Department of Earth Sciences
Durham University

Conference 2014
10th June

Durham University

AHGS
Arthur Holmes Geological Society

Contents

A welcome from Jon Gluyas, Head of Department

Following the success of last year's event, I am delighted to be able to welcome you all to the second Department of Earth Sciences Conference at Durham University. The event provides a chance to showcase Durham's academic excellence across a wide range of Earth Science disciplines, allowing students and staff from across the department an opportunity to present recent pieces of research to colleagues and members of the wider scientific community.

Our current Level 4 undergraduate students will be providing oral presentations throughout the day, concluding their summative research dissertations. The projects are all based around active areas of research and cover a wide range of topics. I hope you are able to attend a selection of the talks and support the students in their final projects with us here in Durham.

I would like to kindly thank our sponsors and industrial partners for supporting the conference, and I hope you get a chance to talk to our visitors throughout the day.

Have a great day, and please remember to stick around to enjoy a drink at the awards ceremony at 6pm.

Best wishes,

Jon

A Brief History of Earth Sciences at Durham

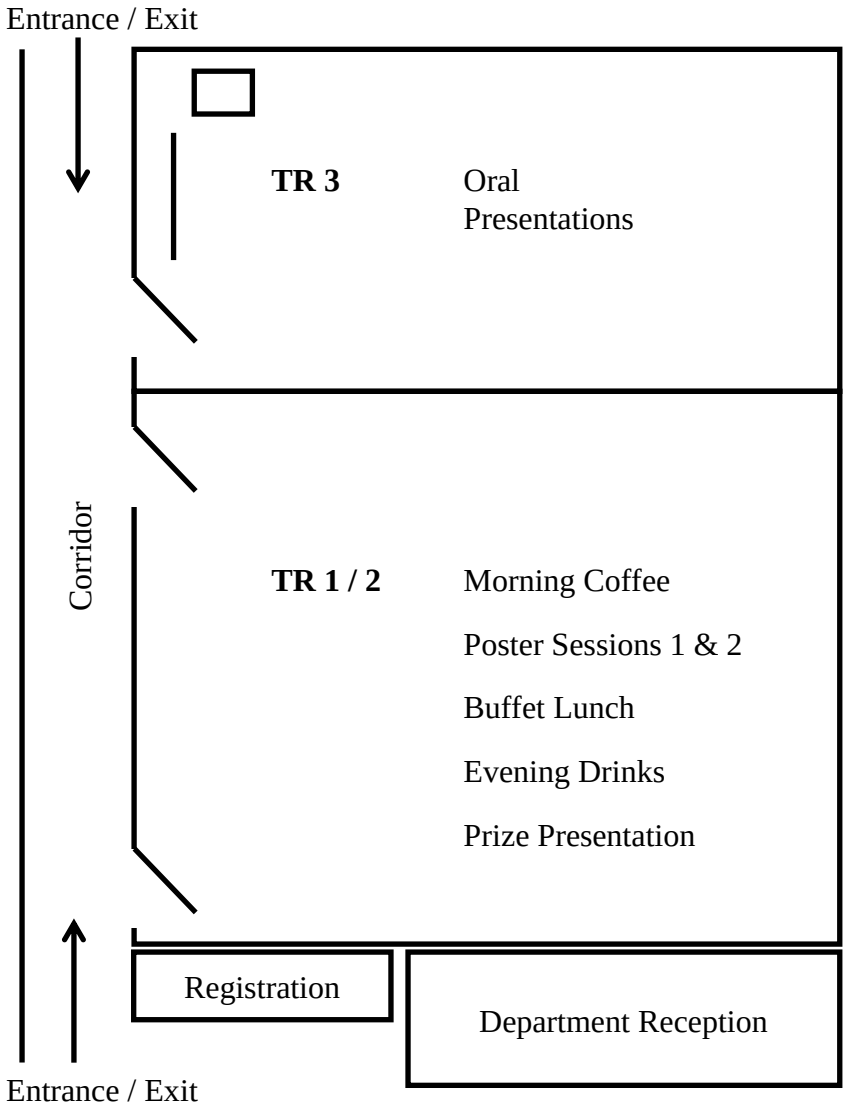
Aspects of the Geological Sciences have been taught at Durham University since its founding, but it was not until 1924 that the Geology Department was created, with Dr (later Professor) Arthur Holmes appointed as its head. Holmes developed a strong department, which produced a succession of distinguished professional geologists. Holmes left the department in 1943, shortly before the publication of his groundbreaking textbook 'Principles of Physical Geology'. Prof. Lawrence Wager was appointed Holmes' successor, and oversaw growth of the department, recruiting Dr David Vincent (Geochemistry) and Dr Fred Stewart (Petrology), both of whom were later elected FRS.

The department in its modern form began with the appointment of Prof. Kingsley Dunham FRS as Head in 1950. Dunham brought huge energy and vision to the role, overseeing a dramatic expansion in staff numbers. The Rookhope Borehole Project was perhaps the stand-out scientific achievement of this period, and marked the rise of Geophysics in the department, led by Prof. Martin Bott FRS. Prof. Malcolm Brown FRS arrived in 1967, and shared HoD duties with Prof. Bott for the next twelve years; petrological, mineralogical and geochemical analysis of moon rocks, returned by the Apollo missions, was a highlight of this period, and laid the foundations for the department's pre-eminent status as a centre for Geochemistry. In 2003, we became the Department of Earth Sciences, and moved to our current home – the Arthur Holmes Building – which includes state-of-the-art laboratory facilities, and purpose-built teaching rooms. The department now comprises 31 academic staff, 30 research staff, 70 PhD students and around 250 undergraduates, and is known internationally as one of the top-rated Earth Science departments in the country.

Conference Timetable

09:15 – 11:00	Oral presentations	TR 3
11:00 – 11:15	Coffee break	TR 1 / 2
11:15 – 13:00	Oral presentations	TR 3
13:00 – 14:30	Poster session 1 & buffet lunch	TR 1 / 2
14:30 – 17:05	Oral presentations	TR 3
17:05 – 18:30	Poster session 2 & evening drinks (sponsored by Getech)	TR 1 / 2
18:00	Awards ceremony	TR 1 / 2
18:30	Close	

Department of Earth Sciences, Floor Plan



Conference Logistics

- **Registration:** From 9am outside TR1. Once you have registered you can come and go as you please throughout the day.

- **Oral presentations**: To listen to the oral presentations, PLEASE ONLY ENTER TR3 AT THE BEGINNING OF A SESSION. Please do not interrupt the oral presentations as they are being assessed. PLEASE DO NOT ENTER/LEAVE IN BETWEEN TALKS!

- **Poster presentations**: Please stand by your posters at the following times:

    - POSTER SESSION 1 (LUNCH): Staff and Postdoctoral Fellows/RAs.
    - POSTER SESSION 2 (AFTERNOON): PhD students and Undergraduates.

- **Poster setup**: Please put up your posters BEFORE the first coffee break (11am).

Awards

The following awards have been kindly sponsored by BP for the conference:

Two poster awards (1 undergraduate and 1 postgraduate): Vouchers for an outdoor shop and a year's membership of a professional society of your choice (total value ~£150 per award)

Two awards for the best Level 4 oral presentations: A rugged/waterproof digital camera and a year's membership of a professional society of your choice (total value ~£300 per award)

These shall be awarded by a panel consisting of both AHGS and BP representatives. Awards will be presented at 18:00 in TR1/2 – make sure you're there!

Industry Exhibition

CGG. Geoscience company providing leading geological, geophysical and reservoir capabilities to its broad base of customers primarily from the global oil and gas industry.

BP. One of the world's leading international oil and gas companies.

Ikon GeoPressure. Provide global best practice in subsurface pressure analysis. Delivering consulting, training and integrated technology to reduce risk and increase success from overpressure and geopressure in exploration, development and production situations.

Gardline. Specialising in marine geophysical, marine geotechnical and environmental surveys.

Getech. For over 25 years, Getech has been using its data and geoscience expertise to help the oil and mining industries locate the Earth's natural resources.

Durham Uni Careers, Employability and Enterprise Centre. CEEC provides a wide range of services to both students and departments, from its core functions of providing careers information, advice and guidance to students and graduates to promoting employability issues within the University.

Message from the organisers

Thank you for attending today's event! If you would like to volunteer to help organise the conference next year, or have any suggestions on how to improve the event in future, please contact claire.horwell@dur.ac.uk

2014 Conference Organising Committee:

Jack Kosky

Jonathan Pickerden

Emma Gregory

Megan Roberts

Simon Dixon

Claire Horwell

Oral Presentations

09:15	**Evans, E.E.**	What can crystal fabrics tell us about how a lava flowed?: A comparative single sample study in two- and three-dimensions
09:30	**McMullan, S.**	Numerical modelling of H2O diffusion and speciation in magmas
09:45	**Moore, G.P.L.**	The Petrology and Geochemistry of the Iyang-Argapura Volcanic Complex in Eastern Java
10:00	**Reilly, T.P.M.**	Investigating the effect of thermal and compositional buoyancy on small-scale convection beneath mid-ocean ridges
10:15	**Morris, I.A.**	Determining the optimum procedures for analysing carbon and oxygen isotope ratios of Dolomite, Calcite and synthetic mixtures
10:30	**Le Cornu, C.**	The Structural Setting, Age and Significance of Sulphide Mineralisation in the North Pennine Ore Field
10:45	**Wetherell, G.F.**	The nature and significance of fault gouge development in Basaltic Lava flow sequences
		COFFEE
11:15	**Kawanzaruwa, T.M.**	Dynamic weakening processes of quartz and olivine gouges at seismic slip rates
11:30	**Barraclough, R.B.**	Implications of Seismic, GPS and Drainage evidence on the evaluation of active tectonics within Eastern Tibet and South-East China
11:45	**Martin, J.M.**	An Investigation into Drainage Reversal along the Yarlung-Tsangpo Suture in Southern Tibet
12:00	**Bowers, J.W.**	Developing methodology for use in modelling secondary petroleum migration in a mud-rich MTD using seal quality cube data
12:15	**Kendaru, K.**	Molecular simulations of low salinity enhanced oil recovery
12:30	**Tasker, J.J.**	Atomistic Simulation Of Organic-Clay Interfaces For Low-Salinity Enhanced Oil Recovery
12:45	**Scott, J.**	The 3-Dimensional Architecture of the Rotliegend Sands of County Durham

LUNCH

14:30	**Kirkley, S.**	Evaluation of Triassic Rot Halite in the Cleveland Basin: Thickness, Lateral Extent and Effect on Stratigraphy
14:45	**Eason, J.D.**	A Multichannel Seismic Investigation into the Upper Crustal Structure of the Costa Rica Rift
15:00	**Schofield, J.K.**	3D Seismic analysis of Gas hydrates and their associated "feathered edge": offshore Mauritania
15:15	**Gill, C.**	Nature and significance of chimney structures and associated teardrop formations of 3D seismic data from gas hydrate sediments offshore Mauritania
15:30	**Dukes, D.R.**	Using Bayesian Probabilities to Estimate Seismic Velocities in order to better constrain Pre-drill Prediction of Overpressure
15:45		*CATCH–UP SLOT*
15:50	**Oldham, C.**	Overpressure in the Manaia Graben, Taranaki Basin, New Zealand
16:05	**Birchley, H.J.**	Calculating the Water Transit-Times for UK Rivers Under Varying Flow Regimes and Conditions
16:20	**Denison-Smith, R.L.**	A phosphorus budget of Great Britain's terrestrial biosphere 1990-2010
16:35	**Jessett, A.L.**	Use of Waste Materials for Phosphate Recovery in Water Treatment
16:50	**Bertram, R.A.**	Assessing and Quantifying the "Ground Air" Store of Carbon Dioxide Located in the Unsaturated Zone

What can crystal fabrics tell us about how a lava flowed?: A comparative single sample study in two- and three-dimensions

Evans, E.E. 09:15

Much work has been done in the field of fluid dynamics and rheology of pure melt and two- or three-phase magmas. Igneous rock fabrics covey extremely useful information about an eruption including magma composition, evolution and mixing, cooling and rate of assent. It is widely accepted that no magma will simply 'freeze' a dynamic fabric in place. Processes such as settling, sticking and changes in rheology as the magma cools would account for variations from such a texture. But to what extent do crystal fabrics deviate from numerical models, especially for lava flows?

Crystals in a flow rotate in a stable manner that can be replicated experimentally in 2D and 3D. Such experiments also demonstrate transient features such as tiling of the crystals and particle-particle interactions. However comparisons between actual samples and there expected numerical models have not been performed. Assumptions are made within the literature that analogues conducted in 2D can be extrapolated into 3D. Considering that these 2D analogues may not fully represent the 2D system this leads to even more assertions.

Therefore this study aims to address the assumption that: a) Two-dimensional studies can be extrapolated into three dimensions. Also b) Crystals can be simply approximated as extreme spheroids (in this study's case, oblate spheroids) when theoretically calculating particle orientation and rotation data. Further to this, the study investigates to what extent numerical models used for moving particles reflect crystal fabrics in crystallised magmas.

The conclusions of this study were that although there is adequate correlation between the numerical models and observed data, the limited data set cannot rule out randomness as the cause of the correlation. The study also shows that 2D data should not be used in place of 3D data where determining the true dimensions of phenocrysts in a sample and their predicted orientation probability distribution.

Numerical modelling of H_2O diffusion and speciation in magmas

McMullan, S. 09:30

Diffusion and speciation of H_2O plays a large role in the dynamics of volcanic eruptions as they cause bubbles to grow and shrink. H_2O speciates into molecular water (H_2O_m) and hydroxyl groups (OH^-). Both species affect the melt in different ways and the ratio of H_2O_m: OH^- is dependent on the environmental conditions of the melt such as temperature, pressure and total water content (H_2O_t). Changes in their environmental conditions affect the rate of diffusion, with diffusion favoured at high temperatures and low pressures.

The H_2O concentration profiles surrounding a bubble can reveal a great deal about the environmental conditions of the melt prior to quench. To be able to study this in more detail, two models have been built: Model 1 – 1-D H_2O_t concentration profiles surrounding a growing or shrinking bubble, Model 2 – 1-D H_2O speciated concentration profiles surrounding a growing or shrinking bubble, where H_2O speciation occurs instantaneously as H_2O_m diffuses. Both models have been benchmarked against experimental data and match well, so are reliable for testing different parameters. Model 1 is valid between T = 403-1629 ^oC, P = 0-1.9 GPa and C_{H2Ot}= 0.1-7.7 wt%, and model 2 is valid between T = 800-1629 ^oC, P = 0-1.9 GPa and CH2Ot = 0.1-7.7 wt%.

Model 2 has been used to test the differences observed in concentration profile, the speciation ratio H_2O_m:OH^-, and the duration of diffusion until equilibrium is reached. It is noted that the main controls on H2O speciation and diffusion is temperature and H_2O_t content, however pressure makes a noticeable difference when P > 0.4 GPa,

and melt mole fraction also makes a slight difference in the results. Diffusion occurs fastest when temperature is high, H_2O_t concentration is high, and pressure is low. When diffusivity is low, the concentration profile has a more convex shape near the bubble wall and a sudden decrease to the background melt concentration. H_2O_m:OH^- ratio is higher at low temperatures, high H_2O_t content, and higher melt mole fraction.

The Petrology and Geochemistry of the Iyang-Argapura Volcanic Complex in Eastern Java

Moore, G.P.L. 09:45

Samples from the Iyang-Argapura volcanic complex have been studied in order to decipher the magmatic processes which affected the evolution of the magma. Sixteen samples were collected and underwent petrographic and geochemical analysis. Thirteen of these samples plotted within basalt or trachy-basalt on a TAS diagram with the other three plotting as andesites.

Thin sections of these samples show the dominant texture to be seriate with the majority of the samples consisting primarily of plagioclase, clinopyroxene, olivine and magnetite phenocrysts (in descending order of total abundance) although the more evolved samples lack olivine and magnetite. The groundmass is commonly microcrystalline and similar in composition to the phenocrysts. In all of the samples there are different phenocryst phases which show a variety of disequilibrium features.

Geochemically there are two distinct groups within the samples, Groups 1 and 2. These groups can then be sub divided. Group 1 is composed of the more evolved samples containing 2.59 to 5.84 wt% MgO whereas Group 2 has a range between 8.42 to 9.16 wt% MgO. Major element Harker diagrams against MgO suggest crystal fractionation as a dominant process for Group 1, with plagioclase and clinopyroxene as the main fractionating minerals. This agrees with conclusions made for both Ijen and Lamongan, local volcanic complexes. Group 2 however contains features such as enriched incompatible elements which suggest an open system process. It is possible that Groups 1 and 2 are linked through fractionation of olivine.

