of producing magnetic images that may resolve features as small as 15 µm, and of detecting field intensities lower than 1 µT. This technology is particularly useful for detecting stray fields from micro-regions of interest preserving the original paleomagnetic signature within a bulk sample that may also contain remagnetised regions. Examples include ancient or altered rocks, extraterrestrial materials, samples containing inclusions or exsolution structures, and in general specimens characterised by spatial heterogeneity. In addition, the high-resolution capability of the MTJ microscope makes it extremely useful for investigating sedimentary archives formed under low accumulation conditions (e.g., speleothems, stromatolites, Fe-Mn nodules) that hold a detectable environmental magnetic signal.

Micromagnetics of individual greigite SD and PSD grains

Miguel Valdez Grijalva ***Imperial College London***

I will present finite element method simulations of individual SD to PSD greigite grains. The effect of configurational anisotropy in the hysteresis parameters is investigated for octahedral and truncated octahedral grains.

A micro-CT approach to the paleomagnetic conglomerate test

Jay Shah ***Imperial College London***

The paleomagnetic field recorded by chondrules can provide insights into the physical history of the meteorite's parent body and the processes and conditions of the early solar system. By using micro-CT scans in order to re-orientate chondrules to their in-situ position, we present a full-vector paleomagnetic study of the chondrules in Bjurböle (L/LL4). Chondrules formed before the parent body accreted, so the magnetic fields recorded by individual chondrules would be expected to be unique and

random in direction, unless there was a stable dynamo field active on the parent body. Previous work has aimed to re-orientate chondrules to determine whether the magnetization is of nebular or parent body dynamo origin. Bjurböle contains tetrataenite, a credible paleomagnetic recorder. Tetrataenite is a transformation of taenite, so its acquired remanence is indicative of whether its parent body had an active magnetic field during its mineralization, and could apply tighter constraints on its lifetime.

Long-term changes in precipitation recorded by magnetic minerals in a speleothem

Mark Bourne ***University of Minnesota***

Magnetic material incorporated within speleothems has the potential to provide useful information about changes in the palaeoenvironment. Speleothems dated using high-precision U-Th radiometric techniques constitute a unique resource for environmental magnetism. Although speleothems have been principally used to reconstruct regional and global climate, measurement of magnetic parameters presents an opportunity to connect large-scale climatic changes with their impact on more localized processes in soils overlying cave systems. Under certain environmental conditions, pedogenic processes can result in the formation of very fine-grained magnetite. Enhancement of pedogenic magnetite in soil profiles is strongly dependent upon local precipitation. Pedogenic magnetite may be subsequently transferred via drip-waters into underlying cave-systems and ultimately incorporated into speleothems as they grow. Here, we show how high-resolution geophysical methods may be employed to analyze a well-dated stalagmite from Buckeye Creek Cave in West Virginia. Using standard magnetic measurements, we find that changes in magnetite concentration follow both changes in stable isotopes measured in the same stalagmite and global climate proxies. We interpret the changes in magnetite concentration as reflecting variations in local pedogenic processes, controlled by changes in regional precipitation. This record demonstrates how geophysical measurements on speleothems can aid interpretations of speleothem climate proxies.

Superparamagnetism in atmospheric particles

Greg McIntosh ***Canterbury Christchurch University***

The contribution of superparamagnetic (SP) particles to atmospheric particulate matter (PM) is an area of active debate in environmental magnetism. Saragnese et al (2011) suggest that they are present as predominantly spherical particles and are closely associated with combustion products. In contrast, Sagnotti et al (2012) suggest that they are present as oxidised rims around large, multidomain particles, and are related to brake abrasion. Here we present the results of a study of atmospheric PM samples with maximum particle sizes of 10, 2.5 and 1 micron. Low temperature magnetometry confirms the presence of SP particles across all size fractions, being relatively more important in the largest, >2.5 micron fraction. Field-cooled, low temperature hysteresis curves show evidence for exchange bias, which we interpret in terms of core-shell interaction of particles with oxidised rims. These results will be discussed in the context of potential sources of the SP particles and how magnetic measurements can help to distinguish between anthropogenic and geogenic PM sources.

Palaeointensity of Proterozoic magmatic rocks from South Am erica using the Preisach method, preliminary results

Anita Di Chiara ***University of Sao Paulo***

Few data are available yet to constrain the geomagnetic field palaeointensity pattern during the Precambrian in South America, due to the lack of suitable
methods and materials. We report here results from a preliminary study to determine the palaeointensity of 1419 Ma rocks from Nova Guarita mafic dykes, (Bispo-Santos et al., 2012; 2014), central Brazil. We initially tried to conduct a Thellier-type
palaeointensity determination, with units returning no palaeointensity records. The reason for failure

was attributed to chemical alteration and a large multidomain component of the remanence. Given the samples instability to heating, we employed for the first time on Precambrian rocks the non-heating Preisach palaeointensity protocol (Muxworthy et al., 2011, Muxworthy and Heslop, 2011). We included a slight modification to the originally published protocol. The work is not complete, but we have been able to recover palaeointensities from units that were unstable to heating. We report initial findings here.

