Durham University
Department of Earth Sciences

Conference 2017
6th June

Durham University

Contents

A welcome from Colin Macpherson, Head of Department

I am delighted to welcome you to the 5th Department of Earth Sciences Conference, which continues to be a wonderful culmination to the academic year and a unique opportunity for the Department's undergraduate and postgraduate students, postdoctoral researchers and academic staff to share the results of their work.

Level 4 undergraduates will be completing their summative assessment today by giving talks about their research projects in TR3 (ES230). Poster presentations in TR1&2 (ES228 and 229) will showcase research and coursework that has been conducted by other groups in the Department. Please take the opportunity to listen to as many talks and see as many posters as you can. It is a fantastic opportunity to learn about the range of work that goes on in the Department.

I would like to extend a warm welcome and the Department's thanks to our sponsors and industrial partners, ERC Equipoise, CGG and OGI for supporting this conference; and thanks to BP for kindly sponsoring the printing of this Abstract Volume.

I hope you enjoy the Conference today and, most importantly, learn about the new and exciting work going on throughout the Department! Please remember to join us to enjoy refreshments in TR1&2 at 3.30pm when we present prizes for the best talks and posters.

Best wishes,

Col

A Brief History of Earth Sciences at Durham

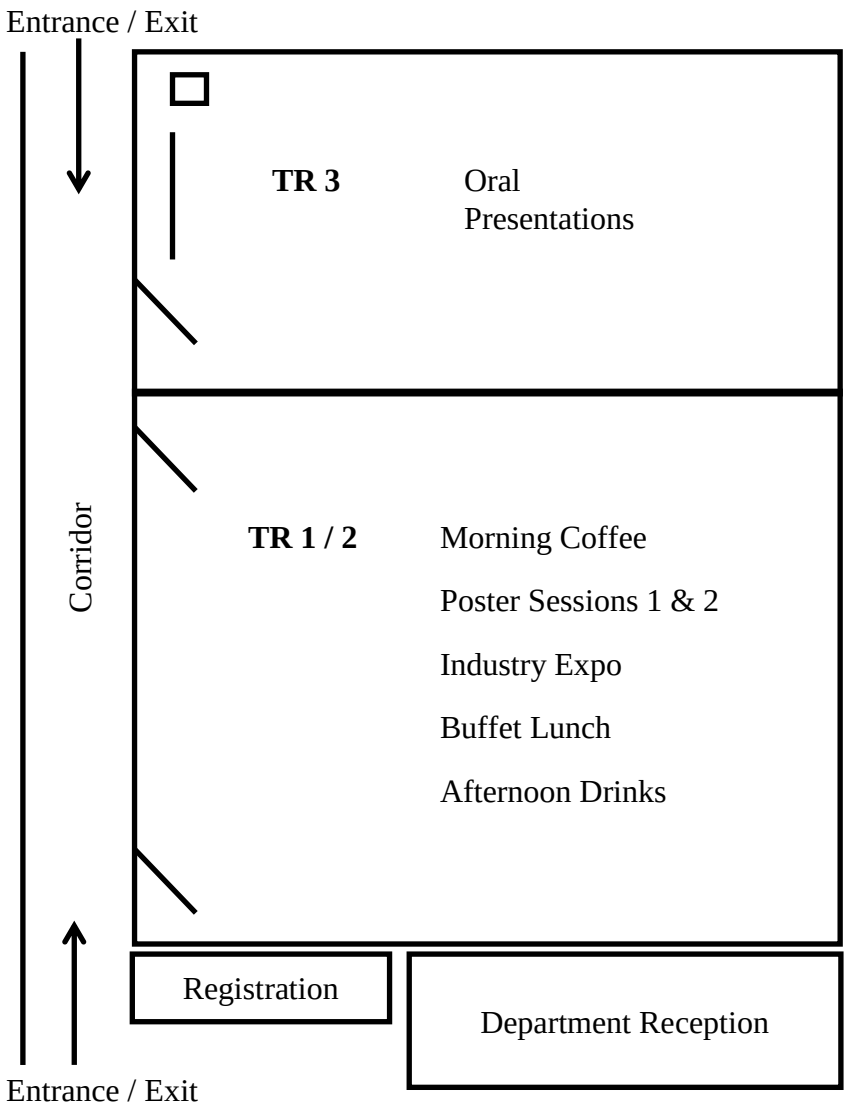
Aspects of the Geological Sciences have been taught at Durham University since its founding, but it was not until 1924 that the Geology Department was created, with Dr (later Professor) Arthur Holmes appointed as its head. Holmes developed a strong department, which produced a succession of distinguished 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 – 10:30	Oral presentations	TR 3
10:30 – 11:00	Coffee break	TR 1 / 2
11:00 – 12:45	Oral presentations	TR 3
12:45 – 14:00	Poster session 1 & buffet lunch	TR 1 / 2
14:00 – 15:00	Oral presentations	TR 3
15:00 – 15:30	Guest Speaker's Address	TR 1 / 2
15:30 – 17:00	Poster session 2, drinks, and prizes	TR 1 / 2

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 (10.30 am).
- **Poster evaluation:**
    - This conference is a great opportunity to interact with your colleagues and to share your research! Notably, peer feedback is of great value, especially when it comes to improving the overall quality of your poster presentation. Therefore, to encourage you in presenting your work this year, but also in the future, at least one colleague will evaluate your poster during the poster sessions.
    - Each delegate will be assigned 1 poster to review. Poster number and the evaluation form for each poster will be given to participants at the registration desk upon their arrival. The form will include a number of criteria to be evaluated, including the scientific quality of the presentation, the design and the author's ability to answer questions, with marks from 0 to 10. The reviewers will be anonymous and will fill in their evaluation form AFTER viewing your poster, and return it to the registration desk. Each poster author will be provided with their review/s by the organising committee, no later than 2 weeks after the conference. It is important that you stand by your poster at the allotted time so that the reviewer/s can talk to you!

Awards

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

Two poster awards (1 undergraduate and 1 postgraduate): Vouchers for an outdoor shop (£50 per award)

Two awards for the best Level 4 oral presentations: Vouchers for an outdoor shop (£50 per award)

Awards will be presented at 16:00 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.

OGI. OGI has more than 25 years of experience in providing groundwater related services to clients and contractors in the United Kingdom.