The proposed driving process for the evolution of the magma is magma replenishment of an unaltered magma chamber causing melting and sudden crystallization. Fractionation of olivine trapped a proportion of the more evolved melt between the crystals, resulting in the variation in incompatible elements seen in Group 2. The rest of the magma within the chamber then mixed freely and subsequent crystal fractionation of plagioclase and clinopyroxene dominated as the main process. Alternatively the magma may have been contaminated by crustal material whilst crystallising.

This hypothesis could be tested through a variety of different methods which include further sampling, isotopic analysis (particularly of the Rb-Sr system) and microprobe analysis of minerals.

Investigating the effect of thermal and compositional buoyancy on small-scale convection beneath mid-ocean ridges.

Reilly, T.P.M. 10:00

It has been theorised that small-scale convection may be a key process in producing the large quantities of melt observed at the continental margins of volcanic rifted margins. This paper investigates how the formation of small-scale convection is affected by mantle viscosity, and how these present themselves in two and three dimensional numerical models. The effect of compositional buoyancy differences in mantle material following rifting is also studied.

The numerical models presented here found small-scale convection form transverse rolls close to the ridge axis, with longitudinal rolls forming at a greater offset from the mid-ocean ridge after a sufficient amount of spreading has occurred. This is consistent with previous research. The thermal

Rayleigh number governs the formation and strength of small-scale convection cells, with these forming for values greater than 2.496 x 10^5. Undulations in the thickness of generated crust were observed as the thermal Rayleigh number was increased. This is interpreted to be due to downwellings forming below the ridge axis, reducing the quantities of melt reaching the surface for regions of smaller melt production.

The compositional Rayleigh number was found to slow initial upwellings in the centre of the model, supressing the initial melting pulse. This factor also enhances instabilities in the central downwellings for models with lower viscosities, resulting in areas with far more melt reaching the surface than others, causing extremely variable melt thickness rather than consistent undulations. Conversely, the compositional Rayleigh number strengthens longitudinal rolls, yet also increases other thermal instabilities in the cooling oceanic crust, leading to non-linear rolls which are not parallel to plate motion.

A comparison of two and three dimensional models was performed and it was found that 2-D models become worse approximations of 3-D models as the thermal Rayleigh number is increased. They can be useful in modelling mantle movement for lower thermal Rayleigh numbers, with the limitation that any 3-D structure such as longitudinal rolls will be missed.

Determining the optimum procedures for analysing carbon and oxygen isotope ratios of Dolomite, Calcite and synthetic mixtures.

Morris, I.A. 10:15

The aim of this project is to characterise stable isotope composition of an unknown Dolomite sample and to determine which analytical conditions within the laboratory setup present in SIBL were optimum for sequential extraction and isotopic analysis of two different carbonate fractions (dolomite and a calcite). For the analysis of the Dolomite sample and the creation of standard δ13C and δ18O values the sample underwent the phosphoric acid method of stable isotope analysis with continuous flow mass spectroscopy.

Following this, the dolomite and calcite used were analyses at different temperatures and after undergoing temperature changes to see if they gave a reliable signature once undergoing the planned separation technique. Next, synthetic mixtures of the Dolomite and a Calcite standard were prepared and these mixed samples then underwent the phosphoric acid method at 25 °C and then either at 50 or 75 °C. The results of this experiment were unexpected as the separation of both minerals did not result in the anticipated chemical signatures but rather composite responses from the two minerals and the effects of fractionation. The project, however, experienced issues within the laboratory which has resulted in incomplete data, not being able to complete enough experiments in both stages of the project, even after an extension to the project the results are still not satisfactory in developing a process within SIBL to separate out the isotopic signatures of two carbonates.

The Structural Setting, Age and Significance of Sulphide Mineralisation in the North Pennine Ore Field

Le Cornu, C. 10:30

The North Pennine Ore Field (NPOF) is located at the centre of the Alston block, a positive structural feature within the North Pennines, and has a diameter of about 30 km. Mineralisation in the ore field includes lead, iron and copper sulphides, the formation of which is highly debated, with current hypothesis suggesting it to be the result of hydrothermal circulation related to the Weardale granite. Previous work has determined that there are 3 main orientations of mineralization, which are thought to be structurally controlled; WNW-ESE, NE-SW and NNW-SSE, however, limited detailed work has been done on this relationship.

This report focuses on 7 localities spread across the NPOF, which have been selected to cover the main orientations and mineral phases. At each locality, the structural and relative age relationship between the deformation events and the mineralisation have been studied via a series of detailed field and microstructural observations, as well as geochemical analysis. This report has concluded that there are 3 main important characteristics of the mineralisation: 1) Sulphide and quartz mineralisation occurred simultaneously via a series of pulsed injections. 2) Mineralisation and fault slip occurred simultaneously, mostly as transtensional movement. 3) Re-Os isotopes from sulphides indicate a mantle source for these fluids, most probably associated with the intrusion of the Whin Sill Complex.

Current hypothesis suggests that the faulting, which controls the mineralisation, was created by a series of E-W compressional events, however, with the use of fault kinematic analysis; this report attributes these structures to a single phase of partitioned dextral transtension during late Carboniferous to early Permian times, most likely created during a time of N-S lithospheric extension.

The nature and significance of fault gouge development in Basaltic Lava flow sequences

Wetherell, G.F. 10:45

The Faroe Islands are formations of basalt emplaced from 59-56ma, related to the North Atlantic igneous province. It consists of 6 formations with faults cutting the Paleocene lava sequences of the Faroe Shetland basin (FSB). Little work has been done on the internal characteristics of shallow, crustal basaltic brittle faults as they develop, and the present research along with previous studies aim to characterise the so far poorly understood geological features of the faults of the Faroes, with specific focus on the development of the fault gouges that form.

The samples of this study come from faults that cut the Beinisvord and Malinstindur formations, both of which consist of thick basalt lavas with minor intercalated volcaniclastic horizons; they represent event 1 and 2 extensional deformations, and event 3 reactivation structures that formed during compression of the FSB at a later stage. This study aims to gain a more in depth, detailed understanding of how fault gouges form in basalts, and what happens to the host rocks during faulting, from a microscopic perspective.

Mode I extensional fractures and clay hydrofractures with oxidation the of surrounding wall rock characterise smaller displacement faults, indicating low strain, and low permeability as no through going fractures exist yet. As displacement increases, clay precipitation, zeolite veining and oxidation become more pervasive, and are cross cut by calcite mineralisation, indicating a higher fluid influx. Veins form interconnecting meshes when metre scale displacement is reached, and this will cause the permeability to increase. Cataclasis onset occurs at decametre scale, and cataclastic foliation areas are caused by alignement of shear fractures. Areas of cataclastic flow facilitate movement on the fault, by grain boundary sliding and rolling. By hectometre displacment, the matrix of the cataclasite areas transitions to a phyllosilicate gouge, and relict basalt is completely broken down and replaced by zeolite.

The development of smectitic and illitic phyllosilicates interpreted from SEM analysis hold implications for the seismicity of the highest scale fault of the study. Phyllosilicates are often invoked as a weakening mechanism for faults, but both the low ratio of phyllosilicates to coarser, relict material and presence of crack seal veins suggests strengthening of the fault.

Dynamic weakening processes of quartz and olivine gouges at seismic slip rates.

Kawanzaruwa, T.M. 11:15

To understand the deformation mechanisms involved during the dynamic weakening of faults, 15 high velocity ($v \approx 1ms^{-1}$), frictional experiments have been performed on quartz, olivine, gabbro and granite gouges (90-150 µm), at room temperature and humidity, at a constant normal stress (15MPa) and at slip rates of $0.01\text{-}1.3ms^{-1}$.

Experiments were arrested at three stages during the evolution of friction; stage 1) the acceleration stage; stage 2) peak friction (0.6-0.85µ); and stage 3) after weakening (0.2-0.4µ). The integration of microstructural analyses and experimental data has resulted in detailed insights on the development of deformation mechanisms during the evolution of friction.

In the case of quartz, low temperature (~199°C), brittle fracturing and cataclasis are the dominant mechanisms in the early stages of the frictional cycle (stage 1). Subsequent thermally activated (350°C) grain boundary migration (GBM) recrystallisation in stage 2 instigates the super plastic behavior (799°C) that leads to the dynamic weakening of quartz.

Olivine displays cataclastic fabrics during the early stages of the frictional cycle (stage 1). In depth microstructural analyses and flow stress measurements (45MPa) show that during stage 2 and 3, experimental specimens exhibit grain sensitive grain boundary sliding (GBS) with diffusion creep. Which leads to the superplastic flow that causes the dynamic weakening of friction.

Granite microstructures show that the initiation of plastic behavior occurs in stage 2, at low temperatures (760°C). However, increasing temperatures (1040-2000°C) trigger the occurrence of thermally activated superplastic flow, which coincides, with the weakening of friction. In contrast, low temperature cataclasis is observed in gabbro during stage 1 and 2; however, stage 2 also demonstrates thermally stimulated (1100°C) GBS dominated diffusion creep. The growth of a thermally activated (1210°C) vesicular molten zone occurs in stage 3 gabbro.

Implications of Seismic, GPS and Drainage evidence on the evaluation of active tectonics within Eastern Tibet and South-East China

Barraclough, R.B. 11:30

Variation of tectonic deformation across the Tibetan plateau is difficult to account for. Eastern Tibet, the focus of this study, is no exception. This study is concerned with the changing form of deformation across eastern Tibet. Rising from 500 m to ~ 3500 m over 50 km across the Longmenshan Mountains, the plateau then steadily raises to ~ 5500 m, through various deformation regions. Thrust faulting becomes enigmatically scarce at elevations between 3000-4000 m, whereas normal faulting becomes more abundant above 4000 m, with strike-slip present at all settings. The introduction of GPS, Shuttle Radar Topography Mission (SRTM) data and improved seismic recording and availability, provides evidence to challenge and re-evaluate the active tectonics of eastern Tibet. The relationship between elevation and deformation type, and a solution for the current active deformation over the central plateau are both explored. Active deformation extends east-west and shortens north-south at high elevations, via propagating north-south striking normal faults, extruding internal drainage into older externally drained areas. This is accounted for when assessing the absence of thrust faulting at elevations above 4000 m.

An Investigation into Drainage Reversal along the Yarlung-Tsangpo Suture in Southern Tibet

Martin, J.M. 11:45

The Yarlung-Tsangpo suture, located in Southern Tibet, is one of the only examples in the world of drainage reversal taking place as a result of tectonic movement. This report investigates the current drainage configuration of the Yarlung-Tsangpo suture in order to determine how this drainage reversal took place. Two hypotheses are tested; (1) regional tilting of the Tibetan Plateau drove drainage reversal by process of river capture; (2) the propagation of the Karakoram Fault in Southwest Tibet after 13 Ma acted as a trigger for drainage reversal along the rest of the suture.

Results from river profiling, and interpretations made from high definition satellite and topographic imagery, suggest that initial drainage capture took place in Eastern Tibet. Headward erosion of the Brahmaputra River, possibly driven by location of the ITCZ over the Himalayas during the Early Miocene, captured eastern drainage from the Yarlung-Tsangpo suture. Driven by regional tilting of Tibet towards the east, the Brahmaputra continued to capture drainage along the Yarlung-Tsangpo suture by headward erosion, resulting in a reversal in drainage direction. This whole process took place over a period of > 8 Ma.

The Gurla Mandhata detachment system, located in Southwest Tibet, was uplifted as a result of southern propagation by the Karakoram Fault after 13 Ma. This did not act as a trigger for drainage reversal, but instead protected west-flowing drainage further along the suture from becoming captured by the Brahmaputra.

A secondary observation made by this report is that drainage gradient along the Yarlung-Tsangpo river system acts as a good proxy for deformation taking place in Southern Tibet. Interactions between normal faults and the Yarlung-Tsangpo River have led to the suggestion that east-west extension throughout Southern Tibet is not evenly distributed between N-S trending normal faulting.

Developing methodology for use in modelling secondary petroleum migration in a mud-rich MTD using seal quality cube data.

Bowers, J.W. 12:00

Petroleum migration in a heterogeneous mud-rich environment can be modelled effectively using seismic inputs and modelling software. Previous research focussed on 2D seismic sections from MTDs in the West African continental margin. The existing knowledge is here expanded by the addition of 3D seismic reflection profiles and a new way to process them; seal quality cubes. This is a new method of handling raw seismic data to give an abstract series of values that can be used to define lithological units and assign threshold pressures to FIDs within a model.

Modelling was conducted using Permedia Suite, this compared the new seal quality values to more traditional inputs used in modelling of petroleum systems; raw seismic and mud percentage data. A detailed and robust methodology is developed and outlined and this is applied to all three datasets. Petroleum migration pathways are comparable across all methods of data processing and this resulted in quantitative analysis that indicated that seal quality values produced similar models and results to the traditional methods and provided more sensitivity than simply using raw seismic data. In addition the pathways observed were similar to those seen in the mud percentage data, but highlighted different areas of poor quality seals.

It is hoped that future research will focus on the possibility of developing the methodologies outlined here for use as an economically viable way of assessing risk of leakage in potential CO2

storage systems within exhausted petroleum fields. Additionally it was suggested that constraining the anisotropic nature of lithological units could lead to more realistic modelling in the future, as will developing new approaches to grouping datasets into rock types as this is currently the main source of potential error.

Molecular simulations of low salinity enhanced oil recovery

Kendaru, K. 12:15

The potential to add reserves to the UK's oil portfolio through low salinity brine enhanced oil recovery (EOR) is huge. The prize of between 3 billion and 8 billion barrels of additional production remains unclaimed and no company has yet to make a clear commitment to pursue this opportunity. EOR methods change the properties of the oil to increase production by increasing its flow through the reservoir.

Clay minerals are ubiquitous in oil and gas exploration and play an important role in characterising the physical and chemical properties of reservoirs. Clays have a unique feature that they are formed of stacks of negatively charged two-dimensional alluminosilicate sheets; these physical and chemical properties of clays make oil production more complex in reservoirs.

Low salinity was first noted as a means of enhancing oil recovery in core flooding experiments, however low salinity EOR has not been simulated using computational methods. Molecular dynamics simulation was used to investigate the atomic and molecular interactions between Na^+ montmorillonite and solutions of varying ionic strength at the clay- solution interface.

These studies show the formation of a Stern and a second cation layer at the clay-solution interface at an atomistic level. The second Na^+ layer is formed to balance negative Cl^- anions concentrated at the centre of the pore space and increases in density with increased ionic strength of the system. The second Na^+ layer may be a barrier preventing water and decane trapped between the Stern and outer Na^+ layer from migrating into the pore space during high salinity water injection during EOR.

Atomistic Simulation Of Organic-Clay Interfaces For Low-Salinity Enhanced Oil Recovery

Tasker, J.J. 12:30

The mechanism through which low salinity enhanced oil recovery works is currently unknown. Experimental methods can be used to begin to quantify the effects but the use of these techniques is limited to laboratory (~nm) and outcrop scales (m). Clay minerals are known to play a role in controlling the ideal conditions for low-salinity enhanced oil recovery. Molecular dynamics can be used to study clays on an atomistic (sub-Å) scale.

Clay minerals are a broad, highly variable class of crystalline aluminosilicates. Some clays swell with the addition of water, among these swelling clays is montmorillonite, a 2:1 clay mineral with a permanent surface charge which can be neutralised by a range of positively charged counterions.

The focus of this investigation is the swelling behaviour of hydrated sodium-neutralised montmorillonite. The ClayFF forcefield is used with the Gromacs molecular dynamics software package to generate a series of simulations. These simulations compare the swelling behaviour of sodium montmorillonite with freshwater and three different concentrations of brine – 15ppt, 35ppt and 50ppt.

The models are then altered and coupled with the TraPPE forcefield in order to investigate the effects of organic material with hydrated sodium montmorillonite. Dodecane is added to the system to serve as an analogue of organic material.

The model simulations are compared to previous work, both experimental and computational. It is shown that it is energetically favourable for montmorillonite to swell with the addition of water, the formation of water monolayers and bilayers is seen. It is shown that the concentration of the interlayer brine does not control the swelling behaviour of clays. Limited data then suggests that electrostatic double layer effects are responsible for the increased well productivity with the addition of low salinity fluid.