Observing remanence structures in sub-micron magnetite at high-temperatures

Adrian Muxworthy ***Imperial College London***

For more than 50 years, palaeomagnetic research has yielded critical insights into the formation and evolution of the Earth, from generation of the geomagnetic field in the core, to plate tectonics and structural deformations of the Earths' crust. Thermoremanence (TRM) acquisition is one of the most important types of natural remanence, yet our understanding of TRM in small grains which display non-uniform magnetizations (pseudo-single domain) is limited both experimentally and theoretically. This talk reports a current Natural Environmental Research Council (UK) project, which uses recent technological advances in direct observations of magnetic structures, to help us understand the effects of remanence behavior at high temperatures of magnetite crystals

A 3D nanoscale approach to nebular paleomagnetism in the Semarkona LL3.0 ordinary chondrite

Josh Einsle ***University of Cambridge***

Solar nebular models suggest that magnetic fields are central to the redistribution of mass and angular momentum in the protoplanetary disk. Using individual chondrules with patches of dusty olivine the strength of these magnetic fields can be measured due to presence of nanoscale Fe inclusions. Since chondrules formed by rapid heating and cooling in the early solar nebula, individual chondrules have the potential to record the magnetic field that was present during their formation, and retain this signal for several billion years. Recently the first robust paleointensity measurement of nebular fields was compleated by measureing dusty olivine grains from the Semarkona LL3.0 ordinary chondrite meteorite in a SQUID microscope. (Fu et al. this meeting) Extracting quantitative information from the paleomagnetic meaurements requires a full understanding of the underlying physical mechanisms producing the measured magnetic signal.
Here we characterise the magnetic behaviour of the same dusty olivine chondrules, using a variety of electron microscopy techniques. Electron holography and Lorentz imaging confirm the dominance of single vortex (SV) states in the majority of the remanence carriers. In-field measurements demonstrate the high stability of this SV state, making them suitable carriers of paleomagnetic information. We present a 3D volume reconstruction of the dusty olivine using Focussed-Ion-Beam (FIB) slice-and-view tomography. Combining the selective milling properties of FIB with the high spatial resolution of the Scanning Electron Microscope we are able to capture images as we make successive slices through a selected region of the sample. For this initial study we present a collection of 400 images taken every 10 nm as we slice through an 10 µm x 10 µm x 4 µm volume of the dusty olivine patch within a single chondrule. Each image possesses resolution around 10 nm allowing us to resolve particles in both the single domain and single vortex size ranges. Once assembled the full data provies quantitative statistics on particle-size distribution, shapes and interparticle spacing. The information is then used to model the macroscopic paleomagnetic properties. This work further extends the central role of electron microscopy in determining the underlying physics of the remanence acquisition process.

Pallasite Paleomagnetism: A Quest for Quiescence of the Core Dynamo

Claire Nichols ***University of Cambridge***

The pallasites are a group of meteorites composed of olivine crystals embedded in an Fe-Ni matrix. The matrix is made up of several distinct microstructures with varying Ni content. The cloudy zone, a µm-scale intergrowth of tetrataenite islands (50:50 Fe:Ni) in an Fe-rich matrix, has the capability to provide time-resolved records of ancient magnetic fields. A previous study (Bryson et al. 2014, Nature, DOI 10.1038/nature14114), has provided new insight into core dynamo dynamics and compositional convection within small planetary bodies. This study also predicts a period of quiescence in dynamo activity between initial thermal and late-stage compositional convection. To test these predictions we have studied the Brenham and Marjalahti pallasites using the same methods as Bryson et al. to investigate the predicted period of low activity of the core dynamo. High-intensity synchrotron x-ray beams were fired at the sample surface; photoelectron emission microscopy (PEEM) and x-ray magnetic circular dichroism (XMCD) were used to acquire compositional and magnetic maps of the microstructures. Images with a 5 µm field-of-view and up to 30 nm resolution were acquired for a range of microstructures including the cloudy zone and plessite, a complex intergrowth of tetrataenite and kamacite (95:5 Fe:Ni). The images of magnetisation are used to calculate the minimum magnetic field intensity the Brenham and Marjalahti experienced. Results suggest both meteorites experienced a relatively weak field, consistent with the predicted lull in dynamo activity. A comparison of the magnetic signals and composition of the cloudy zone has also been made, allowing model simulations for the cloudy zone to be improved by furthering the understanding of the magnetic properties and interaction between the tetrataenite islands and the Fe-rich matrix. The relationship between composition and magnetisation will also be investigated for the plessite, which is currently poorly characterised due to its complex structure.