BGS. The British Geological Survey is a world-leading geological survey. It focuses on public-good science for government, and research to understand earth and environmental processes. It is the UK's premier provider of objective and authoritative geoscientific data, information and knowledge.

Dunelm Geotechnical & Environmental. Dunelm have 50 years' experience as leaders in the field of ground investigation, providing geotechnical, geoenvironmental and site investigation services on a national scale.

FWS. FWS is an established, internationally recognised consultancy with considerable experience providing economic geology, mining, geo-environmental, geotechnical and waste management services to a diverse client base.

EIG. Extractive Industry Geology is a fully independent organisation run by a committee of extractive industry academics, consultants, and other interest groups, with an aim to share knowledge, and promote scientific research and good practice in the field of applied geology.

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

2017 Conference Organising Committee:

Claire Horwell

Chris Saville

Anna Whitford

Sian Arnold

Kit Hardman

Ines Tomašek

Guest Speaker

Dr Sue Loughlin started working for British Geological Survey (BGS) in 1995 after finishing a PhD at Durham University on the Eyjafjallajökull volcano, Iceland. She has been Head of Volcanology at the BGS since 2008 and leads a team of scientists studying topics from volcanic processes to interdisciplinary science and volcanic risk funded by research grants, commercial grants and BGS funds (30%). She worked at the Montserrat Volcano Observatory as Deputy Chief Scientist between 1997 and 1999 and then as Director from 2004 to 2006. At MVO she first compiled short- and long-term hazards assessments and was involved in development and application of novel volcanic risk assessment methodologies. She was instrumental in the UK response to the 2010 eruption of the Eyjafjallajökull volcano and the inclusion of volcanic risk in the UK National Risk Register. Dr Loughlin has worked in Ethiopia, Tanzania, Iceland, Ecuador, Colombia, Mexico, St Vincent and Montserrat. Dr Loughlin was awarded an MBE for Services to Volcanology in 2014 and the Thermo-Fisher Award from the Volcanic and Magmatic Studies Group in 2017. She co-leads the Global Volcano Model network with Professor Sparks at Bristol University.

Oral Presentations

09:15	**Ashman, I. R.**	Stratigraphic Variation in Fracture Densities in the Mudrock Dominated Succession of the Cleveland Basin, Northern England
09:30	**Hornby, A.G.**	The Interaction of Tensile Fractures with the Surrounding Lithology and Other Tensile Fractures
09:45	**Martin, H.M.**	Post Shale Gas: The Geothermal Potential of the Triassic in the Bowland Basin
10:00	**Cullen, E.E.**	Petroleum Migration Modelling of the Offshore Northern Mauritania Basin, Block C-19
10:15	**Rea, F.**	A Regional Analysis of Reservoir Quality in the Brent Sequence, Northern North Sea, UK
10:30 – 11:00		**COFFEE**
11:00	**Mascord, C.S.R.**	Is the 'Tulip Animal' (Siphusauctum sp.) a Stalked Jellyfish (Staurozoa, Cnidaria)?
11:15	**Hodges, Z.V.**	The effect of the geochemical environment on the concentration of amino acids by layered double hydroxides
11:30	**Couper, H.**	Reconstructing East Asian aridity throughout the Holocene and Last Glacial Period using Stalagmite ^{232}Th

11:45	**Li, L.**	Building a Calibrated Rainfall Record for Central America Over the Last 500 Years
12:00	**Desouza, E.**	Investigating Struvite Formation with Northumbrian Water Ltd.
12:15	**Ownsworth, E.**	Tracing the Natural and Anthropogenic Influence on the Chemistry of Estuarine Macroalgae: Insights from the Firth of Forth and Forth Estuary, Scotland
12:30	**Folds, J.L.D.**	Empirical relationships between actual and potential evapotranspiration at the catchment scale
12:45 – 14:00		**Poster Session I / LUNCH**
14:00	**Adams, O.R.**	Investigating the Effects of Secondary Processes on Molybdenum Isotope Fractionation in Eucrites and Diogenites from the Asteroid Vesta
14:15	**Currie, J.**	Trace element mobility during high-pressure metamorphism in subduction zones: the Allalin Gabbros, Switzerland
14:30	**Gibson, D.**	Crustal Delamination in a Hotter Early Earth
14:45	**Johnson, C.**	Determining the crustal structure of the 13N fracture zone on the MAR
15:00		**GUEST SPEAKER - SUE LOUGHLIN**
15:30 – 17:00		**Poster Session II / DRINKS**

Stratigraphic Variation in Fracture Densities in the Mudrock Dominated Succession of the Cleveland Basin, Northern England

Ashman, I.R. **TR3** 09:15

Research into the extensional faults and fractures in the inverted Cleveland Basin was undertaken with the aim of identifying the distribution of structures and extension in analogue sedimentary sequences for unconventional petroleum reservoirs. Fieldwork was conducted in North Yorkshire at Runswick Bay, Skinningrove, Saltburn and Staithes to collect structural transect data. The transect data were collated with existing transects to form a database of 103 transects. The transects span 120 m of the vertical stratigraphic succession in the Cleveland Basin from the Redcar Mudstone Formation to the Whitby Mudstone Formation.

Statistical analysis of the fieldwork data indicates that the spatial distribution of faults and fractures is uniform with very narrow or no fault damage zones observed. In contrast, the distribution of extension is highly clustered and is concentrated on only a few structures. Manipulation of geochemical data from drilled boreholes provided an indication of the brittleness of the lithologies but there is no single, clear relationship between the average fracture densities and the brittleness of a layer.

The resulting conceptual model describes a stress reduction shadow that formed adjacent to an established fracture that precluded formation of a new fracture and led to uniform fracture spacing. Extensional faulting occurred after brittle fracturing and the normal faults inherited the structural network, thus preserving the uniform spacing. Variations in average fracture density were controlled by the thickness of the mechanical layers, the tensile strength of the layer and the proportion of stiff beds to soft beds in the sedimentary sequence.