The 3-Dimensional Architecture of the Rotliegend Sands of County Durham

Scott, J. **12:45**

The Lower Permian Rotliegend Sandstones is a major gas and minor oil reservoir across Europe. It is also a favoured interval for long-term geostorage of carbon dioxide. Indeed CO2 injection is already occurring in one depleted Dutch gas field within the Rotliegend. For optimal development of petroleum reserves, as effective CO2 storage, it is highly depend upon being able to effectively exploit the connected pore space within a reservoir unit. The heterogeneity, anisotropy and architecture of any aeolian deposit is complex, which means that effective exploration and understanding is not always possible. Thus, oil can remain unswept and CO2 migrate where it is not wanted. The key to better reservoir management lies in better reservoir description and understanding of the rock geometry. We are fortunate in County Durham and surrounding areas that we have man made exposures of the Rotliegend sandstone in working and abandoned sandpits. LiDAR scanning of these exposures will enable the construction of a virtual model of the Rotliegend sands, interdune and associated lithologies. Such data and interpretations would then form the precursor for a geological and reservoir model. The model produced uses first order bounding surfaces showing the lateral relationship between surfaces of the two subfacies: duneslip and interdunes, and has now provided the framework for further studies.

Evaluation of Triassic Rot Halite in the Cleveland Basin: Thickness, Lateral Extent and Effect on Stratigraphy.

Kirkley, S. 14:30

Data collected for Potash exploration in North Yorkshire was utilised to generate a model of the Triassic Röt Halite unit. As only one borehole cored this section, most of the data interpreted came from wireline logs. Over 80 boreholes were analysed across North Yorkshire and offshore.

Hypothesised to be deforming in a ductile manner, similar to the Zechstein evaporites below, the Röt Halite was found to show no diapirism. The unit deforms in the same manner as the surrounding units, whilst faults transect the entire unit with no sign of the Röt Halite acting as a detachment layer.

The inversion of the Cleveland Basin means that the current basin depth is not the deepest it has been and the upper layers have been removed. Therefore the pressure exhibited by the overburden is not sufficient to induce passive diapirism and the indurated nature of the overburden means active diapirism cannot breech the overburden. The compressional regime that inverted the basin from the late Cretaceous was accommodated by existing faults generated during rifting. These faults were reactivated inversely and propagated upwards into the post rift sediments. This required less force than initiating a new fault system and therefore resulted in less compressional force acting on the post rift sediments.

This indicates that the Röt Halite, a post rift sediment is likely to deform in a brittle manner and have little effect on the surrounding strata; the ductile deformation ability of Halite is not exhibited here.

Understanding the behaviour and distribution of the Röt Halite will aid understanding of the world's purest and thickest Polyhalite deposit, also in the region, as well as evaporites acting as cap rocks in hydrocarbon plays, regionally and globally. This understanding also promotes thought into brittle deformation, within evaporite units, and the effect faults have on them.

A Multichannel Seismic Investigation into the Upper Crustal Structure of the Costa Rica Rift

Eason, J.D. 14:45

Multichannel Seismic Reflection data collected in 1994 have been processed using dip-moveout correction, pre-stack time migration and Butterworth filters to image the upper crustal structure of the Costa Rica Rift. The seismic lines studied are perpendicular to the ridge axis with a north-south orientation and span a distance of ~215 km. The seismic images reveal an intermittent low frequency mid-crustal reflector interpreted as the layer 2A/2B boundary and a weak reflector beneath the axial valley believed to be the axial magma chamber (AMC). The layer 2A/2B boundary is found at a two-way travel time (TWTT) between 0.15 s and 0.68 s (~225-1012.5 m) and a mean of 0.3 s (560 m ± 100 m) below the basement. The decrease in thickness near the southern end of the profile is argued to represent a transition in the nature of the layer 2A/2B boundary from a lithological boundary to an alteration front. The AMC is imaged at a TWTT of 1.2 s below the seafloor and has a width of 375 m. The distance to the top of the magma chamber is estimated to be 2.9 ± 0.4 km. Uniform layers of sediment overlie the rough basement caused by frequent faulting. Pelagic sediment is first imaged 20 km from the ridge axis and forms a continuous layer approximately 30 km from the axis. The maximum thickness of the sediment is 297.5 ± 30 m and it was deposited at an average rate of 44 m/ma. The faults in the area are typically normal faults parallel to the ridge axis where the distance between adjacent faults is 2.3 km and the majority (75%) are inward facing. The maximum displacement of the sediment is 37.5 m and evidence suggests the faults were formed close to the ridge axis and a large proportion of these faults are now inactive.

3D Seismic analysis of Gas hydrates and their associated "feathered edge": offshore Mauritania

Schofield, K. 15:00

Gas hydrate research is gaining increasing amounts of attention from the present day scientific community. Hydrates are clathrate compounds containing trapped methane within a lattice of ice and can be identified on seismic sections by the identification of a BSR, caused by the acoustic impedance contrast between the hydrate and free gas zone below. Hydrates are thought to be a possible future unconventional energy resource, a good tracker as to continental margin evolution, a component in shallow marine geohazards and importantly a fundamental factor in controlling global climate change.

In this study the nature of the feathered edge, where the BSR intersects with the seabed, is assessed using exceptional 3D seismic data from offshore Mauritania, NW Africa.

Amplitude maps of the BSR and seismic cross-sections both display high and low amplitude areas, with higher amplitude zones implying gas presence. The main accumulations are located at the point where the BSR intersects with the surface, although in isolated locations only defined by the supply of gas. Although mainly through gas chimneys, the presence of migration pathways are vital in expressing the location of these high amplitudes. Pockmarks, phase reversals and high amplitude spots on the seabed indicate localised gas escape, although not along the continual BSR-seabed intersection. The presence of a feathered edge in regards to hydrates remains inconclusive however there is subtle evidence disproving this phenomenon. 'Palaeo-chimneys' can be seen terminating at a point where a BSR is absent yet along a horizon

the base of the hydrates would be expected. The points where methane escapes from the subsurface are discontinuous and can be regarded as feathered. Furthermore, due to methane supply being greater than escape at these points economic implications for gas exploitation could present multiple possibilities.

Nature and significance of chimney structures and associated teardrop formations of 3D seismic data from gas hydrate sediments offshore Mauritania

Gill, C. 15:15

3D seismic data taken from offshore Mauritania displays excellent examples of chimneys - hydraulic fracture systems - in the sediments below the gas hydrate body. Gas hydrates are methane rich clathrates in a frozen ice lattice that occur in the gas hydrate stability zone, the base of which is marked by the bottom simulating reflector (BSR), a phase boundary reflector that indicates the transition between gas hydrate and free gas. The chimneys deliver gas to the BSR, where fracture propagation stops and the gas is diverted by the impermeable gas hydrate above, causing it to travel up-dip, creating teardrop migration patterns of both high amplitude and low amplitude reflections (free gas and gas hydrate respectively). The free gas migrates around old gas hydrate teardrops, which have been incorporated into the frozen lattice through hydrate recycling. Anomalous high amplitude lateral reflections extending horizontally from the chimneys at levels significantly below the BSR suggest potential for free gas migration due to variations in lithology allowing pressurised gas escape from the propagating fractures. At other depths there are signs of similar trending gas migration with low amplitude reflections, suggesting traces of old BSR teardrop migration patterns that have been diagenetically altered, most likely to siderite and dolomite. However, seismic maps of lower levels show either no gas or non-trending gas accumulations.

Using Bayesian Probabilities to Estimate Seismic Velocities in order to better constrain Pre-drill Prediction of Overpressure.

Dukes, D.R. 15:30

Overpressure is defined as a fluid pressure within rocks which is higher than the hydrostatic pressure. It is crucial to fully understand if, and to what extent, an area is overpressured before drilling. This can be achieved using seismic velocities; however, these velocities often lack the resolution necessary to detect the small velocity inversions associated with overpressure. Here, Bayesian probability methods are used to attempt to improve the resolution to a sufficient level. Two seismic lines from Kupe, in the Taranaki Basin, are analysed using Bayesian probabilities. These are then calibrated with two wireline borehole logs to evaluate the accuracy of the data. The results of this calibration shows that Bayesian probability methods have the potential to produce velocity models capable of detecting the velocity inversions associated with overpressure, but further work needs to be completed; specifically though further iterations of processing and improved error analysis.

Overpressure in the Manaia Graben, Taranaki Basin, New Zealand.

Oldham, C. 15:50

The Taranaki basin, located off the west coast of New Zealand is an onshore and offshore Cretaceous Tertiary basin initiated as a succession of fault bounded rift Grabens. Structurally, the basin can be separated into two very distinct regions, the western stable belt and the eastern mobile belt, where the Manaia Graben is located. Existing geological studies indicate the presence of three pressure zones:

Zone A: a near hydrostatic regime that covers the entire basin to varying depths.

Zone B and Zone C: both overpressured, underlying zone A.

The transition between zone A and B can be easily defined as stratigraphic, whereas the pressure transition between zone B and zone C is difficult to explain. It is possible the boundary is structural due to fault zones laterally confining the area or diagenetic due to temperature. Ambiguity is increased in zone C due to a very small number of well penetrations.

Pressure depth plots are presented using mud drilling weight to show the pressure regime in each well. Gamma logs are used to select the mud rocks, sonic logs of these mudrocks are compared to find the Normal Compaction Trend, which in turn is used to find overpressure by Eaton's method. The Equivalent Depth Method is also completed for comparison. Overpressure is then mapped in the different wells across the Manaia Graben. The Kowhai well is used to illustrate the success of these methods, due to the fact that it has been drilled with extreme care, using correct procedures.

Pore pressure prediction is essential in hydrocarbon exploration, yet a definitive method has yet to be established. It is particularly important in the Taranaki basin, due to limited direct pressure measurements and the regular occurrence of wells being drilled under or overbalanced. Without careful planning, drilling through overpressure can produce kicks and losses or destroy the reservoir integrity.

Calculating the Water Transit-Times for UK Rivers Under Varying Flow Regimes and Conditions

Birchley, H.J. 16:05

The understanding of the importance of water quality in rivers and streams is essential to maintaining the condition of our aquatic environments. We can monitor the quality of rivers at fixed stations regularly or sporadically at other points of interest along the river. The study is proposing a model based approach to predicting the water quality at sites in any catchment; both gauged and ungauged by using the water's transit-time down the length of the river.

This is important because the chemistry of a river is constantly changing as it flows downstream. The rates of change are known through laboratory work, for example river-dwelling microorganisms in the UK have been found to degrade estradiol to estrone with a half-life of 0.2 to 9 days at 20°C[1]. Another example would be the oxidation of organic carbon during fluvial transport. Knowing the transit times it becomes possible to predict the concentration of any component of the river water by applying the rate of change to the travel time.

The method used in this study is to take 15-minute logs of flows at gauging stations along a set of rivers and isolate the true flood events, through a series of logic tests. From this a time for each event was obtained and from the flow data we can calculate each value's exceedance flow. For each section of the river a graph is plotted for exceedance against transit time, showing the range of travel times for each flow regime in that section of the river. This means that it is possible to calculate with a reasonable range of accuracy the transit time to any point in that river section between the two stations.

Variation in transit-times was much greater during drought events than flood events, giving greater credence to this method during high flows. For the UK this does not affect the usefulness of this study as model simulations suggests that with climate change the average flow volumes of UK rivers will increase. This is supported by a study of historical data, which shows a positive trend towards higher flows in the UK.

A phosphorus budget of Great Britain's terrestrial biosphere 1990-2010

Denison-Smith, R.L. 16:20

This study estimates the overall phosphorus budget of Great Britain from 1990 to 2010, in order to identify whether Great Britain is a net

source or sink of phosphorus, and the major pathways involved. Inputs to the system that are considered here are fertilizer applications, food and feed imports and atmospheric wet deposition. Outputs that are considered are food and feed movements, direct discharge to the sea and river exports. It is found that phosphorus is accumulating within the soil in Great Britain, as fertilizer applications are still larger than all the outputs combined. The rate of phosphorus accumulation in Britain is slowing as fertilizer applications fall year on year. Direct discharge of phosphorus to the sea is also reducing, probably due to increasingly stringent government legislation. No trends were found in river exports over the length of the study as the errors in the method applied here were too large. Atmospheric deposition was found to be stable and small compared with the overall budget. Food and feed was found to change from a net exporter of phosphorus from Great Britain to a net importer of phosphorus. This is thought to be due mainly to the falling wheat and barley exports and increase in meat imports.

Use of Waste Materials for Phosphate Recovery in Water Treatment

Jessett, A.L. 16:35

Eutrophication is becoming one of the most serious threats to the ecology of fresh waters in the UK, and phosphate pollution from both point and diffuse sources is seen to be the main contributing factor. This study aims to assess the ability of waste materials, including ochre from mine water discharge, and water treatment residuals (WTR), a by-product of the water treatment process, for the remediation of phosphate from waste water in an attempt to alleviate this problem.

During this study, batch tests are undertaken in order to assess the adsorption of phosphate onto four waste materials; ochre collected from two different mine water treatment plants, WTR, and heat-treated (calcined) WTR. The data is analysed using the Langmuir equation in order to determine the maximum adsorption capacity of the materials. An effort was made to assess the mineral phases present in the materials with the aim of determining the phases responsible for phosphate adsorption.

Both types of ochre were shown to have similar maximum adsorption capacities of approximately 19mg PO4/g, while the WTR and calcined WTR showed a maximum capacity of 3.0 and 0.2mg PO4/g respectively. Data was provided by Northumbrian Water Ltd (NWL) detailing their current influent and effluent phosphate levels, and their existing phosphate treatment techniques, including costs. This allowed an approximate determination of the cost of using waste ochre compared with the current use of chemical dosing.

This study concludes that ochre provides a cheap and novel alternative to chemical dosing allowing NWL to adhere to the reduced phosphate levels permissible under regulations set by the Water Framework Directive.

Assessing and Quantifying the "Ground Air" Store of Carbon Dioxide Located in the Unsaturated Zone

Bertram, R.A. 16:50

Concentrations of carbon dioxide (CO_2) in the unsaturated zone are greater than 150 times atmospheric levels, implying generation of CO_2 within this zone. CO_2 measured in soil air and epikarst air does not fully quantify the exceptionally high values recorded in subterranean measurements, such as those taken from cave air and in deep boreholes. Air permeating the whole of the unsaturated zone, "ground air", accounts for this discrepancy. It is contained within the unsaturated zone pore spaces, cracks and fractures and is characterised by high concentrations of CO_2.

Understanding the generation, storage and transfer of CO_2 in the unsaturated zone is required for accurate carbon cycle models. Consideration of this CO_2 store has important

implications for understanding climate change on geological timescales. Additionally, consideration of this CO_2 store will improve our understanding of global carbon cycle models.

Laboratory experiments evaluate the production of CO_2 to maximum concentration under varying quantities of organic material. Estimates suggest ground air CO_2 concentrations of 2-7%. Quantities of organic material between 2.5% and 10% in the unsaturated zone are sufficient to account for these high CO_2 concentrations. Field experiments study the unsaturated zone of beach environments to assess variations within the store. Concentrations vary daily due to the tidal cycle and the resulting "piston effect". The piston effect describes the process of varying hydraulic pressure at the water table, which forces compression and displacement of ground air gases in the deep unsaturated zone.

Calculations based on land area, global porosity, depth to water table and ground air CO2 concentrations, estimate the current global ground air store as 51-698 Gigatons of Carbon (GtC). Since the Last Glacial Maximum (LGM), up to 116 GtC transferred from ground air due to rising sea levels inundating the land and thereby producing a long-term piston effect. This rise alone accounts for up to 55% of the increase in atmospheric CO_2 concentrations recorded in ice cores between the LGM and pre-industrial levels. Ground air in the unsaturated zone is a non-negligible store of carbon; consideration of it in climate models is therefore imperative.