A time-resolved record of magnetic activity on the IVA iron meteorite parent body

James Bryson ***University of Cambridge***

The IVA iron meteorites have been proposed to originate from an exposed planetary core that had its mantle removed by impacts early in the solar system's history. The lack of an insulating core meant this pure-metal body cooled rapidly and solidified from the top-down (from the surface, towards the centre). A significant portion of small body cores have been proposed to have solidified in this manner, yet there are no known observations of magnetic activity generated during this process or the mechanism by which it occurred. In this talk, I will present a time-resolved record of the magnetic activity generated as the deep molten liquid convected within the IVA parent body. This record was inferred from X-ray photo-emission electron microscope (XPEEM) images of the Steinbach IVA iron meteorite, and I will detail the experimental procedures and analysis capable of inferring this information. This record shows that the direction of the field generated by the IVA parent body was unstable over time, and potentially includes the first observation of a magnetic reversal on a body other than Earth. I will argue that this field was unlikely the result of thermal convection (despite the large heat flux out of an unmantled core), and was instead the result of compositional convection generated during core solidification. The implications of compositional convection during top-down solidification will be discussed in terms of likely epochs and the efficiency of magnetic field generation during the early solar system.

Thursday 8th January 2015

Bronze age archaeointensity data from the Levant and Anatolia and its impact of archaeomagnetic jerk and geomagnetic spike theory

Megan Hammond ***University of Liverpool***

We will present high quality archaeointensity data from Turkey spanning the age range 2200 BC to 700 BC. Additionally we will present archaeointensity data for Cyprus from 2400 BC to 2000 BC. The intensity results and associated rock magnetic data were obtained from unoriented pottery samples and oriented burnt mud bricks from two Bronze Age archaeological sites in Southern Turkey: Tell Atchana and Kilise Tepe and from two Bronze Age sites in Central and Northern Cyprus: Marki Alonia and Bellapais Vounous. Archaeointensity measurements were made using microwave and thermal techniques and followed both the Coe and IZZI Thellier-type protocols with corrections for cooling rate. The anisotropy of the samples shaped experiment design. Criteria were applied to the experimental results in order to optimise the number of successful samples. A success rate of 46% from a total of 188 samples was recorded.

The age of the samples were constrained by site stratigraphy, carbon dating of related, suitable material and pottery typology. For each archaeological context/ age group studied a variety of pottery types were analysed to improve the robustness of the results and a proportion of the sherds were checked for within sherd consistency. In addition, a burnt in situ mud brick wall was analysed.

The geographic location of these sites within the Levant and Anatolia enables comparison with the archaeointensity results presented by previous authors who measured exceptionally high ancient fields over the time period presented here. Some of these previous studies have correlated periods of high intensity (so called “archaeomagnetic jerks”) with periods of cooling in the North Atlantic and fluctuations in the length of Swiss glaciers. Additionally the samples studied span a “Geomagnetic Spike”. The implication of our dataset on our understanding of these features of the magnetic field will be presented and discussed.

New archaeointensity data from the SW Pacific

Mimi Hill ***University of Liverpool***

Southern hemisphere archaeomagnetic data are sparse, archaeointensity data especially so. In order to better understand geomagnetic field behaviour in the region and for better constrained global geomagnetic models many more data are needed. Here we present new archaeointensity data from a collection of ceramics from the SW Pacific Islands including Fiji, Tonga, Papua New Guinea, New Caledonia and Vanuatu covering the last 3000 years. The microwave method has mostly been used with a variety of experimental protocols including IZZI and Coe variants. Standard Thellier archaeointensity experiments using the IZZI protocol have also been carried out on selected samples. The data are presented and the influence of the data on the global geomagnetic field model pfm9k.1 is discussed.

Independent testing of extreme archeomagnetic change

Phil Livermore ***University of Leeds***

Various episodes of extreme change in the archeomagnetic field have been reported in the literature, including the "archeomagnetic spikes" of the near-east. In this talk, I summarise work that tests the plausibility of the rapid changes using models of the core-flow that is responsible for any secular variation. I also report on new modelling to quantify the signature in the rate of production of Berylium-10 and Carbon-14 of these geomagnetic events.