The Interaction of Tensile Fractures with the Surrounding Lithology and Other Tensile Fractures

Hornby, A.G. **TR3** 09:30

Tensile fractures are ubiquitous in the upper crust and are potential pathways for fluid migration. By studying well-preserved, three-dimensional exposures of natural hydraulic fractures within the organic rich Mulgrave Shale Member of the Ravenscar Group at Saltwick Bay, Whitby, it is possible to see how these fractures interact with each other and surrounding lithologies. Using 1:5 scale maps and photos of fractures it is possible to study a large array of structures that develop on the fracture surface, defining the propagation direction and velocity, the controls on these values and to see if there is a correlation in structures observed. The most interesting structures include arrest lines, plumoss marks, branch lines, mirror and mist zones. The first two can be used to calculate propagation direction whilst the last four are used to accurately confine propagation velocity. The relationship between these features will be investigated by quantifying: (1) spacings between neighbouring arrest lines measured in directions parallel and perpendicular to sedimentary bedding, (2) scaling relationships between features observed on small and large fractures, (3) orientation of features including branch lines and plumoss marks and (4) possibly the anisotropy of shales. This study shows: (1) fractures with a half-length >32 cm do not develop arrest lines close to the fracture origin, probably due to the initial increase in propagation velocity causing the propagation distance to be greater, as seen in development of higher velocity structures like mist zones, (2) the propagation direction is controlled by the orientation of stress and the anisotropy; planes weaknesses are utilised by propagating fractures within these shales, and (3) lithology has a larger effect on fracture termination than structural obstacles such as branch lines, this is linked to the anisotropy and heterogeneities within the shales. Termination also appears to have little or no effect on arrest

line spacing. This gives a greater understanding of how natural hydraulic fractures link together within an exhumed shale analogue, as those seen at Saltwick Bay. It may also provide an insight into the growth of anthropogenic hydraulic fractures that are induced during stimulation of shale gas and oil reservoirs.

Post Shale Gas: The Geothermal Potential of the Triassic in the Bowland Basin

Martin, H.M **TR3** 09:45

Low enthalpy geothermal resources located within deep Permian and post-Permian sedimentary basins across the UK are estimated to contain at least 300 EJ (x1018 J) of heat, sufficient if fully developed to supply all the heating needs in the UK for the next century. Geothermal technologies are low CO2 emitters, are non-intermittent, unobtrusive, do not attract large emission-based taxes and have long (~25 year) lifespans. The main barrier is the inherent risk associated with geothermal schemes when considering the initial drilling costs and the uncertainty of attaining geothermal energy. It is estimated that 60-70% of the total cost of a geothermal scheme is spent on the drilling phase. Another drawback is the longer pay back times, owing to the relative value of hot water. This report explores the potential of exploiting geothermal energy from terminated shale gas wells. If shale-gas takes off within the UK in a similar manner to North America then abandoned shale-gas wells should be considered as infrastructure that could reduce the risks and initial drilling costs associated with geothermal. The Bowland Basin is a key focus region for shale gas exploration in the UK. The Triassic sandstone target aquifer meets the requirements for a potential geothermal resource. The Bowland Basin has the potential to produce 0.5 MWt extractable heat based on a 30oC temperature depletion. This equates to 4,000 MWh available for local district heating, commercial greenhouses or thermal spa/leisure facilities.

Petroleum Migration Modelling of the Offshore Northern Mauritania Basin, Block C-19

Cullen, E. E. **TR3** 10:00

The hydrocarbon potential in the offshore basin of Mauritania is highly under explored. By modelling migration pathways according to source rock properties, petrophysical characteristics of the lithologies present, and the role of carbonate platforms as potential reservoirs, a more thorough understanding of the hydrocarbon system will be reached. 2D seismic and well data from the Ras el Biada-1A (RAB-1A) and the Al Kinz-1A (AKZ-1A) wells drilled in 1980 provide primary source information which, along with an in-depth literary study, determines the potential of block C19 as a petroleum kitchen and potential reservoir. Lithologies are interpreted from seismic amplitude and their corresponding capillary entry pressures and other petrophysical properties are assigned based on primary or secondary data. The petroleum systems modelling software, Permedia 5000.10, simulates a 2D lithofacies model where secondary migration is based on the invasion percolation theory. Lateral migration is extensive into the carbonate platform present in the Mauritania basin, though further migration out of the system may hinder the vertical migration and subsequent filling of stratigraphic traps. The source rock properties show near identical trends of migration pathways, with only the maximum volumes being expelled altering. Whether the limestone presents itself as a reservoir or trap has little consequence to the modelled migration pathway due to its highly interbedded nature with sandstones, though will greatly impact the potential reservoir properties. Sensitivity testing of the critical oil saturations is shown to have little effect on the model outcomes. Due to the limitations of using a 2D seismic section, it is highly recommended that further 3D seismic data be acquired and it cover a larger area, and further primary data on source rock properties be collected.

A Regional Analysis of Reservoir Quality in the Brent Sequence, Northern North Sea, UK

Rea, F. **TR3** 10:15

The Middle Jurassic Brent Group is the primary hydrocarbon reservoir of the Northern North Sea. It is composed of five formations formed in a marginal marine delta system. The formations have a wide facies distribution and record the progressive transgression and regression of the delta, causing variable reservoir quality. Reservoir quality is a function of porosity and permeability which is controlled by initial sediment composition and diagenesis. Analysis of porosity, permeability and depth data from 65 wells across 7 oil fields, the Dunbar, Hutton, NW Hutton, North Alwyn, Ninian, Staffa and Strathspey fields, was performed to establish the first regional trend in reservoir quality in the Brent Province. It is widely believed that the province has reached its maturity with few classic structural plays remaining and this paper aims to revive the area with new research and results.

The results show the primary control on reservoir quality is diagenesis. Fields analysed are buried to depths greater than 9000 ft and so the effects of compaction have already occurred. Petrographic thin section analysis of ten thin sections from the Murchison and Thistle field revealed the sequence and effects of diagenesis. Detailed data analysis revealed a first order relationship between reservoir quality and productivity. Of particular interest are the North Alwyn and the NW Hutton fields. North Alwyn experiences higher than average porosity, permeability, net to gross and recovery factor. Unlike most Brent fields it has a thick Tarbert formation which undergoes quartz cementation rather than clay cementation, preserving its porosity. Whereas, the NW Hutton field has anomalously low porosity which is due to absence of widespread Tarbert formation. The formation has high porosity and permeability and should be used as an important exploration tool for future fields in the region. The Hutton, Ninian, Strathspey and Staffa fields all follow a similar trend and are interpreted to be linked on a large scale system. Whereas the NW Hutton, North Alwyn and Dunbar fields display anomalous results and may be isolated reservoir packages separated from the main paralic system.