Poster Presentations

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MSc Student

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017	**Brodie, M.W.**	Multi-scale assessment of diagenesis within the Bakken Formation, USA.
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019	**Dichiarante, A.M.**	Transpression, transtension and reactivation during basin evolution: a case study from northern Scotland and Orkney
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035	**Stricker, S.**	Porosity preservation in Triassic Skagerrak sandstones: clay coatings versus effective stress
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037	**Underwood, T.**	MD Simulations of Low Salinity EOR
038	**Zhang, J.**	Origin and implications of magmatic enclaves from andesitic lava dome of Mount Lamington volcano, Papua New Guinea
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040	**Agrusta, R.**	The influence of metastable pyroxene on the dynamics of subduction
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043	**Dempsey, E.D.**	A geological explanation for intraplate earthquake clustering complexity: the zeolite-bearing fault/fracture networks in the Adamello Massif (Southern Italian Alps)
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049	**Harper, D.A.T.**	Biodiversity, biogeography and phylogeography of Ordovician rhynchonelliform Brachiopoda
050	**Holdsworth, R.E.**	Constraining the ages of polyphase fault reactivation of the Gavilgarh-Tan Shear Zone, central India using laserprobe40Ar-39Ar dating of pseudotachylytes
051	**Imber, J.**	Analysis of fault propagation folds using elastic dislocation models
052	**Macpherson, C.G.**	Crustal growth processes recorded by Gunung Guntur volcano, Java, Indonesia
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054	**Oughton, R.**	Bayesian networks for pore-pressure prediction
055	**van Hunnen, J.**	The role of small-scale convection on the formation of volcanic passive margins
056	**Worrall, F.**	Understanding multiple element budgets of peatlands – a role for simple stoichiometry?

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The Structure and tectonic history of the Scremerston region, Northumberland

Killingback, Z.

Level 2 Undergraduate 001

Scremerston, on the Northumberland coastline, shows varying degrees of deformation with an apparent general trend of increasing strain towards the north. This strain was found to be heterogeneous. Structural data and observations made during a one day field trip, along with analysis of aerial photography, have been synthesised to ascertain the nature and causes of the stress field resulting in the observed strain. Analysis of structures including faults, folds and joint sets, to determine the principal stress axes showed the stress field to be highly variable throughout the locality, both spatially and temporally. A west verging trend to the folds in the western section of the locality and an east trending vergence further east is suggestive of a larger-scale syncline, which is inferred to plunge gently north. However, data were insufficient to deduce the symmetry of this syncline. A high degree of mechanical anisotropy between different lithological layers, along with consistent bed thickness and small scale faulting, is suggestive of a flexural slip mechanism of folding. On this scale, the variations in strain are unlikely to result from changes in intensity of stress. Significant difference in the mechanical properties of the different lithologies is a more plausible cause. The deformation is thought to result from an east-west compressional event, the inferred setting being the foreland region of an orogenic belt. A rotation of the tectonic plates during collision, or differences in strength of the basement may be the cause of the change in orientation of the stress field.

The Structure and Tectonic History of the Scremerston Region, Northumberland

Scott, E.M.

Level 2 Undergraduate 002

The Lower Carboniferous age rocks exposed at Scremerston, Northumberland, display many examples of structures indicative of both brittle and ductile deformation. These structures were analysed in an attempt to determine the tectonic history of the region. The study region was divided into 3 areas, from south to north, A, B and C; divisions were based mainly on the different deformation products observed in each area. In area A evidence of extension was present in the form of conjugate joints cutting through planar beds dipping shallowly E. The presence of anti-riedel fractures intersecting a thrust fault in area B suggested the deformation was non-coaxial. Structures associated with non-coaxial shear were also found in area C; the main ones being many meso-scale asymmetric folds, whose attitude and tightness changed from S to N along hinge lines plunging N/NE. These observations combined with data collected from the folds and study of the shape of the outcrops on Google Earth, lead to the hypothesis that the type of strain changed across the region, from compression in the SW to extension in the NE. To accommodate for this variation in strain, an aspect of sinistral shear acted in the NW while dextral shear dominated in the SE. A block diagram summarises the interpreted structures of Scremerston, showing how area A may represent an almost recumbent anticline, whose inclination changes along an axial trace that curves from N-S to E-W. By contrast areas B & C form a large gentle anticline, plunging gently to the N/NE.

Evidence for Heterogeneous Strain and Strain Partitioning: A Structural Analysis of Scremerston

Wimpenny, S.E.

Level 2 Undergraduate 003

Scremerston is located in Northumberland, 5 miles south of Berwick-Upon-Tweed. This locality marks a zone of intense heterogeneous strain with a range of brittle and ductile deformation structures in interbedded Carboniferous limestones, sandstones, coals and shales. We quantitatively and qualitatively assess the deformation structures revealing heterogeneous strain in the form of variable angular shear (γ=0.17 to 1.73), bed dip, linear percentage shortening (s=25 to 67%), joint patterns, fold geometry and fold mechanisms. This can be attributed to a complex multi-cyclic tectonic history involving distinct periods of E-W pure and simple shear deformation followed by N-S compression inducing E-W sub-parallel thrust faulting. On a more localized scale, orthogonal patterns of mode II fractures oriented N-S and E-W in gently dipping limestones at the southern locality appear juxtaposed against a series of tight, asymmetrical folds containing variable joint orientations and relatively high bed dip (30-50^{o}) further north. Therefore, we suggest the previous regional tectonic regime (inverted basin) requires updating to include these extremely localized heterogeneities. One proposed model is that of partitioned transtension in which a regional extension can produce wrench dominated terranes and, hence, could replicate the complex localized patterns of compressional and extensional strain seen at Scremerston

Geology of Tioga Pass, Eastern Sierra Nevada, CA, USA

Ardill, K. and Gaffing, M.

Level 3 Undergraduates 004

The Saddlebag Lake pendant is a well-exposed slab of host rock within a region dominated by the intrusion of granitic plutons. It allows a rare opportunity to investigate the history of this area in the Early Mesozoic, and to examine the processes leading to the formation of the modern day Sierra Nevada mountain range.

1:10,000 field mapping highlights aims to reconstruct a tectonic model, through interpretation of the geology at a local scale. Units are metamorphosed in the hornfels-amphibolite facies, through both contact and regional metamorphic events. A notable feature of this area includes a Triassic caldera fill sequence preserved at Tioga Pass, and potentially intrusive feeder zones. Additionally, a complex structural history of transpression and the exhumation of a broad ductile shear zone come to light in interpretation of field data. Extensive radiometric dating of igneous and detrital zircons adds further context to field observations.

Paleozoic marine sediments were deposited on the continental margin of W. North America. Intensive volcanism during the Early Mesozoic erupted tuffs and lava flows of felsic to intermediate composition in episodic phases. Island arc volcanism was driven by eastward-dipping subduction, prior to pluton emplacement.

The Geology of Berwick-upon-Tweed and Scremerston, Northumberland

Arney, T.A.J.

Level 3 Undergraduate 005

Fieldwork The geology of the far north of the Northumberland coast is mapped and studied in the field to compile a complete geological history. Yoredale cyclothems typical of the Lower Carboniferous of northern Britain are recognised, caused by a periodically abandoned large Mississippi-type fluvially-dominated delta prograding over a carbonate ramp in a subsiding regional setting. Two periods of tectonic activity account for E-W shortening structures and NE-SW extensional structures, forming the complex

and spectacular folding and faulting at Bucket Rocks and Saltpan Rocks.

Ichthyosaurs: The Reptilian Dolphins of the Mesozoic

Edey, A., Landon, E., and Gale, W.

Level 3 undergraduates 006

Ichthyosaurs were Mesozoic marine reptiles. These predators of the ocean are thought to have been streamlined and fast, with modern analogues of tuna and lamnid sharks. This report empirically analyses an ichthyosaur specimen of Jurassic age from the Yorkshire coast of England to determine its feeding behaviour. Body ratios and fin comparison lead to the genus classification of *Temnodontosaurus*. Calculating its swimming speed should allow its feeding behaviour to be determined. There are assumptions involved in using Massare's equation, and potential errors associated with it. The maximum sustained swimming speed was calculated as 10.5 m/s. This was based on a high metabolic constant of 50 as seen in leatherback turtles, a metabolic constant that lies between most reptiles and the lower end of mammals. The high sustained swimming speed calculated indicates that the ichthyosaur was an active forager, which continuously cruised the ocean in search of prey, as opposed to a sit-and-wait ambush predator.

Investigating ocean structure over the Wyville-Thomson Ridge and temperature inversion methods using seismic oceanography

Gregory, E.P.M.

Level 3 Undergraduate 007

Seismic oceanography uses standard seismic reflection processing techniques to create images of ocean finestructure. This enables oceanographic analysis over hundreds of kilometres with fine lateral resolution, an important advance from standard ocean monitoring techniques, and also allows inversion to temperature and salinity values when combined with concurrent measurements. Reflection seismic data over the Wyville-Thomson Ridge, south of the Faroe Islands, is processed and the resultant image shows the presence of warm North Atlantic Water overlying cold Norwegian Sea Deep Water with turbulent events seen along the interface, indicating substantial mixing in the region. This turbulence possibly indicates the presence of a mesoscale eddy and an arrested lee wave structure just north of the ridge. Inversion methods are developed to invert this data back to temperature with an absence of concurrent measurements. This method can give a range of results, from realistic (±1.4 °C from expected temperatures), through to very anomalous (±6.9 °C), and more work must be done to create a more stable and accurate method capable of inverting whole seismic lines to a reliable and high-resolution profile of temperature and salinity.

Estimating internal wave spectra and turbulent dissipation using seismic oceanography

Kosky, J.M.

Level 3 Undergraduate 008

A seismic reflection profile of the Faroe–Shetland Channel reveals a region of reflectivity dipping from c. 300–500 m depth SW–NE, interpreted as representing the boundary between warmer, northeast–going Arctic Mediterranean inflow waters overlying cooler, southwest–going outflow waters. Automatic tracking of horizons within this zone of reflectivity yields horizontal wavenumber spectra which support the notion of internal waves of wavelength 0.5–3 km travelling a significant distance along the channel, as well as evidence of smaller wavelength turbulence which may help to explain (and constrain temporal variations of) "turbulent patches" observed by Hosegood et al. (2005). It is also shown that seismic section signal to noise ratio

(SNR) has a significant effect on the slope of produced spectra and, thus, subsequent interpretations of such spectra. As a result, it is suggested that future work should focus on providing a well constrained threshold SNR value for seismic reflection profiles suitable for the production of reliable horizontal wavenumber spectra.

Composition and Treatment of flowback Water from Hydraulic Fracturing, Lancashire.

Barraclough, R.V., Birchley, H.J., Kendaru, K., and Moore, G.P.L.

Level 4 Undergraduates 009

Hydraulic Fracturing has the potential to boost the UK energy market with the BGS estimating the Bowland Basin alone holds 1300 trillion cubic feet of gas. A lot of concern has been raised with regards to the risks to local people and the environment, of which there has been a lot of focus on the impacts of the fracturing fluids pumped into the well and the flowback fluids that are brought back to the surface. The composition of fracturing fluid from Preese Hall-1 is described, including the chemicals that were used and that were given permission to be used, by the Environment Agency.

The key pollutants in the flowback fluid have been identified to be NORM, iron, lead and Nitrogen. It was found that the levels in flowback water were consistently above EU regulations for drinking water. The environmental and health impacts of these key concerns are discussed and the water quality has been compared to that of water in the aquifers as well as the local tap water which is used for the fracturing fluid. Finally options for treating the fracturing fluid so it is safe to be released into the waterways have been explored discussing the potential of using a coagulating agent or reverse osmosis to remove the contaminants.

Calculating the Water Transit-Times for UK Rivers Under Varying Flow Regimes and Conditions

Birchley, H.J.

Level 4 Undergraduate 010

The understanding of the importance of water quality in rivers and streams is essential to maintaining the condition of our aquatic environments. We can monitor the quality of rivers at fixed stations regularly or sporadically at other points of interest along the river. The study is proposing a model based approach to predicting the water quality at sites in any catchment; both gauged and ungauged by using the water's transit-time down the length of the river.

This is important because the chemistry of a river is constantly changing as it flows downstream. The rates of change are known through laboratory work, for example river-dwelling microorganisms in the UK have been found to degrade estradiol to estrone with a half-life of 0.2 to 9 days at 20°C[1]. Another example would be the oxidation of organic carbon during fluvial transport. Knowing the transit times it becomes possible to predict the concentration of any component of the river water by applying the rate of change to the travel time.

The method used in this study is to take 15-minute logs of flows at gauging stations along a set of rivers and isolate the true flood events, through a series of logic tests. From this a time for each event was obtained and from the flow data we can calculate each value's exceedance flow. For each section of the river a graph is plotted for exceedance against transit time, showing the range of travel times for each flow regime in that section of the river. This means that it is possible to calculate with a reasonable range of accuracy the transit time to any point in that river section between the two stations.

Variation in transit-times was much greater during drought events than flood events, giving

greater credence to this method during high flows. For the UK this does not affect the usefulness of this study as model simulations suggests that with climate change the average flow volumes of UK rivers will increase. This is supported by a study of historical data, which shows a positive trend towards higher flows in the UK.

Does hydraulic fracturing cause contamination of aquifers with methane?

Kendaru, K.

Level 4 Undergraduate 011

Studies in the USA have shown that high levels of methane have been recorded within areas of active hydraulic fracturing. Arguments for suggest methane has migrated through formations, through induced fractures, leakage through gas wells and by well failure. Arguments against indicate the insufficient height achieved by induced faults to create a pathway from the source to aquifer. The source of the methane is disputed, as methane naturally migrates through formation over geological periods and can occur at much shallowed depths.

Fracking Hazards, Lancashire

Kendaru, K., Moore, G., Birchley, B., andBarraclough, R.

Level 4 Undergraduates 012

Hydraulic fracturing, or "fracking" is a contentious issue in the Fylde area, Lancashire. Fracking hazards discussed are existing faults, earthquakes and flow through the formation. Permeability of the formations above the Bowland Shale suggest that there are very few channels of migration for fracking fluids and natural gas and contamination of aquifers is very unlikely. The 3D model shows that the location of the well drilled at Preese Hall has a deeper depth to the top of the Bowland Shale, creating a thicker barrier to prevent surface contamination.

Rhenium and Osmium in Fucus vesiculosus: Active Uptake or Accident

Gómez, B.R.

MSc Student 013

The Rhenium (Re) and osmium (Os) are used in source rock geochronology, yet debate exists on how these elements end up within the organic matter present. Owing to Re not having a role in biology a commonly held assumption is often made that this means Re is only incorporated in the biomass when the organism has died, and entered an anoxic, reduced, zone within the water column. However, it has been observed that brown macroalgae concentrates many metals, including Re to many 1000's of times the background level in seawater.

The data thus far is very sparse with some experiments showing that Re is most likely stored inside algal cells than on the external surface.

It has been postulated that Brown algae may inadvertently take Re up, or confuse it for another metal or anion. It has been shown that at low pH Re can associate with some biopolymers, but in seawater, the pH is not low, and Re is being taken up many fold times the background concentration of seawater. Macroalgae have vacuoles at extremely low pH so these could play a role.

An understanding of these geochemical processes is important, as if Re is uptaken actively, it changes the way that may account for the presence of Re and Os in crude oil.

As such, the current project seeks to examine how and where seaweeds store Rhenium and Osmium. The experimental work has three components:

To culture *Fucus vesiculosus* (brown algae), as it is shown to be one of the species that stores more Re and Os, in the presence of different concentrations of Re and Os. By this approach

the limit on uptake of the metals will be established.

To separate the seaweed into different parts (holdfast, stipe, tips…) in order to know where in the seaweed Re and Os are stored.

Finally, to fractionate the seaweed cells (vacuoles, mitochondria, chloroplasts…) to see where in the cells these metals are stored.

In long-term experiments we would also like to see if Re is taken up through competing with other ions or as co-ions.

MiST – Microalgae in Sewage Treatment

Mahony, J.

MSc Student 014

High concentrations of nitrogen and phosphorus in waste are problematic for sewage treatment companies. Releasing high levels of nitrogen and phosphorus into the environment can cause issues such as eutrophication and is thus regulated by the EU Waterways Directive. However nutrients are expensive to remove from wastewater. Northumbrian Water Ltd. (NWL) is interested in growing microalgae on final stage anaerobic digestate liquor (ADL) as a method of nutrient removal. It has the potential to remove nutrients in an environmentally sustainable manner, as well as producing a valuable by-product (e.g. the algae could be used as feedstock for further biogas production or as protein for animal feed).

Scenedesmus obliquus was chosen as a suitable microalgal species and cultured in diluted autoclaved, ADL in sterile conditions. Optical densities (OD) were taken to record microalgal growth. Ion chromotography analysis measured nutrient levels. Initial experiments focused on determining how storage and treatment affected ADL nutrient concentrations and whether (OD) measurements were a suitable microalgal growth proxy in a turbid solution. Preliminary growth trials in varying concentrations of ADL showed that increased ADL concentrations inhibited growth of *S. obliquus*. It was also observed that at 10% ADL the microalgae started exponential growth after a 10 day lag. Sub-cultures of this "acclimated microalgae" in varying concentrations of ADL (1%-20%) appeared to show that the microalgae can adapt to certain conditions and thus grow faster (shorter lag time) when re-introduced to these hostile environments than non-adapted cultures. Further pH data is required to confirm this.