Palaeogeomagnetism of Brunhes-age sediments in Alaska

Ted Evans ***University of Alberta***

Windblown sediments deposited in Alaska over millions of years carry a remarkably stable remanent magnetization. But the paleodirections observed are significantly biased towards shallow inclinations and easterly declinations. This leads to virtual geomagnetic poles (VGPs) that are "far-sided" and "right-handed" in the sense introduced by Wilson (1970). Far-sidedness can arise from the presence of a persistent axial quadrupole component, but right-handedness has never been adequately explained. Recently-published palaeomagnetic results from the North Atlantic (Stoner et al., 2013) suggest that high-latitude flux lobes play an important role during the Holocene (104 years). To explain our Alaskan results, such lobes would have to persist a hundred times longer.

Geomagnetic Implications of Inner Core Translation

Jon Mound ***University of Leeds***

Earth's inner core possesses a seismic structure that could be explained as the consequence of a bulk translation. However, seismic anomalies are not the only immediate result of a translating inner core; in this scenario, lateral variations of heat flow would arise at the inner core boundary that could influence core convection and dynamo to an observable extent. We use geodynamo simulations to investigate the geomagnetic signature of such heterogeneity and whether the structure of the resulting fields and secular variation are compatible with observations, using a combination of established and newly developed criteria of field morphology. We consider three models that span a range of amplitudes for inner core boundary heat flow variations and incorporate seismically inferred variations at the core-mantle boundary. Imposing hemispheric heterogeneity at the inner core boundary promotes the formation of high-intensity flux patches at high-latitudes and american longitudes in our models. Measures of the global structure of field morphology indicate that the model with the strongest inner boundary forcing best matches the observed field for the past 400 years; however, that model tends not to reproduce the observed quietness of Pacific secular variation. An east-west hemispheric bias in the long-term average of the magnetic field would suggest that hemispheric inner-core heterogeneity has an important influence on the dynamics of the outer core.

Multipolarity Remanences in Lower Oceanic Crustal Gabbros Recovered By Drilling at Hess Deep (Integrated Ocean Drilling Program Expedition 345)

Antony Morris ***Plymouth University***

A long-term goal of the scientific ocean drilling community is to understand the processes by which the ocean crust is constructed through magmatism, deformation, metamorphism and hydrothermal cooling. Insights into the magnetic properties of the lower crust have come from drilling at oceanic core complexes and in tectonic windows. At the Hess Deep Rift, propagation of the Cocos-Nazca Ridge into young, fast-spreading East Pacific Rise crust exposes a dismembered, but nearly complete lower crustal section. Here, IODP Expedition 345 (Site U1415) recovered primitive plutonic lithologies including gabbro, troctolitic gabbro and olivine gabbronorite. These rocks exhibit cumulate textures similar to those found in layered basic intrusions and some ophiolite complexes. Metamorphism is dominated by background greenschist facies alteration associated with cataclastic deformation that likely results from Cocos-Nazca rifting. Some intervals display complex, multiple remanence components within individual samples. A high temperature component unblocks above 500°-520°C and an intermediate temperature component of nearly antipodal direction unblocks between 425°-450°C and 500°-520°C. In addition, a few samples display a third component that unblocks between 100-350°C that is nearly parallel to the highest temperature component. These multiple, nearly antipodal components suggest that remanence

was acquired in different geomagnetic chrons, and represent the first multipolarity remanences seen in Pacific lower oceanic crust. Similar remanence structures, however, have been reported in lower crustal gabbros recovered from slow-spreading rate crust along the Mid-Atlantic Ridge, and have been interpreted to reflect protracted accretion or protracted cooling. In contrast, at Hess Deep unblocking temperatures appear consistent with temperatures inferred for successive phases of alteration, suggesting an alteration history spanning at least two polarity chrons.

Abstracts for poster presentations

The age of the Morrison Formation (Western Interior, USA): A Magnetostratigraphic Approach

Authors: **D. Baliklov, S. Maidment, A. Muxworthy**
Presented by: **Dominika Baliklov, *Imperial College London***

A paleomagnetic study of four logged Morrison Formation sections from NE Utah and central Colorado, USA, was carried out for correlation and dating of the formation using the Geological Polarity Timescale. Stepwise thermal and alternating field demagnetization was used to isolate the characteristic remanent magnetization, identified by principal component analysis and Fisher statistics. Results show predominant normal polarity associated with steep, northerly inclinations, except at Dinosaur National Monument Visitor Centre, Utah, where three reversals have been identified. The main dinosaur fossil bearing bed at this locality, Quarry Sand, is of normal polarity and correlates to the M22 marine magnetic anomaly sequence, using a previously acquired $^{40}Ar/^{39}Ar$ date of 148.97±0.12 Ma. This implies at least an Upper Tithonian age of ~147 Ma for the top of the Morrison Formation.
The absence of reversals in the upper parts of Morrison Formation at Gunnison, Colorado, suggest a stratigraphically lower upper contact than that observed in Utah, implying that the sections is no younger than ~148 Ma/M22. However, thermomagnetic and SEM analysis reveal the presence of iron sulphides and iron cement, indicating possible alteration and overprinting of the original magnetic signal. Virtual geomagnetic poles calculated for each locality show that all but one of the sections agree with previously published Morrison Formation paleopoles and/or the apparent polar wander path of the North American craton.