Is the 'Tulip Animal' (Siphusauctum sp.) a Stalked Jellyfish (Staurozoa, Cnidaria)?

Mascord, C.S.R. **TR3** 11:00

Dominating the fauna of the Tulip bed locality of the Burgess Shale, British Columbia, *Siphusauctum gregarium* is a taxonomically problematic mid-Cambrian animal. In its initial description, the animal was described as a stalked filter feeder, possibly belonging to the early Bilateria. However, the animal shares a number of anatomical similarities with modern members of the phylum Cnidaria, particularly the Stauromedusae (Staurozoa).

In order to clarify the animal's phylogenetic relationship to modern fauna, the morphology and anatomy of a specimen of Siphusauctum sp. was described and compared with that of living and extinct Cnidarian groups. A character matrix examining 58 species of modern and extinct Cnidaria was constructed, including two specimens of Siphusauctum (S. gregarium and the un-named species described), and examined using the free TNT phylogenetic software. In total 127 characters were coded examining the anatomy and morphology of polyp and medusal stages, the colonial and reproductive behaviour and the kind of nematocysts present in the species examined. Coding information was obtained through examination and description of fossil material and preserved specimens or extracted from published literature. The data includes representatives of each of the major extant Cnidarian classes - Anthozoa, Hydrozoa (Hydroidolinae and Trachylinae), Scyphozoa (Discomedusae and Coronomedusae), Cubozoa and Staurozoa (Stauromedusae) along with species of extinct Cnidarian's.

The results are supportive of a taxonomic classification of Siphusauctum as a member of an

extinct sister clade to modern Stauromedusae, one of the more derived Cnidarian clade. Synapomorphies include a stalk, non-biomineralized periderm, a long functional manubrium and gut and a bunched tentacular arrangement. The presence of such derived cnidarians in the Cambrian and other fossil evidence is supportive of rapid early diversification of the Cnidaria throughout Ediacaran the early Cambrian and Ediacaran. The abundance of Siphusauctum also suggests the phylum was very common in the Cambrian, possibly due to their lower metabolic demands allowing them to thrive in the lower productivity of the Cambrian ocean.

The effect of the geochemical environment on the concentration of amino acids by layered double hydroxides

Hodges, Z.V. **TR3** 11:15

One of the main origin of life theories is that of the 'Peptide World' in which amino acids could have originated on Earth via gas-phase reactions, synthesis at hydrothermal vents or from extra-terrestrial material. In order to form peptides from amino acids in an aqueous environment, a means of selecting, concentrating and protecting these prebiotic organic molecules would have been required. Adsorption to mineral surfaces has been invoked as one mechanism for the formation of peptides. Layered double hydroxides (LDHs), or anionic clays, are a suite of inorganic lamellar compounds capable of adsorbing anions, such as amino acids, within their interlayer spaces.

Particular LDH minerals of interest in the origin of life include green rust, considered to have been one of the most common components of early ocean sediments, and brucite, formed via serpentinization at hydrothermal vent settings, as these could have played a role in the concentration of amino acids from solution. In this study, the Mg^{2+}/Al^{3+} LDH is used as a substitute for green rust. The ability of Mg_2Al-LDH to uptake amino acids via ion-exchange is investigated, as this method of intercalation is most relevant to prebiotic synthesis.

A co-precipitation reaction was used to prepare Mg_2Al-NO_3 LDH, which was subsequently used in ion-exchange reactions with glycine, leucine, histidine and aspartic acid at pH 10. Here, the first study on the effect of temperature (30, 60, 90°C) and competition on the uptake of amino acids via ion-exchange is reported. The four different amino acids were successfully intercalated into Mg_2Al-LDH via ion-exchange at alkali pH and it has been demonstrated that both temperature and competition affect amino acid uptake. Additionally, the use of proton nuclear magnetic resonance (^1H NMR) as a novel quantitative measure of uptake is investigated, although further refinement of the method is required. The ability of LDHs to intercalate amino acids via ion-exchange at alkali pH could be relevant to prebiotic peptide formation at alkaline settings on the primordial Earth; thus highlighting the important role that these layered minerals may have played in the origin of life.

Reconstructing East Asian aridity throughout the Holocene and Last Glacial Period using Stalagmite ^{232}Th

Couper, H. **TR3** 11:30

This study presents stalagmite ^{232}Th as an accurate proxy for atmospheric aerosols, describing variations in aridity to a higher degree of accuracy than loess deposits and Ca2+ records. A calibration curve between present day Aerosol Optical Thickness (AOT) and recent 232Th describes a positive relationship (R^2 = 0.47) which is subsequently applied to 314 stalagmite records. Paleo-AOT consequently acts as a representation for past local and global aridity. Variations in East Asian AOT (EAAOT) are interpreted to be changes in the strength of the East Asian summer monsoon (EASM). Throughout the Holocene, a weakening in the EASM is associated with decreasing Northern Hemisphere insolation. Additionally, millennial-scale fluctuations coincide with 7 out of 8 Bond events and there is evidence for two further drying

spells at ~5 and 2 kya BP. When compared with ice core 18O and calcium concentrations across the last glaciation, AOT responds remarkably clearly to known climate perturbations such as the Younger Dryas and Bølling-Allerød interstadial. D-O and Heinrich events observed in EAAOT mirror millennial-scale variability observed during the Holocene. Conversely, long-term trends are controlled by obliquity and precession induced insolation variations. This study concludes that a coupled control of North Atlantic ice-rafting events and NH insolation variability drives changes in East Asian aridity both during the Holocene and last glacial period. The potential for extreme drying events in East Asia is demonstrated throughout this study and the possible extent of aridification in East Asia is an important future socio-economic issue.