Characterization of diagenetically altered mudrocks from offshore mid Norway (Cretaceous)

András, P., Aplin, A., Goulty, N., and Jones, S.

PhD Student 015

Accurate pore pressure prediction is essential for well planning. Direct pore pressure measurements may be available from permeable reservoir formations. In mudrock sequences pore pressures can only be estimated indirectly, by empirical methods from seismic reflection data and wireline log responses.

In low temperature environments pore pressures can be estimated from porosity assuming that porosity loss is entirely mechanical and is driven by vertical effective stress according to Terzaghi's Principle. By establishing relationships between porosity and vertical effective stress for mechanically consolidated mudstones, pore pressure can be estimated from vertical stress (overburden thickness) and measured or log-inferred porosities.

In higher temperature environments, methods based on a porosity-effective stress relationship fail to deliver accurate pressure predictions. This is because in the deeper and hotter parts of basins porosity reduction continues due to chemical rather than mechanical compaction processes, and leads to underestimation of pore pressure. Temperature affects the kinetics and equilibrium of chemical processes; it causes mineral transformations, grain dissolution and

cementation. The porosity-effective stress methods for estimating pore pressure must be used with extreme caution where siliciclastic or biogenic mudstones have been subjected to temperature-related mineralogical changes.

The overall objective of this project is to investigate the link between non-mechanical compaction, the consolidation state of mudrocks and their physical properties as determined by wireline logs. We have selected one suite of samples from the Lower Cretaceous offshore mid-Norway. A set of different methodologies including XRD, SEM, HRXTG, and MICP will be applied to describe the composition, texture and physical properties of mudstone samples. Results will allow us to test the extent to which mineralogical changes lead to porosity loss independent of pore pressure and the extent to which pore pressure signatures are retained by mudstone fabrics.

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Plate rotation during continental collision and its relationship with the exhumation of UHP metamorphic terranes: application to the Norwegian Caledonides.

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PhD Student 016

Lateral variation and asynchronous onset of collision during the convergence of continents can significantly affect the burial and exhumation of subducted continental crust. Here, we use 3D numerical models for continental collision to discuss how deep burial and exhumation of high and ultrahigh pressure metamorphic (HP/UHP) rocks are enhanced by diachronous collision and the resulting rotation of the colliding plates. Rotation during collision locally favours eduction, the inversion of the subduction, and may explain the discontinuous distribution of ultra-high pressure (UHP) terranes along collision zones. For example the terminal (Scandian) collision of Baltica and Laurentia, which formed the Scandinavian Caledonides, resulted in the exhumation of only one large HP/UHP terrane, the Western Gneiss Complex (WGC), near the southern end of the collision zone. Rotation of the subducting Baltica plate during collision may provide an explanation for this distribution. We explore this hypothesis by comparing orthogonal and diachronous collision models and conclude that a diachronous collision can transport continental material up to 60 km deeper, and heat material up to 300 °C hotter, than an orthogonal collision. Our diachronous collision model predicts that subducted continental margin material returns to the surface only in the region where collision initiated.

The diachronous collision model is consistent with petrological and geochonological observations from the Western Gneiss Complex and makes predictions for the general evolution of the Scandinavian Caledonides. We propose the collision between Laurentia and Baltica started at the southern end of the collisional zone, and propagated northward. This asymmetric geometry resulted in the counter clockwise rotation of Baltica with respect to Laurentia, consistent with paleomagnetic data from other studies. Our model may have applications to other orogens with regional UHP terranes, such as the Dabie Shan and Papua New Guinea cases, where block rotation during exhumation has also been recorded.

Multi-scale assessment of diagenesis within the Bakken Formation, USA.

Brodie, M.W.[1], Aplin, A.[1], Gluyas, J.[1], Drenzek, N.[2], and Garcia-Fresca, B.[2]

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PhD Student 017

Famed as being the largest continuous oil accumulation ever assessed by the USGS, the Bakken Formation in the Williston Basin, USA, is a mixed conventional and unconventional oil resource. Until recently, the Bakken was viewed as a marginal resource due to its generally low permeability. However, recent advances in horizontal drilling, coupled to hydraulic fracturing, have led to a boom in production from the Bakken. A key challenge in understanding diagenetic processes in petroleum reservoirs is the effect of scale. For example, how do the micron-scale SEM observations relate to bulk flow properties on the centimetre-metre scale? If the effect of diagenesis on multiple scales is not recognised then this can lead to errors in flow rate predictions and reservoir volume calculations. A key aim of this PhD study is to develop a methodology to systematically assess the extent of diagenesis and the nature of pore systems at multiple scales within the reservoir section of the Bakken Formation. A 1cm3 of each sample is cut with a companion thin-section. The cube of sample is then systematically analysed using the following techniques: hand specimen description, transmitted light thin-section analysis, micro-CT scanning, SEM imaging, FIB-SEM imaging, BET surface area analysis and MICP analysis. The results enable the definition of the pore systems of a suite of recognisable, diagenetically-modified lithofacies which will form the building blocks to construct larger-scale models of reservoir quality, in the context both of fluid storage and fluid flow.

The behaviour and microstructural evolution of clay-bearing carbonate faults during high-velocity friction experiments.

Bullock, R.J., De-Paola, N., and Holdsworth, R.E.

PhD Student 018

Seismogenic faults hosted in carbonate rock sequences frequently contain varying proportions of clay. To assess the effect of clay content on the behaviour of such faults, we performed friction experiments (v = 1.3 m/s; σn = 9 MPa) on gouges containing 50:50, 80:20 and 90:10 ratios of calcite:montmorillonite and calcite:illite-smectite. Experiments were conducted under both dry and wet (water-saturated) conditions.

Dry clay-bearing gouges produce a characteristic slip-weakening curve comprising an initial hardening phase, where friction evolves to a peak value (μp) of 0.62-0.76, followed by a dramatic decrease in frictional strength within the first 0.5 m of slip to a constant steady-state value (μss) of 0.23-0.33. All of the wet clay-bearing gouges show a profoundly different behaviour, with negligible slip-hardening and almost immediate steady-state sliding with μss <<0.2.

The microstructure of the deformed dry gouges is characterized by slip localization within a narrow principal slip zone containing bubbles, consistent with frictional heating and thermal decomposition of calcite. Deformed wet gouges, however, are characterized by distributed deformation, with no evidence for heating.

The very weak behaviour of the wet gouges is attributed to the formation of interconnected networks of wet clays, which have very low frictional strength, following compaction prior to shear. Thus, when slip initiates, it preferentially occurs on the weak, interconnected clay-rich layers; the low friction and lack of slip localization suppress frictional heating. In contrast, dry gouges lack these interconnected weak layers and must undergo cataclasis and slip localization before thermally-activated mechanisms can

induce dynamic-weakening and steady-state sliding.

Transpression, transtension and reactivation during basin evolution: a case study from northern Scotland and Orkney

Dichiarante, A.M.[1], Holdsworth, R.E.[1], McCaffrey, K.J.W.[1], Dempsey, E.D.[1], Selby, D.[1], De Paola, N.[1], Conway, A.[2], Wilson, R.[3], and Ogilvie, S.[4]

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PhD Student 019

The onshore Devonian sedimentary rocks of the Orcadian basin host significant amounts of fracturing, faulting and some localized folding. Most published accounts have assumed Devonian ages for the supposedly extensional faulting in the Orcadian Basin, with some limited inversion and reactivation proposed during the Carboniferous. More recently, however, regional studies, palaeomagnetic dating of fracture fills and structural studies in the adjacent basement rocks suggest that significant amounts of faulting may be related to the development of the contiguous offshore West Orkney Basin (WOB) during the Mesozoic.

New field and microstructural analyses of the structures found within the Devonian cover sequences in Scotland and Orkney reveal 3 main groups of structures based on orientation, kinematics and infill. All are transtensional or transpressional on local to regional scales mainly due to reactivation of pre-existing structures.

We propose that the deformation episodes are related to: i. Devonian sinistral transtension (ENE-WSW extension) related to the Great Glen Fault Zone (GGFZ) in part controlling the formation of the Orcadian basin and proto-WOB (≡ Group 1); ii. Late Carboniferous – Early Permian inversion (local E-W shortening) related to dextral reactivation of the GGF (≡ Group 2 structures); iii. Permo-Triassic rifting (NW-SE extension) which formed both new faults and locally reactivated earlier structures (≡ Group 3).

Mechanical and lithological controls on the development of heterogeneous fault zones: an example from the southern Dead Sea Fault System, Israel

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PhD Student 020

We present here data from exhumed sections of the southern Dead Sea Fault System, Israel, an active continental transform fault that has accumulated 105 km of sinistral displacement since the mid-Miocene. The so-called “fault cores” of these sections are highly heterogeneous and contain material formed by a variety of processes: cataclasites and fault gouges formed by brittle deformation; mechanically entrained shale material from adjacent wall rocks; and authigenic mineral phases resulting from alteration and pressure solution. Through operation of grain-size reduction and diffusive mass transfer processes, we see a bulk change from fault rocks dominated by relatively strong phases displaying no obvious fabric (feldspars, quartz) through to foliated phyllosilicate-rich (chlorite, smectite) fault rocks which likely have much lower frictional strengths. Mechanically entrained shale can also efficiently introduce large volumes of potentially weak material into fault zones. Shale gouges contain microfolds on the centimetre to micron-scales, and preserve evidence of “ductile” deformation at shallow depth and low-T conditions.

We demonstrate here how the heterogeneous nature of mechanically complex fault zones is influenced by both the initial mineralogy of protolith rocks and syn-tectonic processes. The development of layers of aligned phyllosilicate minerals has the potential to significantly alter the physical properties and mechanical strength of a fault zone, even when present in low volumes (as little as 5%). The precipitation and/or entrainment of weak mineral phases may account for the evidence of both aseismic creep (microfolding) and potential seismogenic slip (rock pulverisation) within these fault zones, recording different stages in their evolution.

Rusty River Hypothesis: Understanding Iron-Carbon-Climate Feedback Utlizing Iron Stable Isotopes

Hawley, S.M., Burton, K.W., Williams, H.M., Pogge von Strandmann, P.A.E.

Metal Transport in the Environment Initial Training Network

PhD Student 021

Rivers are the dominant source of iron and aluminium (hydr)oxides to near coastal environments. We have analyzed river waters and sediments from Greenland for major and trace elements, and iron stable isotopes to better understand the controls on (hydr)oxide formation in glacial and non-glacial river systems.

Riverine suspended sediments from glacial rivers are enriched in heavy iron stable isotopes relative to the bed load. Oxide formation is known to retain heavy iron in the solid phase consequently heavy suspended loads are consistent with (hydr)oxide precipitation onto larger clay mineral surfaces. Model estimates based on our chemical analysis also suggest that glacial rivers produce significantly more (hydr)oxides than their non-glacial counterparts.

The relative magnitude and extent of glacial and non-glacial weathering in sub-artic terrains depend on Earth's climate. If glacial and non-glacial weathering produce and transport hydr(oxides) differently then hydr(oxide) production is by exentesion climatically sensitive. Evidence strongly suggests that (hydr)oxides protect organic matter from microbial degradation creating a global 'rusty sink[1]' for organic carbon in marine sediments. Carbon burial moderates atmospheric carbon dioxide levels and Earth's climate, potentially creating a weathering driven iron-carbon burial-climate feedback cycle. This 'rusty river hypothesis' significantly expands upon Martin (1990)'s Iron Hypothesis[2] by removing the geographic constraints and uncertainties in carbon burial inherant in Martin's original hypothesis.

Late field life of the East Midlands Petroleum Province: A new geothermal prospect?

Hirst, C.M., Gluyas, J.G., and Mathias, S.A.

PhD Student 022

Insitu Oil production data for the Welton Oilfield (located in the East Midlands Petroleum Province) has been reviewed in order to ascertain peak production volumes for both oil and water. In addition, temperature data has been obtained for oil wells across the field. This has been used to provide a quantification of the available geothermal resource of exploitable Carboniferous strata (both oil bearing and non-oil bearing) within the oilfield. An estimate of 3.8 MWt has been calculated for the Welton field based on peak production volumes of 265,823 m^3 yr^{-1} oil and 490,314 m^3 yr^{-1} water. Assuming an 80% load factor, this equates to 27 GWh of heat energy available for consumption by the domestic market. This is enough thermal energy to cut the heat consumption of over 1200 homes immediately surrounding the wellhead by 100%, or offset between 5 and 12 % of the heating requirements of Lincoln City (located 8km southwest). Alternatively the heat could be used within commercial greenhouses covering an area of 35,555-103,225 m^2 (dependant on intensive vs extensive crop management).

The exploitation of this resource using existing oil well infrastructure significantly reduces the costs that are usually associated with geothermal exploration. Removal and sale of heat from the co-produced water will improve the economics of tail end production by lowering the effective total operating expenditure; ultimately the warm water contained within these fields has the capacity to reduce CO_2 emissions and provide clean, green, cheap, non-intermittent heating.

Dynamics of lithospheric thinning and melting by edge-driven convection

Kaislaniemi, L. and van Hunen, J.

PhD Student 023

We have studied the dynamics of the mantle melting and lithosphere erosion during edge-driven convection (EDC), a process that takes place at locations of pronounced lithosphere thickness gradients. EDC has been shown by previous studies to be, for example, a viable mechanism for flood basalt formation and for the recent volcanism around the edges of the Colorado plateau. Recently, EDC has been suggested to explain the thinning of the lithosphere, consequent high topography, and Cenozoic volcanism at the Moroccan Atlas mountains. We have tested this hypothesis.

Results from our numerical mantle convection models show that varying amounts (15-45 km) of lithospheric erosion and asthenospheric melts due to EDC is possible. EDC can lead to significant dynamic topography in order of a hundreds of meters. Mantle melting due to EDC has a pulsating nature, periods of which vary from 10 to 30 Myrs. These periods correspond to the length of quiet periods between magmatic pulses observed at the Atlas mountains.

Additionally, our models show that the two competing mechanisms for EDC (EDC sensu stricto and contintental insulation) may occur simultaneously, for the upwelling caused by the continental insulation forms a convection cell, smaller in size but otherwise similar to the EDC sensu stricto convection cell, next to the edge.

Towards a nanoscopic understanding of oil-sandstone wettability: implications for enhanced oil recovery

Kareem, R.M.A., Cubillas, P., and Greenwell, H.C.G.

PhD Student 024

Due to the continuous rise in the demand of oil across the globe and diminish availability of conventional sources, enhanced oil recovery (EOR) operations are increasingly deployed to extend crude production. In most cases EOR involves injecting low salinity water into the reservoir (waterflooding). Therefore, reservoir-rock wettability is thought to be a key controlling parameter along with water composition. In spite of this, a detailed understanding of the fundamental chemistry controlling wettability in mineral surfaces typically present at pores is still lacking. With this in mind we are currently carrying out a detailed micro/nanoscopic study to unravel the fundamental controls behind oil/water wettability in quartz and clay mineral surfaces. These two minerals are the most important phases exposed within the pores of sandstones.

Initial experiments have been carried out using environmental scanning electron microscopy (ESEM) and atomic force (AFM). ESEM has been used to scan quartz surfaces of various roughnesses. These surfaces have been studied without treatment and after being aged in crude oil, dodecane (model oil phase) and dodecane/dodecanoic acid mixtures. Over these surfaces water was condensed and the contact angle measured. AFM was used to study the crystals before and after water condensation with the goal of observing any residual organic molecules. Results indicate a change in the contact angle after aging. In addition, AFM measurements (using functionalised probes) are been taken on kaolinite and montmorillonite

crystals in the presence of different low-salinity solutions with the goal of observing variations in adhesion amongst various functional groups.

Fluid Release and the Deformation of Subducting Crust

Maunder, B., van Hunen, J., Magni, V., and Bouilhol, P.

PhD Student 025

It is known that slab dehydration is crucial in subduction dynamics and for the formation of arc-magmatism. Previous studies of this process have constrained this intake and subsequent release of fluids into the mantle wedge by considering the stability hydrous phases within the slab.

Other, more dynamical effects of this hydration state and partial melting have also been suggested, such as the possibility of “cold plumes”, crustal delamination, and subduction channel return flow. These processes have been inferred to play a role in the generation of continental crust over time through accumulation and melting beneath the overriding plate.