The International Geomagnetic Reference Field (IGRF) version 12: The BGS candidate and final model

Authors: C. Beggan, B. Hamilton, V. Ridley, S. Macmillan, A. Thompson & IGRF-12 candidate selection panel
Presented by: Ciaran Beggan, *British Geological Survey*

The International Geomagnetic Reference Field (IGRF) model is a reference main field magnetic model updated on a quinquennial basis. The latest revision (version 12) was released in January 2015. The IGRF-12 consists of a definitive model (DGRF2010) of the main field for 2010.0, a model for the field at 2015.0 (IGRF12) and a prediction of secular variation (IGRF-12 SV) for the forthcoming five years until 2020.0. Nine candidates were submitted for consideration to the IGRF selection panel led by Erwan Thebault (Nantes) and Chris Finlay (DTU Space) by various international teams. The final DGRF and IGRF12 models were computed from all candidates using a Huber weighting in space scheme. In this poster, we outline the modelling steps for the three BGS candidate models and compare them to the other submitted candidates and the final official models released as IGRF-12.

Temperature and grain size dependence of the attempt time \tau_{0} for fine magnetic particles

Authorts: T. Berndt, A. Muxworthy, G. Paterson, M. van Ginneken
Presented by Thomas Berndt *Imperial College London*

In order to calculate the relaxation time for fine magnetic particles, one needs to know the attempt time \tau_0. This quantity remains poorly constrained and is commonly assumed to be constant, although theory predicts a temperature and grain size dependence. Here we present a new method to measure the attempt time including its temperature and grain size dependence, by making use of

viscous magnetic decay experiment of a saturation isothermal remanence at different temperatures. Moreover the method allows to determine the grain size distribution of a sample

Scanning magnetic microscopy studies of plessite region in iron and stony-iron meteorites

Author: R. Blukis
Presented by: Robert Blukis *University of Cambridge*

Iron and stony-iron meteorites show complex intergrowths of metal phases on all length scales from centimeters to nanometers. This research focusses on plessite, a micrometer scale intergrowth of Fe-Ni phases with an approximate bulk composition of 10-25% Ni. Plessite undergoes a complex formation process of martensitic transition followed by diffusion driven exsolution, producing a complex 3D microstructure of kamacite, taenite and/or tetrataenite. Due to the presence of high coercivity phases such as tetrataenite, plessite has a great potential as a paleomagnetic remanence carrier thereby enabling measurements of magnetic fields present in the early solar system. Due to its unique structure plessite could also recored fields at a different time period compared to fields extracted from other regions in the meteorite such as the cloudy zone therefore providing complimentary magnetic field information. However, its magnetic properties are largely unknown. A plessite region of the Imilac meteorite, belonging to the pallasite group of stony-iron meteorites, was analyzed using magnetoresistive tunnel-junction (MTJ) scanning magnetic microscope. MTJ measures the z-component of magnetic stray field a few micrometers above the sample surface with a spatial resolution of few tens of micrometers. The remanent magnetic fields of the sample were measured after the sample was exposed to a saturating field of 2.1 T, followed by progressively larger backfields up to 2.1 T with a step of 5 mT between 0 T and 0.05 T, 50 mT between 0.05 T and 0.5 T and 100 mT from 0.5 T to 2.1 T. The results show that plessite has different apparent magnetic properties than large individual grains of its principal components kamacite and tetrataenite. The magnetization of the sample appears to change in steps with linearly increasing backfield indicating components with different coercivites. As the mechanisms by which different components acquire their magnetic remanence are unknown it is an active research area in our group.

Model Jerks: Insights from Observations and Synthetic Models

Authors: W. Brown, P. Livermore, J. Mound
Presented by: William Brown *University of Leeds*

The geomagnetic field is generated by the constant motion of the fluid outer core and varies on timescales from months to millions of years. Geomagnetic jerks are rapid changes in the secular variation of Earth's magnetic field, 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. Jerks can be seen in magnetic observatory records over the last 170~years and in satellite data of the last 15~years. This data coverage, spatially limited and/or temporally restricted, makes it difficult to interpret the true character of jerks at the surface or their origins in the core. This leads us to investigate what further insight we can gain from synthetic magnetic fields such as those which are described by modelling stochastic processes. Such fields are not restricted by the temporal smoothing of most magnetic field models and can better represent rapid variations such as jerks.