Building a Calibrated Rainfall Record for Central America over the Last 500 Years

Li, L. **TR3** 11:45

Stalagmites provide highly-resolved and well preserved climate proxies in their carbonate. A thorough understanding in their petrology and environment can provide invaluable records of long term variability in past climate. Most commonly utilised proxies, stable isotope ratios of oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$), are mainly controlled by 2 factors: composition of soil zone and type of bedrock limestone resolution. These in turn are controlled by the local climate and therefore a complete interpretation of stalagmite isotope data can deconvolve it into a calibrated rainfall record. An unprecedented calibrated record of rainfall for Central America over the past 500 years was built using a highly-resolved stalagmite $\delta^{13}C$ record from Yok Balum Cave, Southern Belize. Monthly instrumental rainfall records from 1966 onwards was available to allow for an accurate calibration. The YOK-G stalagmite stable isotope record has a bi-monthly resolution and allows palaeo-seasonality and intra annual rainfall over the last 500 years to be interpreted. This study suggested that the climate in Central America has changed drastically since the industrial period began in 1850. Climate cycles, relationships between rainfall pattern and climate modes have been analysed. Climate forecast presented concerning results: there will be less than 2 months a year with over 400 mm of rainfall by 2021, total annual rainfall amount will reach zero by 2120 and average rain season onsets will be delayed till September by 2051. This study also demonstrated an increasingly irregular timing for rain season onsets. Suggestions for further analysis and methods to improve the calibrated records were also presented.

Investigating Struvite Formation with Northumbrian Water Ltd.

Desouza, E. **TR3** 12:00

Struvite ($MgNH_4PO_4.6H_2O$) formation causes major blockages in the pipes and pumps in wastewater treatment works. This can lead to extortionate maintenance costs and even a full site closure. Since 2013, Bran Sands Regional Sludge Treatment Centre has experienced extreme operational issues costing in excess of £145,000 annually due to struvite concretions within the sites pipes and pumps.

Synthetically produced struvite crystals were observed under various conditions in order to assess the impact of molar ratio, initial supersaturation, turbulence and aeration on formation. A comparison of Bran Sands and Howdon RSTCs reveals that the slight differences in operational parameters, and the addition of aeration at Howdon, has meant struvite concretions do not form at Howdon.

In this investigation, multiple analytical techniques were utilized, including: powder X-Ray Diffraction (XRD), Scanning Electron Microscopy (SEM) and Atomic Force Microscopy (AFM). Powder XRD confirmed the identity of the crystals as struvite. Optical AFM images of the laboratory-grown crystals show that different morphologies of struvite present are dependent on the initial molar ratio of solution. SEM images of crystal samples from both plants show that

struvite at Bran Sands RSTC forms larger, individual crystals compared to Howdon where the struvite forms 1 mm aggregations of many smaller crystals.

This investigation concludes that flow rate, pipe material, magnesium concentration, pH and operating temperature all compound the struvite issues experienced by Bran Sands RSTC. Aeration of the Post Digester Storage Tanks has been shown to be the most efficient way to reduce the struvite concretions seen at Bran Sands RSTC.

Tracing the Natural and Anthropogenic Influence on the Chemistry of Estuarine Macroalgae: Insights from the Firth of Forth and Forth Estuary, Scotland

Ownsworth, E. **TR3** 12:15

Fifty samples of macroalgae (seaweed), encompassing five different species, were collected from twenty-five locations along the Firth of Forth and Forth Estuary in Scotland. Macroalgae has been shown to reflect the chemistry of the waters in which it lives and so has value as a proxy working as an environmental indicator. The macroalgae samples have been analysed for a number of different elements including: rhenium, osmium, arsenic, iodine and trace metals including zinc, lead and cadmium. The aim of this study is to understand how and why the abundances of these elements in macroalgae change across the longitude of The Estuary. Most of the elements show some trend in abundance across the longitude, whether it is an increasing trend (As, I, Cd, U, Re, Os), a decreasing trend (Pb, Cu) or a mid-estuary peak (Ni, Zn). Macroalgae elemental abundance is controlled by a number of factors including salinity, mixing, and intra- and inter-macroalgae species differences such as affinity for uptake, age, growth rates, and exposure to the atmosphere. In many cases it appears mixing plays a role in the overall macroalgae abundances, with mixing between end members of freshwater riverine inputs, and saltwater inputs from the North Sea. This is seen to have the largest effect on arsenic, iodine, lead, copper, cadmium and uranium abundances. Non-conservative mixing processes are also observed, mainly affecting zinc, nickel, silver, cobalt, rhenium and osmium, due to in-estuary sources such as natural and anthropogenic inputs from the surrounding geology, sewage and industry. The abundances of each element studied increase in the order: Os << Re < Ag < U < Cd < Co < Ni < Pb < Cu < As < Zn << I. Iodine (67 – 5061 ppm), lead (0.047 – 4.1 ppm) and cadmium (0.006 – 0.93 ppm) abundances found in the macroalgae are at relatively safe levels in regards to human consumption. This is important as some macroalgae species in the study site are harvested for the food industry. However, arsenic was found in high abundances (0.66 – 38 ppm), with many samples exceeding the UK limit of arsenic in regular foods.

Empirical relationships between actual and potential evapotranspiration at the catchment scale

Folds, J.L.D. **TR3** 12:30

In rainfall-runoff modelling a linear drying curve is often adopted to relate actual/potential evapotranspiration ratio (AE/PE) with soil moisture deficit (SMD) as it's believed to be a realistic representation of the complicated soil-water-evapotranspiration system. The linear model is tested against a step function to determine which produces the best streamflow predictions for 5 UK river catchments. To understand why the linear model is commonly used a literature review is conducted to examine the Feddes model and -15 bar wilting point which are some of its fundamental mechanics.

Analysis of the two models was conducted with the Nash Sutcliffe logarithmic efficiency coefficient and it was found that for all 5 catchments the step function produced a better model than its linear counterpart. Upon review the -15 bar wilting point for plants was found to be unreliable at best, with a combination of inaccurate measurements taken in the early

20th century and incorrect assumptions relating soil moisture content and hydraulic head, hampering the concept. This revelation discredited the Feddes model as one of its fundamental assumptions is that permeant wilting point will occur for all plants around the -15 bar point which is wrong.

The resulting conclusions drawn are; that the step function is the recommended method of representing AE/PE as a function of SMD, soil texture and meteorological conditions play a large role in model performance, finally the concept of -15 bar wilting point and its use in root models is limited as it was established by outdated science trying to quantify dynamic variables with static ones. The study has highlighted the need to redo Briggs and Shantz experiments with modern matric suction pressure measuring equipment to determine whether or not the concept of a uniform permeant wilting point should be discarded.