Water content and melt fraction have a strong control on the rheology of the system. Therefore we investigate the effect of these parameters on the dynamics of a subducting slab, with the aim to establish the physical bounds on the delamination process. To do this we use a coupled geodynamical-petrological model that tracks dehydration and melting reactions in order to factor in the rheological effect of metamorphism and magmatism on slab and mantle wedge dynamics. We focus primarily on the strength of the subducting crust and the possibility of delamination. We then extend this investigation by considering whether early earth crust formation could have been the result of such a processes by looking at a hypothetical Archean setting.

Study of structural change in volcanic and geothermal areas using seismic tomography

Mhana, N., Foulger, G.R., Julian, B.R., and Peirce, C.

PhD Student 026

Volcanic Long Valley caldera is a large silicic volcano. It has been in a state of volcanic and seismic unrest since 1978. Farther escalation of this unrest could pose a threat to the 5,000 residents and the tens of thousands of tourists who visit the area. We have studied the crustal structure beneath 28 km X 16 km area using seismic tomography. We performed tomographic inversions for the years 2009 and 2010 with a view to differencing it with the 1997 result to look for structural changes with time and whether repeat tomography is a capable of determining the changes in structure in volcanic and geothermal reservoirs. Thus, it might provide a useful tool to monitoring physical changes in volcanoes and exploited geothermal reservoirs. Up to 600 earthquakes, selected from the best-quality events, were used for the inversion. The inversions were performed using program simulps12 [*Thurber*, 1983]. Our initial results show that changes in both Vp and Vs were consistent with the migration of CO2 into the upper 2 km or so. Our ongoing work will also invert pairs of years simultaneously using a new program, tomo4d [*Julian and Foulger*, 2010]. This program inverts for the differences in structure between two epochs so it can provide a more reliable measure of structural change than simply differencing the results of individual years.

The fate and composition of DOC

Moody, C. and Worrall, F.

PhD Student 027

This study presents the results of a series of experiments investigating rates of degradation and the composition of dissolved organic carbon.

Water from two sites on the river Tees in the North Pennines, UK, one headwater stream (catchment area 0.2 km^2) and one tidal limit (catchment area 818 km^2), was sampled monthly for more than one year. Samples of at least 20 litres were allowed to settle, but were not filtered, and the supernatant tapped off for evaporation to dryness. The residue of the evaporation was subjected to elemental, calorimetric and thermogravimetric analyses. The thermodynamics and stoichiometry of the reaction of the degradation of DOC to CO_2 were calculated in order to understand controls and limits on DOC turnover.

Water taken at the same sampling times each month was put in to quartz-glass tubes and exposed to natural sunlight for up to 70 hours. A number of control samples were foil-wrapped to prevent exposure to sunlight. Water was sacrificially sampled every few hours to measure the dissolved organic carbon concentration to look for photo- and bio-degradation. Suspended sediment and various other variables were also measured.

Results of the degradation showed that up to 50% of the DOC from the peat headwater stream is lost within the first 4 hours of exposure to light. Samples kept in the dark had a much lower rate of loss, as did the light and dark water samples from the tidal limit of the catchment.

Holywell Shale: Evaluating the gas potential

Newport, L.P.

PhD Student 028

We present a geochemical and geological characterisation of the Holywell Shale, North East Wales (Namurian) and assess its potential for shale gas production. Alongside the recent change in US gas supplies, with a significant portion met through domestic shale gas production, shale gas is increasingly being explored for in Europe. In the UK, the Carboniferous shale (specifically Namurian – 313 - 326Ma) has been the main focus of this exploration. The Holywell Shale occupies a sub-basin of the Bowland basin which contains the Bowland Shale Formation. Previous studies of the Holywell Shale have focussed on its potential as a source rock for the East Irish Sea gas fields; the fossiliferous marine bands it contains; and its implications for the palaeoclimate during the Namurian. In the present work, the Holywell Shale has been characterised from both a mineralogical aspect (using powdered X-ray diffraction) and on a geochemical aspect (using total organic carbon and carbon isotope analysis) in order to provide greater understanding of the organic matter characterisation and its links with pore space and mineralogy.

Neutron diffraction study of aqueous tetramethylammonium at elevated pressures and temperatures.

Patel, R.

PhD Student 029

Tetramethylammonium (TMA) is particularly useful in the oil and gas exploration sector as it aids in the inhibition of swelling in clay mineral-rich shale formations which are encountered whilst drilling for oil hydrogen nuclei is used to investigate the hydration region of 1 molal TMA at increasing temperatures and pressures simulating well-bore conditions. This study was carried out on NIMROD at ISIS to exploit the extended Q-range of the instrument, thus offering unparalleled high-resolution of any meso-structures and the longer range ion-ion correlations. We have found that the TMA –TMA correlation has two distinct geometries and despite increasing pressure, the TMA acts to fix the bulk like water structure.

Formation of the volcanic margins of West Greenland and North-Eastern Canada

Peace, A., McCaffrey, K., Imber, J., Hobbs, R., van Hunen, J., and Gerdes, K.[1]

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PhD Student 030

On the West Greenland and North-Eastern Canadian margins, as with many other volcanic passive margins (VPMs), a mantle plume has been proposed to elevate mantle temperatures to account for the large volumes of magmatism present. Observations attributed to a mantle plume include: the initiation of seafloor spreading in the Labrador Sea and Baffin Bay; the presence of large volumes of both extrusive and intrusive magmatism; the interpretation of seaward dipping reflectors (SDRs); the modelleling of underplating by a high-velocity body; and the presence of high $^{3}He/^{4}He$ ratios in picrites. The presence and role of mantle plumes during the formation of VPMs however remains equivovcal, and cannot explain many of the larger scale features observed on the West Greenland and North-Eastern Canadian margins.

Here we consider potential spatial and temporal mismatches between proposed hotspot track locations and independently dated geological events. These mismatches include; the timing of seafloor spreading initiation; location of seafloor spreading and the presence of 'pre-plume' coast parallel dyke swarms. These observations lead us to propose that the mantle plume hypothesis alone cannot satisfactorily explain the formation of all the geological features observed along these margins and that alternative mechanism(s) should be considered.

Understanding the fundamental mechanisms involved in the formation of volcanic passive margins is critical in the reduction of exploration risk on such margins, as they place constraints on the structural and thermal evolution of the margin. This is particularly relevant as exploration activity extends further into frontier regions such as the West Greenland margin

Transform Passive Margins - Formation of the Marginal Ridge

Phethean, J.J.J.

PhD Student 031

Transform Passive Margins (TPM) result from oblique extension during continental breakup. Passive margin segments orientated normal to the spreading direction are offset by these large transform faults. TPM undergo 3 main phases of structural and thermal evolution (after Lorenzo, 1997):

1. Rift phase: Active continent–continent shearing.

2. Drift phase: Active continent–ocean transform boundary.

3. Passive phase: continent–ocean fracture zone.

Margin parallel structural highs are characteristic of this type of margin. Their formation has been attributed to thermal uplift during the drift phase as a hot Mid Ocean Ridge (MOR) passes directly next to cold un-rifted continental lithosphere. This thermal uplift however should be transient and cannot explain the long lived structural highs that we observe today.

Supporting this notion seismic reflection data from offshore Kenya, combined with gravity and magnetic data from the adjacent Somali basin, show no structural high along areas of the margin passed by a MOR. Instead the Davie Ridge only formed along segments of the margin not passed by a MOR, and can be seen from seismic interpretation to be the result of a large cretaceous inversion event. This suggests that the passing MOR induces coupling between the oceanic and continental plates through injection of magma, resisting the formation of marginal ridges in these areas. The inversion event witnessed offshore Kenya is contemporaneous with the breakup of India and Madagascar. The E-

W compression may therefore have been the result of ridge push forces related to the formation of the Indian Ocean.

Fracture Attributes and Fluid Flow in Volcanic Passive Margins

Raithatha, B.G.

PhD Student 032

Hydrocarbon reservoirs commonly contain an array of fine-scale structures that control fluid flow in the subsurface, such as polyphase fracture networks and small-scale fault zones. These structures are unresolvable using seismic imaging, hence outcrop-based studies have been used as analogues to characterize fracture networks and assess their impact on fluid flow in the subsurface. In this study, we combined field data and terrestrial LIDAR-derived 3D, photo-realistic virtual outcrop datasets, collected from fault zones at a range of displacement scales (0.001– 4.5m) within a volcaniclastic sand- and basaltic lava unit sequence in the Faroe Islands.

Detailed field observations were used to constrain the virtual outcrop dataset, and a workflow was developed to build a discrete fracture network (DFN) models in GOCAD® from these datasets. Fault zone geometry and properties vary significantly with increasing displacement through volcaniclastic (claystones, sandstones) and crystalline units (lava flows). Fractures propagate initially within the mechanically stronger crystalline units, before linking through volcaniclastic units. The resultant through-going faults show refraction through the sequence, with steep faults reactivating cooling joints in the crystalline units, linked by variably inclined faults in the volcaniclastic layers. Volcaniclastic sandstones deform initially by ductile flow: at >1.0 m displacement and are progressively dragged into the fault plane forming a smear. Fracture density is greatest at the restraining apex of bends in the master fault plane, decreasing into the volcaniclastic sediments, probably reflecting the timing of fracture initiation in each of the units (i.e., early fracture in the lava; ductile flow followed by fracture in the sediment).

Preserving Cambrian Bodies in Sirius Passet, North Greenland: a unique Lagerstätte

Strang, K.M., Harper, D.A.T., and Armstrong, H.A.A.

PhD Student 033

Water The Sirius Passet Lagerstätte of Peary Land, North Greenland, occurs in marine mudstones and represents the oldest Cambrian exceptional preservation of soft tissues, predating the Burgess Shale by ~10 million years. The Lagerstätte contains a weakly to non-mineralised largely arthropod fauna, which is characterised by three main types of fossil preservation; films, moulds and permineralised guts. Thin section, SEM, BSE and SEM-EDAX analysis haves been carried out on the films and preliminary results show these are composed mainly of silica, with a noticeable depletion in clay minerals. Permineralised, microbial mats are associated with the fossils and scattered through the thin sections. It is postulated that the films were formed during an early phase of silicification which may be associated with the growth of coccoid cyanobacteria. Further work continues to try and constrain the timing of silicification. Initial results show there is no clay over printing in the films, indicating that the Sirius Passet is not only the oldest of the Cambrian Lagerstätte, but also unique.

Palaeoecosystems Research Group

Strang, K.M., Harper, D.A.T., Armstrong, H.A., and Herringshaw, L.

PhD Student 034

The Palaeoecosytems Group aims to understand the fluctuating compositions, diversities and structures of ecosystems during the last billion years and their relationships to climatic and environmental change. Researchers within the

group have international reputations in the taxonomy, palaeoecology and distribution in time and space of fossil organisms. The group have expertise in many of the key invertebrate groups, microfossils, particularly their applications in palaeoclimate interpretation and trace fossils, especially the impact of bioturbation on the history of our planet. Our research is strongly grounded in geological fieldwork. Interdisciplinary research programs include: Early Palaeozoic Lagerstätten, Palaeozoic ecosystems (including origin, diversifications and extinctions), reconstructing deep time climates and bioengineering of marine sediments. Our research is funded from a range of sources including the Natural Environment Research Council (NERC), Agouron Institute, the Danish Council for Independent Research, the petroleum industry and charities. We have a wide network of research collaborators in the UK and overseas, particularly in western Europe, Canada, the USA, China and Australia. The group work in a large variety of spectacular field areas, where Lower Palaeozoic rocks crop out, ranging from the Arctic wastes of North Greenland to the roof of the World in Tibet.

Porosity preservation in Triassic Skagerrak sandstones: clay coatings versus effective stress

Stricker, S., Jones, S., Goulty, N., and Aplin, A.

PhD Student 035

Current understanding of porosity preservation in sandstone reservoirs tends to be focused on how diagenetic grain-coats of clay minerals and microquartz can inhibit macro-quartz cementation. However, the importance of vertical effective stress (VES) in maintaining high primary porosity to depth is often underestimated.

Where pore fluid pressures are high (low VES), the early arrest of compaction can allow preservation of high porosity to depths. The development of overpressure reduces the stress on intergranular and cement-grain contacts and so inhibits pressure dissolution and compaction.

This study focuses on the fluvial sandstones of the Triassic Skagerrak Formation, Central Graben, North Sea. The Skagerrak reservoirs with high overpressures commonly have high porosities, less macro-quartz cement and variable amounts of diagenetic chlorite grain coats. Pore pressures within the Skagerrak Formation can exceed 35MPa at depths of 4000mbsf where temperatures are above 140°C. Retained primary porosity up to 35% can be found in many of the fluvial channel sandstones.

Early results from on-going research using detailed quantitative petrography, SEM analysis and wireline data sets has identified the key diagenetic phases that has helped to preserve high porosities. Macro-quartz cements and other cementation processes have been inhibited by a combination of factors: presence of early diagenetic clay grain-coats and chlorite cements, the relatively low ambient VES reducing the deleterious effects of grain-contact pressure solution and late stage hydrocarbon migration. This research has important implications for understanding the role of overpressure for porosity preservation and the lesser role played by chlorite grain coatings in High-Pressure High-Temperature reservoirs.

The development of porphyroclastic texture in a peridotite xenolith from sub-arc mantle: physicochemical conditions and timescale

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PhD Student 036

Deformed peridotites provide information vital to our understanding of mantle dynamics. Here we utilise the trace element composition of different olivine populations within a porphyroclastic arc

peridotite xenolith and its host lava to constrain the conditions and timescale under which such textures may be generated. We show that the observed texture formed through reaction with a primary arc magma containing ~3.8 wt. % H_2O at a temperature of ~1230 °C and an oxygen fugacity equivalent to ~2 log units above the fayalite-magnetite-quartz buffer. Significant cryptic zoning of trace elements and water in olivine porphyroclasts are consistent with chemical diffusion in response to this process. Modelling of the Ca concentration profiles of multiple crystals reveals a timescale of approximately one year, which we interpret to represent the time between the infiltration of hydrous melts into the local ambient upper mantle wedge and the formation and eruption of the xenolith. Modelling of the concentration profiles of other trace elements shows that they generally diffuse at similar, rapid rates under the conditions of formation. Our results suggest that similarly textured samples from other peridotite suites may retain chemical signatures pertaining to the final reactions of primary melts within the mantle before crustal differentiation.

MD Simulations of Low Salinity EOR

Underwood, T.

PhD Student 037

In an age of increasing energy demand it is clear that we must utilise our energy resources as efficiently as possible. Presently oil is recovered through primary methods (pressure differentials) and secondary methods (water flooding), however this can still leave over two-thirds of the original oil left within a reservoir. In recent years it has been noted that using a low-salinity flooding fluid can have a marked effect upon the amount of oil produced. This is thought to be due to the interactions between the organic oil compounds and inorganic clay minerals within the reservoir. Using computational molecular simulations we show that it is the exchange of charged oil compounds with mobile cations that is the primary driver for this phenomenon

Origin and implications of magmatic enclaves from andesitic lava dome of Mount Lamington volcano, Papua New Guinea

Zhang, J., Davidson, J.P., Humphreys, M.C.S., Macpherson, C.G., and Neill, I.

PhD Student 038

Real world geological datasets, such as fracture networks, are restricted spatially and have limited resolution at all scales of observation. These limited observations may be interpreted to provide information regarding general trends which can subsequently be applied to geological models. The interpretation of geological data almost always involves human input which introduces interpreter bias into the workflow.

We investigated the effect of interpreter bias on interpretations of fractures picked from satellite data. Participants were asked to digitise the fractures seen in a satellite image and were asked to fill in a questionnaire to assess their level of prior knowledge or experience, with respect to structural geology and fracture picking. People's experience level included aspects such as time spent studying geology and in particular structural geology, as well as their level of fracture picking experience.

The fracture data were then processed to derive statistics for fracture length, orientation, density and intensity, all characteristics which could be used as inputs for a discrete fracture network model. We considered the variability in results produced by different interpreters and the effect of this variability on discrete fracture network models.

Plagioclase Growth and Crystal Stratigraphy: a Window into Cryptic Amphibole Fractionation

Zhang, J.