FORCulator: a micromagnetic tool for simulating first-order reversal curve diagrams

Authors: R. Harrison, I. Lascu
Presented by: Richard Harrison *University of Cambridge*

We describe a method for simulating first-order reversal curve (FORC) diagrams of interacting single-domain particles. Magnetostatic interactions are calculated in real space, allowing simulations to be performed for particle ensembles with arbitrary geometry. For weakly interacting uniaxial particles, the equilibrium magnetization at each field step is obtained by direct solution of the Stoner-Wohlfarth model, assuming a quasi-static distribution of interaction fields. For all other cases, the equilibrium magnetization is calculated using an approximate iterated solution to the Landau-

Lifshitz-Gilbert equation. Multithreading is employed to allow multiple curves to be computed simultaneously, enabling FORC diagrams to be simulated in reasonable time using a standard desktop computer. Statistical averaging and post processing lead to simulated FORC diagrams that are comparable to their experimental counterparts. The method is applied to several geometries of relevance to rock and environmental magnetism, including densely packed random clusters and partially collapsed chains. The method forms the basis of FORCulator, a freely available software tool with graphical user interface that will enable FORC simulations to become a routine part of rock magnetic studies.

Long-term geomagnetic field variation and it's relation to whole-mantle convection: hypothesis testing using new palaeomagnetic data from the Devonian.

Authors: **L. Hawkins, A. Biggins, M. Hill, R. Duller, J. Holt, A. Shatsillo, V. Pavlov**
Presented by: **Louise Hawkins** ***University of Liverpool***

Long-term geomagnetic field variation and it's relation to whole-mantle convection: hypothesis testing using new palaeomagnetic data from the Devonian.
Variations in the geomagnetic field, such as field reversal, are largely attributed to stochastic processes. However, it is statistically unlikely that they produce the variations in reversal frequency observed over tens to hundreds of millions of years. A major transition from a peak in reversal frequency in the Middle-Late Jurassic (~150-170 Ma) to the Cretaceous Normal Superchron (CNS; 84-121 Ma) suggests a significant transition in geodynamo behaviour at this time. This coincides with a change in the virtual (axial) dipole moment from a low in the Jurassic to a high in the Cretaceous, although the latter is contentious. Mantle convection occurs over similar timescales and has been proposed as the driving mechanism for this variation in geomagnetic field behaviour (Biggin et al. 2012). As the distribution of mantle plumes and sinking slabs changes with time so does heat flow across the core-mantle boundary (CMB) and the power available to drive the geodynamo. Numerical modelling suggests that both changes in the total heat flow across the CMB and the spatial pattern of heat flow result in changes in reversal frequency and the mean dipole moment.
Similar patterns in geomagnetic field behaviour to those observed in the Mesozoic may have occurred in the Palaeozoic; however there is insufficient reliable palaeomagnetic data to test this. Initial results for the Devonian virtual (axial) dipole moment (Biggin & Thomas 2003) are close to Jurassic values, suggesting similarities in the geodynamo behaviour preceding the Permo-Carboniferous Reversed Superchron (PRCS) to that preceding the CNS. Recent work on samples from Russia to constrain Devonian pole positions has highlighted a suite of localities with samples suitable for palaeointensity work. Preliminary Thellier and Microwave palaeointensity work from these localities also give very low palaeointensity values. Further microwave work on these samples is planned to confirm the reliability of these values. Future work will include palaeointensity measurements from Early Devonian volcanics of the Midland Valley, Scotland and magnetostratigraphy on Devonian successions to constrain the reversal frequency.

New Paleomagnetic Data from the Wadi Abyad Crustal Section & their Implications for the Rotation History of the Oman Ophiolite

Authors: M. Meyer, A. Morris, M. Anderson, C. MacLeod
Presented by: Matthew Meyer, ***Plymouth University***

The Oman ophiolite is an important natural laboratory for understanding the construction of oceanic crust at fast spreading axes and its subsequent tectonic evolution. Previous paleomagnetic research in lavas of the northern ophiolitic blocks (Perrin et al., 2000) has demonstrated substantial clockwise intraoceanic tectonic rotations. Paleomagnetic data from lower crustal sequences in the southern blocks, however, have been more equivocal due to complications arising from remagnetization, and have been used to infer that clockwise rotations seen in the north are internal to the ophiolite rather than regionally significant (Weiler, 2000).