Investigating the Effects of Secondary Processes on Molybdenum Isotope Fractionation in Eucrites and Diogenites from the Asteroid Vesta

Adams, O.R. **TR3** 14:00

Molybdenum isotopes have the potential to be useful tracers of planetary differentiation. Since Mo is moderately siderophile, it preferentially partitions into the core of a planetary body and is strongly depleted in the silicate mantle. The magnitude of Mo isotope fractionation in the mantle can help to assess the conditions of metal segregation during core formation.

A previous study (Burkhardt et al., 2014) suggests that heavy Mo stable isotope compositions of eucrites, which are achondrite differentiated meteorites from the asteroid Vesta, reflect post core formation processes. Additionally, it concludes the need for a detailed understanding of any post core formation Mo isotope fractionation in order to use Mo as a suitable tracer for core formation.

In this study, mass dependent Mo isotope fractionation has been investigated for eucrites and diogenites, from the asteroid Vesta, and also for primitive chondrites. These data, combined with existing major and trace element data and petrographic observations, form the basis of exploring Mo isotope fractionation induced by post core formation processes. These processes include partial melting, impact contamination and weathering. In particular, Mo isotope fractionation data from diogenites may provide an interesting addition to the eucrite and howardite Mo fractionation data currently available in the literature. Diogenites are mafic cumulates with high MgO, and some reports suggest that they are parts of the Vesta mantle. Therefore, a comparison of eucrites and diogenites might elucidate any effects of melt differentiation. By understanding post core formation processes, we hope to achieve a better understanding of core formation fractionation, and therefore of core formation conditions. It is hoped that from this research, constraints for the conditions of planetary differentiation on Vesta can be better established, and this knowledge will be compared to our understanding of the formation of other differentiated bodies, for example Earth, Mars and the Moon.

Trace element mobility during high-pressure metamorphism in subduction zones: the Allalin Gabbros, Switzerland

Currie, J. **TR3** 14:15

This study aims to investigate the trace element budgets of gabbroic eclogites and associated vein samples in the Allalin Gabbro a series of gabbros, metagabbros and gabbroic eclogites from subducted oceanic crust at the mineral scale, and explore their origins as a product of element mobility in subduction zone fluids.

Samples of gabbroic eclogites and associated transitional eclogite and metastable gabbros have undergone metamorphism at very high pressures (>2GPa), and form the Allalin Gabbros, part of the Zermatt-Saas Ophiolite (ZSO) in the Western Alps.

Petrographic analysis has revealed a wide range of assemblages in the Allalin, due to the rocks' complex metamorphic history, variable alteration and recrystallisation, and the varied effect of fluid interaction with gabbroic lithologies. Trace element measurements will be used to assess element fluxes during subduction and fluid interaction.

Some localised veining is present in the samples, and has been assessed petrographically. These samples have been analysed to determine vein mineralogy and geochemistry, to interpret their origin in the context of the gabbros' metamorphic history. Veins in the ZSO have formed at a wide range of PT conditions at various stages of subduction and exhumation, and the veins in this project have notably different mineralogies and chemistries.

Existing microprobe, ICP-MS and XRF datasets will be combined with element data obtained by LA-ICP-MS as part of this project, and used to assess changes in trace element budget of gabbroic eclogites. The same process will be applied to vein samples, to infer a detailed element budget of vein fluids.

Questions include:

- To what extent are the trace element budgets of eclogite minerals controlled by initial gabbroic mineral budgets?
- To what extent are trace element budgets of eclogite minerals controlled by fluid interaction and chemistry?
- Which elements are mobile in fluids on the local scale? Does this have wider significance?
- Is this mobility representative of elements in other subduction zones, and can it be used in studies of mantle material or arc magmas in general?

Crustal Delamination in a Hotter Early Earth

Gibson, D. **TR3** 14:30

The effects of raised global internal temperature upon plate tectonics during the Archean eon remains a controversial issue. Much of the debate hinges on the theoretical style of crustal subduction during the early stages of Earth's development, an essential component in the uniformitarian view of plate tectonics. The process of crustal delamination - whereby cool, thermally buoyant crust separates from a warmer and weaker underlying harzburgite layer at the 670-km transition zone – has been proposed as possible mechanism for crustal subduction under these conditions. This study aimed to investigate the feasibility of such a process by recreating suggested crustal and upper mantle conditions within a 2D model. The most significant parameters were altered in an iterative process with the intent to find the threshold between pairs of parameters at which crustal delamination could occur.

The variables of slab velocity, crustal thickness, crustal viscosity, and the strength and thickness of the harzburgite layer were investigated, and a universal equation was produced defining the relationships between them. Slab velocity and the strength ratio between harzburgite and crust were deemed the most sensitive factors. This led to the conclusion that crustal delamination requires a fairly specific set of circumstances to operate, but that these could be achieved in situations with a slow basalt-eclogite transition and high levels of partial melting. As a mechanism in the early Archean, crustal delamination would potentially have contributed in helping to control the Earth's heat flow, recycling the oceanic crust, and aiding the onset of mantle layering. In the present-day, the presence of thin (~50km) crustal fragments above the 670-km transition zone could go some way to explaining the presence of hot spots, half-mantle convection, and unsampled reservoirs of primordial material.

Determining the crustal structure of the 13N fracture zone on the MAR

Johnson, C. **TR3** 14:45

Fracture zones along the mid-Atlantic ridge (MAR) provide detailed insight into much of the crustal heterogeneity observed in the Atlantic oceans. The distinct scars left behind by transform faults and their corresponding fracture zones can be identified for tens of thousands of kilometres offset from the spreading ridge in ocean basins. This study aims to un-earth the crustal seismic velocity and density structure of the 13N MAR fracture zone, through comprehensive geophysical methods, and further understand its spatial and temporal evolution within the context of the larger spreading centre region. 13N fracture zone crust was interpreted to be comprised of a fracture zone valley overlying a region of thinned, and fractured crust. The 13N fracture zone was found to support a region of high velocity material below the fracture zone valley, with a significantly reduced velocity gradient, similar to normal oceanic layer 3. However, here, this has been attributed to high degrees of lower crust and upper mantle serpentinization triggered by the percolation of hydrothermal sea waters deep into the lithospheric crust. In addition to this, gradual thinning of the crust was identified for tens of kilometres away from the fracture zone valley, indicating the effects of the reduced magmatic supply along a ridge spreading segment. Moreover, a further remnant or supplementary fracture zone was identified ~30km south of the 13N, which raises questions as to the implications of ridge jumping around areas of fracture zone segmentation.