PhD Student 039

Mount Lamington came into unrest in 1951 and produced an andesitic lava-dome after initial

explosive eruption. Numerous basaltic-andesitic magma enclaves are found in dome-lava, together with harzburgite and dunite nodules identified as Papuan Ultramafic Belt (PUB) ophiolite fragments. Previous study suggests the 1951 dome-lava has been geochemically modified by PUB contamination based on higher-than-expected Cr and Ni concentrations and the presence of PUB nodules. Aiming to (i) understand the petrogenetic relationship between the dome-lava and magmatic enclaves hosted therein, and (ii) constrain the role of PUB modification to magma geochemistry, we carried out whole-rock Sr-Nd isotopic analysis and updated trace element with ICP-MS analysis on andesite, enclaves and PUB xenoliths. Our analysis shows that the 1951 lava samples are both geochemically and isotopically homogeneous and free from PUB contamination. Trace element modelling reproduces compositions of mafic enclaves by mixing an inferred underplating basaltic magma with an averaged PUB, followed by further mixing with overlying andesitic magma. The enclaves are diktytaxitic, which suggests that they formed when hot, volatile-enriched, phenocryst-poor mafic magma was emplaced into the undercooled, heavily crystalline, long-resident overlying magma chamber of andesite. Fresh amphibole phenocrysts of andesitic lava indicate fast magma ascent, and fast magma ascent after long-time sitting in magma chamber can be explained as the andesite magma was remobilized by the volatile and thermal flux from recharged mafic magma, and pushed up to the surface. So we conclude that the 1951 andesite-dominated eruption of Mount Lamington is triggered by mafic magma recharge.

The influence of metastable pyroxene on the dynamics of subduction

Agrusta, R., van Hunen, J., and Goes, S.

Postdoctoral Research Assistant 040

Tomographic images show that some slabs penetrate straight into the lower mantle, whereas others seem flatten and stagnate in the mantle transition zone. The dynamics of cold subducting slabs are mainly controlled by negative thermal buoyancy forces and by buoyancy anomalies due to density contrasts of the different mineralogical phases. Recent experiments show that pyroxene transforms to its high-pressure phase (garnet-majorite) at very slow rates, and pyroxene can remain metastable to temperatures as high as 1400 °C (van Mierlo et al., 2013).

Because metastable pyroxene may potentially persist in subduction zones over large volumes and to great depths, a self-consistent subduction model has been used to investigate the influence of metastable phase on the dynamics of subducting oceanic lithosphere. The phase boundary of pyroxene to garnet (250 km equilibrium depth) is considered together with the phase transition of olivine to spinel (410 km equilibrium), and spinel to perovskite-magnesiowustite (670 km equilibrium). The kinetics of the phase transition in pyroxene-garnet is treated considering a temperature-dependent diffusion rate. To quantify the buoyant contributions of the metastable phase on the subduction dynamics, an extensive parameter sensitivity study has been performed.

Preliminary results from this study illustrate that the buoyancy effect of metastable phase is significant.

Slab age and phase change kinetics are the most dominant parameters, and buoyancy effects are stronger for old subducting lithosphere and for low diffusion rates, favoring the slab stagnation in the transition zone.

Hillslope position affects carbon flux from peat soils

Boothroyd, I.M.

Postdoctoral Research Assisstant 041

Peatlands are important terrestrial carbon stores, both in the United Kingdom and globally. The

cool and wet climate of the UK allows blanket bog peatlands to form in upland regions, with peat deposits covering the landscape across entire hillslopes. Blanket bogs are important sinks and sources of CO2 and dissolved organic carbon (DOC). Many factors affect the carbon cycle of peatlands, including climate, hydrology, vegetation, land management and topography. Although hillslope position can influence the hydrology of peatlands, the effect it has on the production and transport of different carbon species is poorly understood.

This poster investigates the impact hillslope position has upon the hydrology and gaseous and fluvial carbon pathways of blanket bogs in upland regions. Water table depth, CO2 fluxes and DOC concentrations were studied at two hillslopes in the Peak District, Derbyshire, across four hillslope positions: top-slope, upper mid-slope, lower mid-slope and bottom-slope.

Results show that water table depth is strongly affected by slope position, leading to water table drawdown on mid-slopes, with water tables closer to the surface on top and bottom-slope positions. Ecosystem respiration is significantly greater on the upper mid-slope than the bottom-slope, while net ecosystem exchange, the sum of ecosystem respiration and photosynthesis, is a greater daytime carbon sink on the bottom-slope than the upper mid-slope. Slope position is an important control upon DOC cycling, with concentrations decreasing from the top-slope to bottom-slope.

Redefining the Trans-Himalayan batholith in the frame of the India-Eurasia collision.

Bouilhol

Postdoctoral Research Assistant 042

The Himalayan belt as well as the paleo-Eurasian margin show structural and lithological lateral continuities that host the key to our understanding of the India-Eurasia collision. On the western end of the orogen these continuities are perturbed by the presence of the Kohistan Ladakh paleo-island arc (KLA) that was part of an intra-oceanic island arc chain offshore of the Eurasian margin within the neo-Tethys. The KLA is now wedged between India and Karakoram with the Shyok suture separating the KLA in the north from the Karakoram, whereas in the south the Indus suture isolates the KLA from the Indian continent. The middle to upper crustal portion of the KLA is characterized by granitoids that defines the KLA Batholith. The KLA Batholith is often accepted to represent the western termination of the trans-Himalayan Batholith, the lateral continuation of the Gangdese Batholith defining the southern edge of the Lhasa block. Here we present the compilation of geochemical and geochronological data on the different batholiths, and call for a reassessment of the interpretation of the Trans-Himalayan granitic belt. The evolution of the trace elements and isotopic signatures of the granitoids that form the different batholiths clearly demonstrates that the KLA Batholith was not part of the Eurasian margin, and should not be identified as being part of the Trans-Himalayan Batholith. Together with the recent informations on suture formation, defining the Shyok-Tsangpo suture as the locus of collision at 40 Ma, as well as the geochemical evolution of the Shyok-Tsangpo suture zone units, the data allow reinterpreting the lateral continuities of the lithologies along the Himalayan belt and shade light on the India-Eurasia collision

A geological explanation for intraplate earthquake clustering complexity: the zeolite-bearing fault/fracture networks in the Adamello Massif (Southern Italian Alps)

Dempsey, E., Holdsworth, R.E., Imber, J., Bistacchi, A., and Di Toro, G.

Postdoctoral Research Assistant 043

Interconnected networks of faults and veins filled with hydrothermal minerals such as zeolite are widespread in many orogenic terrains. These fractures commonly form at relatively low temperatures (e.g. < 200°C) late in the tectonic

history and represent significant phases of fluid flow and mineralisation during exhumation. Zeolite-bearing fractures spatially associated with the Gole Larghe Fault Zone in the Southern Italian Alps are preserved along an interconnected network of variably orientated pre-existing structures. They show evidence of repeated episodes of hydraulic tensile fracturing and small magnitude (total offsets <5m) shear displacements. We use geological observations and Coulomb stress modelling to propose that repeated seismogenic rupturing of larger offset faults led to local stress transfer and reactivation of widely distributed smaller pre-existing structures in the wall rocks. The differing orientations of the pre-existing features within what is assumed to have been a single regional stress field led to the simultaneous development of reverse, strike-slip and extensional faults. The kinematic diversity and cyclic nature of the hydraulically-assisted deformation suggest that the mineralised fracture systems represent a geological manifestation of intraplate micro-earthquake clusters associated with fluid migration episodes in the upper crust. Our observations highlight the role of crustal fluids and structural reactivation during earthquakes.

Early Earth melt production in a subduction zone, a petrological model

Magni, V., Bouilhol, P., van Hunen, J., and Kaislaniemi, L.

Postdoctoral Research Assistant 044

A large part of the Archean continental crust is made of a composite rock assemblage dominated by granitoids belonging to the TTG series (tonalite-trondhejmeite-granodiorite). The modus operandi of this sodic granitoids is still disputed. An “arc” signature seems to be present in TTGs, suggesting a formation of continental crust in subduction zone settings. Moreover, they show strong similarities with modern adakites, which are thought to be formed by melting of the oceanic subducting crust.

We present the results of a study where numerical models of subduction are integrated with a thermodynamic database. Our goal is to investigate under which conditions slab melting can be achieved if at all. Our reference model of an early Earth regime, with a high mantle potential temperature, show that the slab dehydrates early, ending up being composed of a dry eclogites. Importantly, our models show that dehydration melting is not achieved in the slab crust; yet, water-present melting of the “dry” eclogites can be achieved if a dehydration reaction occurs in the deeper portion of the slab, fuelling the melting reaction with water. The dehydration reactions that occurred within the slab are able to metasomatize the overlying mantle wedge, forming hydrated peridotites, that becomes a melt source when dragged down by corner-flow. We investigate the effect of different important parameters, such as, mantle potential temperature, subduction velocity and slab composition, on the dehydration and melting processes, to be able to specify the different types of magmas that can be generated in an early-Earth subduction zone.

BritGeothermal- Geothermal Research Partnership

Adams, C.A.[1] and Gluyas, J.G.[1]

Academic Staff 045

BritGeothermal is a new UK based research partnership between the Universities of Durham, Glasgow and Newcastle and the British Geological Survey. The consortium brings together some of the top researchers in the field of low enthalpy geothermal energy and has the two most recent deep geothermal wells drilled in the UK as part of its portfolio. BritGeothermal welcomes collaboration with other research groups and organisations working in the field of deep geothermal energy. The partnership provides a virtual geothermal energy research centre that aims to research and promote the potential of deep geothermal energy as part of

the future energy mix for the UK to both government and commerce.

Although geothermal energy plants are common in areas of the world with volcanic activity, such as Iceland and New Zealand, geothermal energy is a largely untapped resource in the UK. The UK's geothermal gradient, is the rate at which the Earth's temperature increases with depth and has an average value of 26°C per km. It is possible to drill wells to abstract water (groundwater) from geological formations at depths of 1km or more, to extract heat for industrial and domestic space heating. In response to the oil crisis during the 1970's, the entire UK was mapped by the BGS for its geothermal potential. This study revealed that the UK's geothermal resource was around 100GW, which could meet the entire heat demand of the UK. The UK has one geothermal heating scheme at Southampton that has been operating for the past 25 years.

The UK's low enthalpy geothermal resources are associated with deep granites (e.g. the Cornubian Batholith and the Weardale Granite in the North Pennines) and hot aquifers located in several deep sedimentary basins across the UK (e.g. the Wessex and Cheshire Basins). Further geothermal potential exists in production waters from offshore and onshore oilfields and also from flooded abandoned mineworkings. The consortium members are also working on deep geothermal energy projects in other areas of the globe.

Energy Recovery from Abandoned Mineworkings

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Academic Staff 046

A major period of colliery closures during the late 1980s to early 1990s has left the UK with a legacy of abandoned mineworkings most of which are now flooded. Environmental concerns associated with colliery closure include subsidence and uncontrolled discharges of contaminated groundwater at surface. Liability for remediation in the UK rests with the Coal Authority who continue preventative dewatering at some collieries and have installed treatment systems at sites where minewater is discharging.

Aside from the negative impacts of mine abandonment, opportunities exist to exploit the vast volumes of groundwater at temperatures of 12-20^{o}C that lie a few hundred meters below surface within the subterranean plumbing network of the abandoned workings. The temperature of these resources can be used directly for cooling or upgraded using heat pumps to provide space heating offering the opportunity for thermal storage with heat extraction taking place during the winter months and heat rejection during the summer. The benefit of using these ultra-low enthalpy resources is that they are located beneath many of our towns and cities and could benefit a wide range of energy users.

Minewater has been used as a source of thermal energy previously for individual developments in the UK and as part of district wide heating schemes at Heerlen in the Netherlands and Spring Hill Nova Scotia and the British Geological Survey have assessed the potential of abandoned mineworkings in Scotland to provide heating for the City of Glasgow. Durham University are currently investigating the potential for the abandoned mineworkings of West Cumbria to provide a low carbon energy source for a district wide heat network that could benefit local homes and businesses. The project could help to inform government intentions to develop heat networks that could supply up to 14% of the UK's future heat demand whilst providing a cost-effective alternative where it is not economically or technically viable to install or retrofit individual micro-generation systems.

UK Low Enthalpy Geothermal Resources: The Cheshire Basin

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Academic Staff 047

On the 29th December 2013, San Miguel volcano (aka Chaparrastique volcano) in eastern El Salvador erupted after almost 40 years of quiescence. The flanks of the 2130 m-high volcano are covered in coffee plantations up to 1500 m altitude and the country's second city, San Miguel lies 12 km to the east. The 3 hour Vulcanian eruption produced a 7 km-high eruption plume that dispersed ash over >20 000 km2 of El Salvador and Honduras. 5000 people were evacuated from a 3 km-wide radius of the volcano. The eruption ejected ballistic blocks into coffee plantations and produced a transient pyroclastic density current that flowed 700 m down the western flanks and knocked over trees. Proximally, the fall deposits can be divided into: A) 15 cm of poorly sorted, lithic-rich tephra; B) 4 cm of vesicular scoria of basaltic-andesite scoria. In medial regions (1-3 km from the volcano), the fall deposits are composed of A) a basal white ash layer containing ash-coated clasts and ash aggregates that is not seen in proximal parts, B) a grey lithic fine ash layer, and C) a layer of coarse ash to fine lapilli-grade scoria. The upper two layers can be traced >40 km from the volcano where they thin to < 0.5 mm thick. Initial phreatomagmatic explosivity is indicated by abundant hydrothermally altered lithic clasts, the presence of ash aggregates, ash-plastered rock surfaces in the crater and the absence of charred vegetation engulfed by the pyroclastic density current. The last phase of the eruption was predominantly magmatic and was driven by the vesiculation of basaltic andesite magma. Understanding hazards at San Miguel volcano is a priority due to the high population density and the commercialisation of the volcano's flanks. Reconnaissance fieldwork indicates that the volcano has produced substantially larger eruptions in the past.

UK Low Enthalpy Geothermal Resources: The Cheshire Basin

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Academic Staff 048

Geothermal energy from low enthalpy resources within the UK is a hot topic; whilst the UK has only one working geothermal system (Southampton), there is scope for geothermal energy to be a big part of the UK energy portfolio. A major assessment of UK geothermal resources undertaken by the British Geological Survey identified low enthalpy resources associated with UK basins totaling about 300 EJ – enough to supply the UK's heating requirements for 100 years.

One of the more prospective areas for development of geothermal energy is the Cheshire Basin. It comprises Permo-Triassic sediments extending to 4.5km depth, underlain for the most part by Carboniferous strata. Temperatures are estimated to reach 100°C at 4.5km.

The underlying Carboniferous Coal Measures and Namurian shales are gas and oil prone respectively and in the linked East Irish Sea Basin to the north-west have sourced the petroleum deposits found in the Morecambe Bay and Liverpool Bay. Shows of petroleum are common in the Cheshire Basin but only two sub-commercial deposits have been found. We also know from many wells in the East Irish Sea Bain that the strata are permeable, capable of flowing at rates of about 10 liters sec^{-1} a figure comparable with that achieved by the UK's single

low enthalpy geothermal scheme in Southampton.

The Cheshire Basin is likely to have moderate temperature (~100ºC) formation water in permeable horizons. It also lies close to the large population centers of Manchester and Liverpool both of which could benefit from low carbon, district heating schemes.

Biodiversity, biogeography and phylogeography of Ordovician rhynchonelliform Brachiopoda

Harper, D.A.T.

Academic Staff 049

Phylogeographic evolution and changing distribution and diversity of rhynchonelliforms through the Ordovician are linked to its dynamic palaeogeography. Early Ordovician (Tremadocian and Floian) low-diversity faunas were punctuated by local species pumps, notably on the South China Palaeoplate. During the Early to Mid-Ordovician (Dapingian–Darriwilian), marine life experienced an unprecedented hike in diversity at species, genus and family levels, firmly installing suspension-feeding benthos as the main component of the Palaeozoic fauna. The continents were widely dispersed together with a large number of microcontinents and volcanic arcs related to intense magmatic and tectonic activities. Climates were warm and sea levels, high. Pivotal to the diversification is the role of gamma (inter-provincial) diversity and by implication the spread of continents and frequency of island arcs and microcontinents. Provincial patterns were disrupted during the Sandbian and early Katian with the migration of elements of the benthos into deeper-water regimes, enjoying more cosmopolitan distributions. Later Katian faunas exhibit partition between carbonate and clastic environments. During the latest Katian, patterns were disrupted by poleward migrations of warm-water taxa in response to changing climate, facilitating low-latitude species pumps in carbonate settings. The Hirnantian was marked by severe extinctions across orthide-strophomenide clades within few, but well-defined, climatically-controlled provinces.