Here we demonstrate the importance and advantages of sampling crustal transects in the ophiolite in order to understand the nature and variability in magnetization directions. By systematically sampling the lower crustal sequence exposed in Wadi Abyad (Rustaq block) we resolve for the first time in a single section a pattern of remagnetized lowermost gabbros and retention of earlier magnetizations by uppermost gabbros and the overlying dyke-rooting zone. Results are supported by a positive fold test that shows that remagnetization of lower gabbros occurred prior to the Campanian structural disruption of the Moho. NW-directed remagnetized remanences in the lower units are consistent with those used by Weiler (2000) to infer lack of significant rotation of the southern blocks and to argue, therefore, that rotation of the northern blocks was internal to the ophiolite. In contrast, E/ENE-directed remanences in the uppermost levels of Wadi Abyad imply large, clockwise rotation of the Rustaq block, of a sense and magnitude consistent with intraoceanic rotations inferred from extrusive sections in the northern blocks. We conclude that without the control provided by systematic crustal sampling, the potential for different remanence directions being acquired at different times may lead to erroneous tectonic interpretation.

IODP Expedition 351 Izu-Bonin-Mariana Arc Origins: Age model for Site U1438

Authors: A. Morris, M. Aljahdali, A. Bandini, R. do Monte Guerra, S. Kender , M. Maffione & IODP Expedition 351 Scientists
Presented by: Antony Morris *Plymouth University*

We report preliminary paleomagnetic and paleontological results from International Ocean Discovery Program (IODP) Expedition 351, which recovered an unprecedented ~1.4 km thick volcaniclastic sedimentary record documenting the initiation and subsequent evolution of the Izu-Bonin-Mariana (IBM) intra-oceanic arc-basin system. Magnetostratigraphic and biostratigraphic constraints provide a high-resolution temporal framework for interpretation of this record. Paleomagnetic analyses of archive half core samples provide a continuous record of the geomagnetic field inclination down to 847 mbsf that allows construction of a detailed site magnetostratigraphy that closely matches the Geomagnetic Polarity Timescale (Gradstein et al., 2012). A total of 87 geomagnetic reversals have been recognized in the studied succession, extending back to ~36 Ma. Despite sporadic microfossil occurrences in parts, calcareous nannofossils, planktonic foraminifera and radiolarians each contribute to the age model for the entire Site. All nannofossil marker species for Oligocene to Eocene Zones NP25 to NP19/20 are recognised. Beneath paleomagnetic control (847–1449 mbsf), foraminifera and radiolarians provide the only age control. The most salient features of the age model are that: (i) average linear sedimentation rates during the Plio-Pleistocene range from 1.4 to 2.2 cm/ka; (ii) there was a reduction in sedimentation rates to 0.25 – 0.5 cm/ka throughout the Miocene; and (iii) sedimentation rates sharply increase again in the Oligocene to Late Eocene to a maximum of ~20 cm/ka. These quantitative constraints closely match (non-quantitative) inferences based on the lithostratigraphy of the site, with fine-grained/coarse-grained sediments dominating in periods with low/high sedimentation rates respectively.

Characterisation of biogenic magnetite from sediments of the SW Iberian Margin using FORCs and principle component analysis.

Authors: J. Muraszko
Presented by: Joy Muraszko *University of Cambridge*

Magnetotactic bacteria (MTB) are ubiquitous in marine and freshwater environments and can be a significant source of stable natural remanent magnetization (NRM) as well as a paleoenvironmental tracer. Thus, their identification and characterization is crucial for the interpretation of magnetic records. MTB have been reported to concentrate at or slightly below the oxic-anoxic interface in sediments. This study aims to further investigate the dependence of MTB abundance in relation to geochemical gradients. Interpretation of magnetic measurements was aided by oxygen, pH and

redox profiles determined from sediment pore waters using micro-electrodes inserted directly into core tubes. Two short sediment cores from a bathymetric transect of the SW Iberian Margin were subsampled and analysed for magnetic properties.
First-order reversal curves (FORCs) act as a fingerprint of the magnetic mineralogy of bulk samples, providing a distribution of coercivities and interaction fields. Analysis of FORC diagrams is an exceptional tool for distinguishing superparamagnetic (SP), single-domain (SD), pseudo-single domain (PSD) and multi-domain (MD) signals. Through the means of FORC analysis it is possible to quantify the contribution of the biogenic component represented by SD particles (magnetofossils). Principle component analysis (PCA) was used to describe the variability in the data as a method of 'unmixing' the magnetic signal and quantitatively characterizing the main contributing components.