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The Structure and Tectonic History of the Scremerston Region, Northumberland

Blackwell, A

Level 2 Undergraduate 01

During a one day field trip to Saltpan Rocks near Scremerston, Northumberland, observations and measurement data for structural analysis were collected to determine the deformation history of the region. An E-W trending cross section taken across the wave-cut platform has been interpreted as juxtaposing the fold limb of a regional antiform/synform pair which is suggestive of an approximately E-W σ1 direction for compression. To the west, parasitic, class 1B folds have been observed upon the interpreted regional folding. By considering the dominant fold amongst these, structural analysis was carried out. The northerly profile plane demonstrates an inclined asymmetric, closed antiform/synform pair with a westerly vergence whilst the southerly profile plane depicts a slightly inclined, open fold with an easterly vergence. The vergence and fold tightness change spatially implies a non-coaxial, heterogeneous stress field during deformation and an increasing E-W compressional stress to the north. The anisotropic competence between lithologies composing the folds, retained bed thickness and small scale fold accommodation faults indicate the folds developed by a flexural slip mechanism. Furthermore, hybrid hydraulic calcite veins crosscut the fold perpendicular to the fold hinge indicating a N-S tensile palaeostress syn-folding which combined with the fold analysis has allowed an oblate finite strain ellipsoid to be assigned. The presence of both brittle and ductile deformation is thought to suggest a basal brittle crust location whilst the change in fold vergence may imply a syn-deformation sinistral shear mechanism. A fore-arc basin of a subduction zone setting has been proposed.

Alaskan Avalanche Risk Assessment

Jenkins, B.

Level 2 Undergraduate 02

Snow avalanches are a relatively unpredictable natural hazard that can cause substantial damage to people and property caught in their path. This investigation attempts to apply an empirically derived model, using arcGIS, to predict where avalanches may be likely to occur, and their potential flow distance, near a popular tourist destination in Alaska.

Areas likely to generate an avalanche can be predicted by giving six different attributes of an area's topography an index and combining these indexes to produce a risk factor (Slope, Aspect, Altitude, Plan/Profile curvature and Roughness). The index values and risk factors have been empirically derived by applying this technique to locations where many natural avalanches have occurred and weighting the indexes to make the model output match the natural data.

Once high risk areas have been identified, the flow direction and length of avalanches from these areas can be estimated using a theoretical model looking at slope angles. The model used here was theorised based on debris flow friction mechanics and was then calibrated to existing flow propagation data. Full implementation of the model allows for a three-dimensional flow estimation using iterative regression calculation. However, in this study a one-dimensional approach was used to simply estimate the general direction and length of a potential avalanche.

One large very high risk area was identified in this study roughly four kilometres squared in size. Flow direction and length was estimated and potential avalanches are not predicted to encroach on any heavily populated areas.

The structure and tectonic history of the Scremerston region, Northumberland

King, A.G.

Level 2 Undergraduate 03

Geological field work was undertaken in Scremerston, situated in Northumberland on the North Sea coast, 3 miles south of Berwick-Upon-Tweed. Detailed observations, field sketches and structural data was collected in order to interpret and hypothesise likely folding mechanisms and overall tectonic setting of the highly deformed Lower Carboniferous sedimentary sequence exposed at Scremerston. It was found the deformed rocks have been subject to high strains with an Rxz value > 1 and due to the asymmetrical nature of folds, non-cylindricality and presence of en-echelon veins, strain was non-coaxial. The main fold analysed is interpreted to be a minor fold, likely a second order fold, which is part of a greater fold system where there is a larger scale antiform to the west. The fold is of constant layer thickness and composed of more competent limestone beds interbedded with less competent shale. The strong mechanical anisotropy, along with slickenlines observed on the limbs of the fold, is indicative of a flexural slip mechanism. Flexural slip is closely related to a flexural flow mechanism which formed the higher order parasitic folds. The deformation is hypothesised to be dextral strike-slip where a left-stepping offset along a dextral fault has led to the formation of a restraining bend with σ1 acting in an E-W direction and σ3 acting N-S and is tensile (due to the presence of mode I tensile fractures striking E-W). The strike-slip deformation formed a shear zone allowing parasitic folds to form and exemplifies the heterogeneous strain present.

An investigation into the nature of the hotspot beneath Hawaii

Wild, H.

Level 2 Undergraduate 04

Since J. Tuzo Wilson's theory of a mantle hotpot beneath Hawaii (1961), extensive research has been undertaken in order to establish the hotspot's nature and its effect on the geology of Hawaii. Research was initially into the age relation of volcanoes along the Hawaiian and Emperor island chain but soon advanced towards earthquake frequency analysis and P-wave analysis of the region. The aim of this poster is to compile and analyse the data produced from this research through the use of the geospatial computer programs: Arcmap and Arcscene. This geospatial analysis displayed in this poster has shown sufficient evidence for the Hawaiian hotspot, which extends down to greater than 900km and possesses a bent geometry, as indicated by the low P-wave velocity shadow. This hotspot has also been interpreted as a cause for isostatic instability across Hawaii, which is expressed through the nature and distribution of faults similar to those found during synorogenic collapse. Geostatistical analysis was also conducted on earthquake data, which along with active volcano distribution, allowed for the estimation of the current hotspot location.

Foraminifera and ice cores provide evidence for orbital forcing as a partial explanation of global climate change

Craik, P.S.