Constraining the ages of polyphase fault reactivation of the Gavilgarh-Tan Shear Zone, central India using laserprobe40Ar-39Ar dating of pseudotachylytes

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Academic Staff 050

The Gavilgarh-Tan shear zone (GTSZ, Fig. 1), central India provides an excellent opportunity to carry out infra-red laserprobe40Ar/39Ar dating of a variety of fault rocks generated across the frictional-viscous (brittle-ductile) transition zone during the multiple reactivation and progressive exhumation of this crustal fault (Fig. 2). The GTSZ initially experienced ductile deformation at > 15 km depth forming mylonites which yield early Neoproterozoic (ca. 880 Ma) ages. These were overprinted by two distinct sets of pseudotachylytes. An early dextral set, formed at ca. 11-15 km depth with a local mylonitic overprint, give a late Neoproterozoic age (ca. 672 Ma). A later sinistral brittle set yield Ordovician ages (ca. 459 Ma) and represent possibly the first record of Pan African tectonic activity in Central Indian Tectonic Zone. A final phase of brittle faulting is broadly post-Cretaceous as it cuts the Lameta Formation and the Deccan Trap flows and the occurrence of active geothermal springs along some faults may indicate further neotectonic activity. Our findings demonstrate that the GTSZ has a long history of repeated tectonic rejuvenation from the Neoproterozoic up to at least the Cenozoic. They also further demonstrate that the 40Ar/39Ar laserprobe dating tool can be useful for determining ages of overprinting deformations in reactivated crustal-

scale fault zones, provided the age data are carefully constrained using detailed field and microstructural observations.

Analysis of fault propagation folds using elastic dislocation models

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Academic Staff 051

The Monoclines are commonly observed above the tips of blind normal faults that cut sub-horizontal sedimentary rocks and likely result from fault-tip folding. Previous studies have hypothesised that monocline geometry is established early in the fault development, which suggests that simple elastic dislocation (ED) models can be used to provide insights into the kinematic controls on monocline geometry.

This poster describes the monocline geometries produced in series of ED models in which an isolated, planar, elliptical fault is embedded within a homogeneous, isotropic elastic half space. The use of idealised fault geometries is a useful starting point, avoiding the additional complexities associated with fault interaction and linkage. Our models contain faults with dips between 30° and 90°, aspect ratios between 1 and 3, and variable burial depth. The ranges of modelled fault dips, aspect ratios and average displacement gradients were chosen to be consistent with those previously reported from normal faults in British Coal Measures strata.

Our models emphasise the role of fault dip, but also highlight the importance of fault burial depth in controlling monocline geometry. The latter information is commonly lacking or imprecisely constrained for natural faults. Nevertheless, for isolated natural faults where the geometry, slip distribution and tip line depth at the time of faulting are known any departures from idealised geometries, predicted by ED models, may provide information on the role played by mechanical stratigraphy in controlling monocline geometry.

Crustal growth processes recorded by Gunung Guntur volcano, Java, Indonesia

Macpherson, C.G.

Academic Staff 052

Crustal growth in subduction zones can occur in two principal ways. First, existing crustal terranes can be combined along the plate margin or along faults within the overriding plate. Such tectonic juxtaposition may be accompanied by, or followed by, melting of one or all of the terranes involved. Second, melting of the mantle wedge can emplace new basalt into the overriding plate. Magmatism at Guntur volcano, Java, Indonesia, several processes related to such growth. At least two crustal terranes contaminated magma. One has a continental origin and was derived from Gondwana before being added to southern Eurasia during the early- or mid-Cretaceous. This contaminant affected early magma at Guntur and is clearly distinct from mafic crust with which young magma interacted. The latter probably represents oceanic crust trapped between two Gondwana continental fragments. Thus, subduction-related magmatism at Guntur represents magmatic blending of tectonically juxtaposed Mesozoic oceanic and Pre-Cambrian Gondwana continental lithosphere.

Interaction between magma and different crustal terranes have controlled the composition of material erupted from Gunung Guntur. The Old Series suggests a stable deep plumbing system that supplied relatively homogeneous basaltic andesite to the shallower crust, where it interacted with the continental contaminant. The Young Series lavas suggest that a wider variety of more mafic melts reached the shallow crust. In combination with the clear distinction of the contaminants for the two series, the switch from the Old to the Young series may reflect a

significant reconfiguration of magma transport and storage beneath Gunung Guntur.

Heat, fluids and weakening: experimental clues on the microscale processes of high velocity sliding friction

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Academic Staff 053

Fault rocks undergo abrupt dynamic weakening and lubrication during seismic slip, reputedly associated to thermally triggered physico-chemical processes. Recent experiments systematically explore rock friction under crustal earthquake conditions (fast slip rate 1<V<6 m/s, intermediate normal stress 5<σ<50 MPa, pore water pressure or dry, various lithologies).

The detailed evolution during experiments is confronted to the predictions of various thermal weakening models (flash weakening, superplastic diffusion creep, frictional melt lubrication).

In the absence of melting and/or pressurization, the weakening transient is compatible with flash weakening of the contact asperities, in a revised version of the model proposed by Archard (1958) and Rice (2006). A simple model where the strength of the slip zone is directly controlled by Arrhenious-like thermal dependence also provides a reasonable fit. In all cases it is critical to include the effect of heat sinks (latent heat of phase transitions) in the evolution of temperature at the interface.

In silicatic rocks under coseismic conditions, the initial flash-weakening phase is followed by pervasive melting and subsequently shows a behavior compatible with the lubrication model of Nielsen et al. (2008, 2010).

The effects of water pore pressure on the mechanical evolution vary subtly depending on lithology and amount of sliding. These effects provide interesting clues as regards the strain mechanisms at the asperity scale.

Bayesian networks for pore-pressure prediction

Oughton, R.

Academic Staff 054

When drilling a borehole to reach a hydrocarbon reservoir it is crucial to understand the pressure regime in the rock. If an overpressured area is encountered unexpectedly it can have costly and dangerous results. Predictions of pressure are made using a variety of sources of information; some is observed data made whilst drilling, or from nearby wells, while some comes from the experience of the geologists. The standard prediction workflow involves a combination of ad hoc empirical formulae using limited subsets of the data and adjusting according to understanding of the area, with no rigorous or coherent framework for quantifying the uncertainty. We are developing a Bayesian network model that combines the available data with experts' knowledge in order to produce pore-pressure predictions with an uncertainty estimate that takes into account the whole process.

The role of small-scale convection on the formation of volcanic passive margins.

van Hunen, J., Phethean, J.J., and Reilly, T.

Academic Staff 055

Volcanic passive margins (VPMs) are areas of continental rifting with abnormally large amounts of newly formed igneous crust, up to 30 km, while magma-poor margins have initial oceanic crustal thicknesses of <7 km. Proposed mechanisms for the formation of these different types of margins include variation in rifting speed or history, enhanced melting from mantle

plumes, and enhanced movement and melting zone by small-scale convection (SSC). Understanding the mechanism is important to constrain the petroleum potential of VPM.

Here, we numerically elaborate the effect of SSC on the rate of crust production during continental rifting in 2D and 3D models. Conceptually, SSC results in patterns of up/downwelling mantle material typically 100-300 km. If occurring shallowly enough, such upwellings lead to decompression melting. Subsequent mantle depletion has multiple effects on buoyancy (from both latent heat consumption and compositional changes), which, in turn, can affect mantle dynamics under the MOR, and can potentially enhance SSC and melting further.

Decompression melting leads to a colder (melting latent heat), thermally denser, but compositionally more buoyant residue. Competition between thermal and compositional buoyancy determines the mantle dynamics after rifting initiation. For a mantle viscosity >~10^{22} Pa.s, no SSC occurs, and 7-8 km-thick crust forms. For mantle viscosity <~10^{21} Pa.s, SSC might be vigorous and can form passive margins with a crustal thickness >10-20 km. If thermal density effects dominate, convection inversion occurs for low viscosities, and mantle downwellings underneath the rift/ridge area result in significant upwelling return flow, enhancing further decompression melting, and create VPMs.

Understanding multiple element budgets of peatlands – a role for simple stoichiometry?

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Academic Staff 056

A few studies have considered the carbon budget of peatlands; fewer studies have considered the N budget of peat soils, none have considered both together, and furthermore, we could include the oxygen and the energy budgets. By including a range of types of flux the study can not only comment on the overall stoichiometry of the ecosystem but also its oxidation state and thus assess. The study has shown:

1. Over the 13 year study period, the total carbon balance varied between a net sink of 20 to - 91 tonnes C / km^2 / yr

2. Overall, the total N budget of the peat ecosystem varies from -1.0 to +2.5 tonnes N/km^2/yr, i.e.in some years the ecosystem is a net source of N.

3. Oxidation state (C_{ox}) decreases through the profile with DOC and POC fluxes acting as means of removing oxidised carbon.

4. The energy budget shows a long term decline in evaporation for a catchment that is independent of changes in air temperature or net radiation. Changes in net radiation are accommodated by increases in sensible heat flux and concomitant changes in the Bowen ratio.

5. The study suggests that the catchment is responding to change by limiting evaporation and this suggests the system is near equilibrium and not a far-from equilibrium system.

By combining elemental and energy budgets it is possible to write stoichiometric equations for the ecosystem and assess its efficiency and future direction under ongoing change.

Four flavours of orogenic plateau magmatism: What's melting beneath the Turkish-Iranian Plateau?

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Academic Staff/PDRA 057

Orogenic plateaux are sites of abundant mantle-derived magmatism in a collision setting, but there is little understanding of its geodynamic cause in spite of widespread assumptions that

slab break-off or lithospheric thinning are the controlling factors.

Late Cenozoic magmatism is distributed across the Turkish-Iranian Plateau (TIP). Tethyan slab break-off beneath the Bitlis-Zagros suture occurred at 15-10 Ma but magmatism extends 1000 km from the suture and still occurs today. (1) Close to the Arabia-Eurasia suture in Eastern Turkey, little or no mantle lithosphere is present. Magmatism is mostly calk-alkaline, sourced from the asthenosphere or any remaining mantle lithosphere, and is strongly affected by crustal contamination. (2) In the Lesser Caucasus, magmatism is alkaline, less contaminated and is derived from subduction-modified lithosphere. (3) Close to the suture in Iran, the lithosphere has thickened to >200 km during collision. Magmatism is volumetrically limited, sourced from the mantle lithosphere, with highly enriched alkaline or ultrapotassic signatures. (4) Beyond 500 km from the suture zone, magmatism is sparse: dominantly OIB-like in Eastern Iran, alkaline but arc-like in the Alborz, and more felsic above the thick crust of the Greater Caucasus.

While slab break-off may explain some of the magmatic activity close to the suture zone in Turkey, there is no single trigger or source of magmatism elsewhere. Random, small-scale convective removal of lithosphere may be a key process in generating sustained volcanism far from the site of break-off both in space and time.

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Education And Training for the Oil and Gas Industry: Case Studies in Partnership and Collaboration by Jim Playfoot and Phil Andrews is the first of four Getenergy Guides to be published by Getenergy and Elsevier. This volume brings together, for the first time, eight powerful case studies in which universities, colleges and training providers are working with oil and gas companies to produce capable, competent people for the industry.

This essential companion illustrates not only the carefully researched details of each partnership but also offers commentary on the cases presented drawing on Getenergy's decade of experience in uniting universities, colleges, training providers and the upstream oil and gas industry on a global basis.

Volume 1 will be published in June 2014 with future volumes currently in development. For more information on the Getenergy Guides, or to order a copy of Volume 1, contact Frankie Carlin (frankie.carlin@getenergyevent.com).

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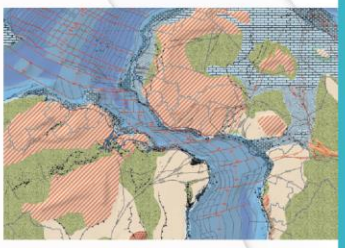

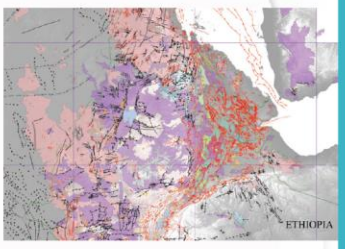

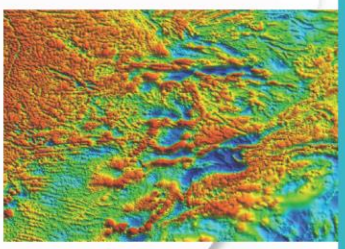

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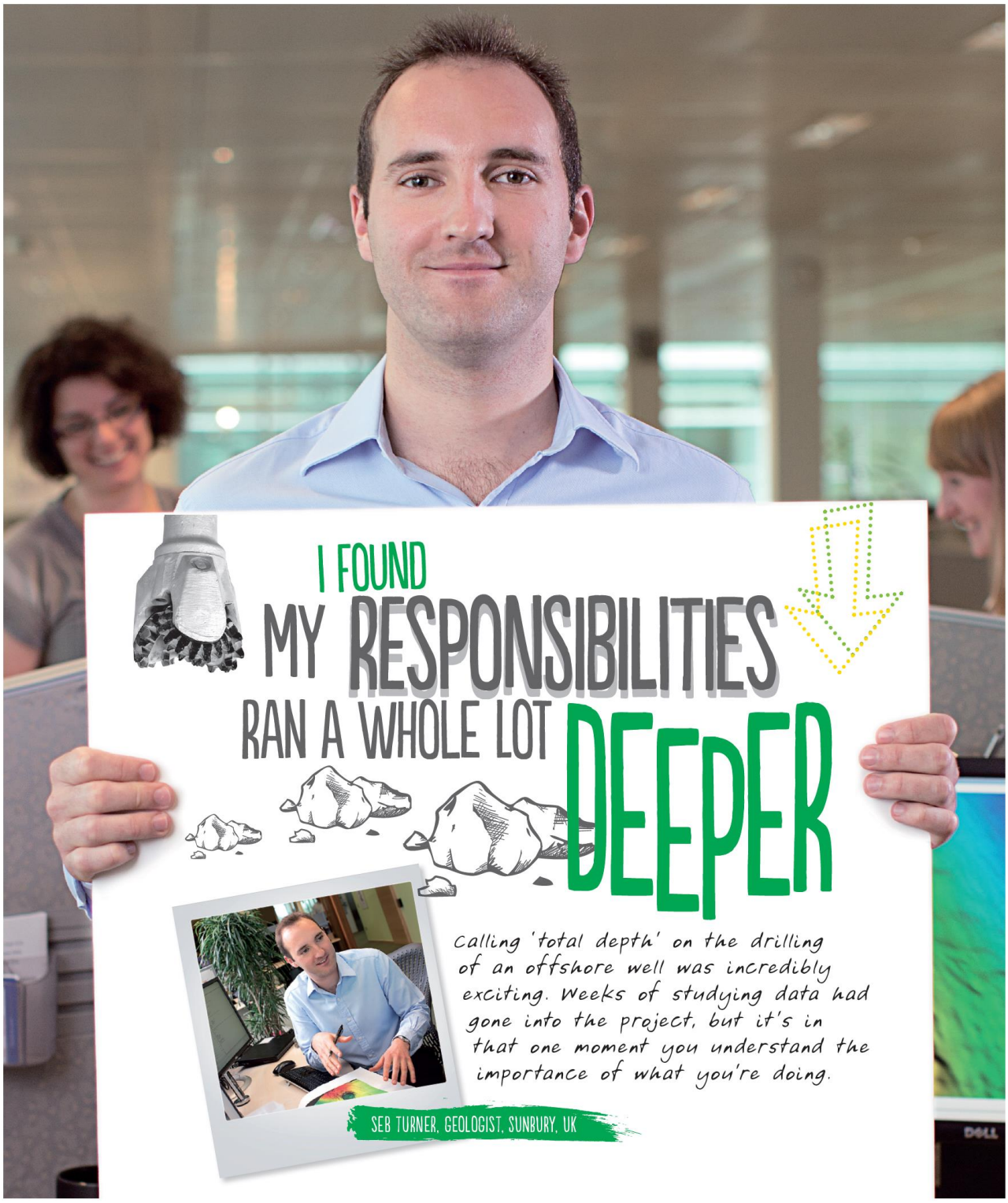

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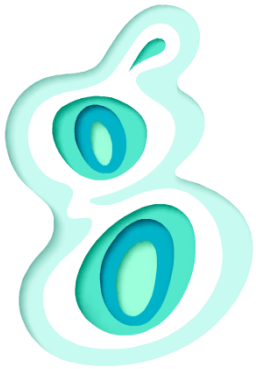

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