Simulating paleointensity data from multidomain specimens

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The manifestation of multidomain (MD) grains in paleointensity data is one of the primary reasons for experimental failure and ambiguity in the reliability of accepted results. To better characterize MD effects we take the novel approach of incorporating realistic levels of experimental noise into a phenomenological MD model and systematically exploring the parameter space of paleointensity experiments (the choice of protocol, laboratory and ancient field strengths, and angular dependences). Our model predictions qualitatively and quantitatively compare well with real data from MD specimens and predict recently observed MD behavior. We also explore the quantification of the fraction of natural remanent magnetization used to make a paleointensity estimate and find that FRAC, a recently proposed alternative quantification, is consistently better at isolating accurate results than the traditionally used f. On the basis of ensuring at least an accurate average paleointensity estimate, we recommend minimum FRAC values of 0.65, 0.45, 0.65, and 0.55 for the Thellier, Coe, Aitken, and IZZI protocols, respectively. Building upon this, we use the models and stochastic optimization to develop new sets of selection criteria (MCRIT) designed to maximize the likelihood of accepting accurate estimates from a suite of specimens influenced by MD behavior. Using a quasi-independent synthetic data set generated from the MD model and a fully independent real data set compiled from control paleointensity experiments, we demonstrate that the MCRIT criteria outperform their original counterparts, in terms of their ability to isolate accurate results with low scatter. The use of independent constraints in the data selection process are vital if we wish to remove the arbitrariness that hinders the identification of reliable paleointensity data.

The magnetic properties and palaeodirections of basalts in Iceland: preparation to test the geocentric axial dipole hypothesis (GAD)

Authors: R. Supakulopas, A. Muxworthy, A. Døssing, C. MacNiocaill, M. Rooshuus
Presented by: Radchagrit Supakulopas ***Imperial College London***

This study plans to research the palaeomagnetic signal of basalt sequences from Northern Iceland in order to eventually test the geocentric axial dipole hypothesis (GAD). The rocks cover an age range of 0-7 Ma rocks. Fieldwork to collect rock samples was held in Eyjafjardalur in August 2014; as such only preliminary results are presented her: palaeodirectional and rock magnetic data. A second field campaign to collect two more units will be held in summer 2015.

Oligocene-Miocene Transition

Authors: T. van Peer
Presented by: Tim van Peer ***University of Southampton***

The nannofossil ooze drilled at Site U1406 (40°21'N 51°39'W, IODP Expedition 342, Paleogene Newfoundland Sediment Drifts) provides an exceptional sedimentary archive as it has been

deposited at a relatively high sedimentation rate (several cm/kyr) during the Late Oligocene to Early Miocene. U-channel measurements of this interval are in good agreement with the shipboard data and reveal distinctive patterns of normal and reversed polarity. Supported by the shipboard biostratigraphy, it can be correlated to the Geomagnetic Polarity Time Scale (GPTS) between C6Bn.2n and C8n.2n (~22 to ~25.5 Ma), and also supports the XRF-based splice refinements. Additionally, colour and elemental alternations of this unprecedented high-resolution record have great potential to be used in an astronomical tuning of the Late Oligocene to Early Miocene GPTS, as other South Atlantic or equatorial Pacific tunings are based on marine records with low sedimentation rates.

Restoring Detailed Geomagnetic and Environmental Information from Continuous Sediment Palaeomagnetic Measurement through Optimised Deconvolution

Authors: C. Xuan, H. Oda
Presented by: Chuang Xuan, *University of Southampton*

The development of pass-through superconducting rock magnetometers (SRM) has greatly promoted collection of paleomagnetic data from continuous long-core samples. However, the output of pass-through measurement is smoothed and distorted due to convolution of sample magnetization with the magnetometer sensor response. Although several studies could restore high-resolution paleomagnetic signal through deconvolution of pass-through measurement, difficulties in accurately measuring the magnetometer sensor response have hindered the application of deconvolution. We acquired reliable sensor response of an SRM based on repeated measurements of a precisely fabricated magnetic point source, and present an improved deconvolution algorithm incorporating new parameters to account for realistic errors in sample measurement position and length. Deconvolution of 1000 synthetic measurements with realistic noise closely resembles the “true” magnetization, and successfully restored fine-scale magnetization variations including the “excursion”. Our analyses show that inaccuracy in sample measurement position and length significantly affects deconvolution estimation, and can be resolved using the new deconvolution algorithm. Optimized deconvolution of 20 repeated measurements of a u-channel sample yielded highly consistent deconvolution results and estimates of error in sample measurement position and length, demonstrating the reliability of the new deconvolution algorithm for real pass-through measurements. A MATLAB based software UDECON with graphic user interfaces is developed to conveniently prepare and perform optimised deconvolution using the new and improved algorithm.