Level 3 Undergraduate 05

It is widely believed that climate change trends can be explained and modelled by considering the variations in the Earth's orbit - the Milankovitch theory. In this project, δ18O trends from benthic foraminifera and atmospheric data from Antarctic ice cores were considered. Using various methods of computational time-series analysis on these climate proxy records, it was observed that global climate appears to display periodicities corresponding to orbital cycles. Initial spectral analysis showed strong periodic trends corresponding to cycles in orbital eccentricity, obliquity, and precessional index. The data sets seem however to be related to orbital cycles in a

non-simple way; more detailed short-time Fourier transform (STFT) analysis also showed orbital frequencies, but revealed different periodicities at different points in longer δ18O records. This suggests that while Milankovitch forcing almost certainly plays some part in climate change, the relationship is more complex with significant dependence on other factors.

Carbon and nitrogen isotope stratigraphy of the Triassic/Jurassic boundary in the UK

Love, T. & Gröcke, D.R.

Level 3 Undergraduate 06

The Triassic/Jurassic boundary (TJB) and associated mass extinction event occurred at ~201.3 Ma, and was coincident with large igneous province (LIP) formation – Central Atlantic Magmatic Province (CAMP). The boundary is generally identified by the first appearance datum of the ammonite *Psiloceras*, but this occurs within the Hettangian and not at the TJB. Previous research has proposed that the 'initial' carbon isotope excursion seen at the stratigraphic boundary can be used more reliably as a global stratigraphic marker of the TJB, instead of using ammonite biostratigraphy. Although this has been demonstrated in many global locations, the TJB carbon isotope excursion has been used in this study to correlate section from across the UK in order to investigate the palaeoceanographic nitrogen isotope cycle over this extinction interval. In this study we provide high-resolution organic carbon isotope ($d^{13}C_{org}$) and total nitrogen isotope ($d^{15}N_{tot}$) curves from three UK cores at the BGS: Felixkirk Borehole (North Yorkshire), Cockle Pits (East Riding of Yorkshire) and Great Orton (Cumbria). All three cores were correlated using ($d^{13}C_{org}$ against the isotopic type-section at St Audrie's Bay (Somerset). This allows us to directly compare each site with respect to regional variation of nitrification or denitrification using $d^{15}N_{tot}$. Felixkirk Borehole shows a distinct shift from more positive $d^{15}N_{tot}$ values (~+4‰) in the Triassic to less positive values in the Jurassic (~+1‰). This change across the TJB suggests a significant palaeoceanographic change from one that was dominated by intense upwelling of ^{15}N-enriched nitrate into a suboxic/oxic zone in the surface waters whereby denitrification occurs to a period of nitrification in an oxygen-rich environment whereby nitrification and N_2-fixation occurred in the Hettangian, Jurassic. In comparison, Cockle Pits record variable d15N values between +2‰ to +4‰, whereas Great Orton records little variation with a gradual trend from ~+4‰ to +3‰ across the TJB interval. Total organic carbon, pyrite sulphur isotope ratios and iron-speciation data will also be presented from Felixkirk Borehole that support this palaeoceanographic change across the TJB interval in the UK.

Development and Testing of a Monte Carlo Markov Chain Inversion of Seismic Oceanography Data

Passey, E.M.

Level 3 Undergraduate 07

Seismic oceanography provides a technique to utilise marine seismic data to image full-section thermohaline structures of the oceans, where direct measurements cannot be taken. When combined with CTD data, temperature and salinity profiles can be recovered from seismic oceanography data. MCMC methods are a powerful tool to perform mathematical inversion for complex problems with many parameters, allowing for the quantification of all aspects of uncertainty in the problem. Here, an MCMC inversion written by Tang *et al*. (2016) is developed to recover T-S profiles of water bodies over the Wyville-Thomson Ridge. Firstly, the method is tested against constrained synthetic data created from CTD data, and T-S profiles are recovered accurately with errors of 0.01°C and 0.01 psu. Secondly, the method is tested on real seismic data that has undergone standard processing and sparse spike deconvolution, with little success. Further testing of synthetic data

shows that the method is not robust enough to handle the large thermohaline contrasts observed at the Wyville-Thomson Ridge without massive constraint on prior models. Improvements to the method have been suggested in order to strengthen the inversion for data sets with steep thermohaline gradients.

Investigating struvite formation at Bran Sands Regional Sludge Treatment Center

Desouza, E.

Level 4 Undergraduate 08

Struvite ($MgNH_4PO_4.6H2O$) formation causes major blockages in pipes and pumps at wastewater treatment works leading to extortionate maintenance costs and even full site closures. Since 2013, Bran Sands Regional Sludge Treatment Centre has experienced extreme operational problems due to struvite concretions, costing in excess of £145,000 annually.

Synthetically produced struvite crystals were observed under various conditions to assess the impact of molar ratio, initial supersaturation, turbulence and aeration on formation. In this investigation, multiple analytical techniques were utilized, including: powder X-Ray Diffraction (XRD), Scanning Electron Microscopy (SEM) and Atomic Force Microscopy (AFM). Powder XRD confirmed the identity of struvite. Optical AFM images of the laboratory-grown crystals show the presence of different morphologies depending on initial molar ratio of solution. SEM analyse of crystals from both plants show that Bran Sands RSTC forms larger, individual crystals compared to Howdon where the struvite forms 1 mm aggregations from smaller crystals. AFM analyse of epitaxial dissolution of struvite shows the emergence of interlacing step sequences.

This investigation concludes that flow rate, pipe material, magnesium concentration, pH and operating temperature all compound the struvite issues experienced by Bran Sands RSTC. The AFM surface analyse, coupled with struvite's dependence on initial supersaturation, supports a diffusion controlled growth mechanism. A comparison of Bran Sands and Howdon RSTCs reveals that the slight differences in operational parameters, and aeration at Howdon, has meant Howdon does not from struvite concretions. Aeration has been shown to be the most efficient way to reduce struvite concretions at Bran Sands RSTC.

The effect of the geochemical environment on the concentration of amino acids by layered double hydroxides

Hodges, Z.V.

Level 4 Undergraduate 09

One of the main origin of life theories is that of the 'Peptide World'. To form peptides from amino acids in aqueous environments on the early Earth, a means of selecting, concentrating and protecting these prebiotic organic molecules would have been required. Adsorption to mineral surfaces has been invoked as one mechanism for the formation of peptides.

Layered double hydroxides (LDHs) are a suite of inorganic lamellar compounds capable of adsorbing anions within their interlayer spaces. Particular LDH minerals of interest in the origin of life include brucite and green rust; in this study, the Mg^{2+}/Al^{3+} LDH is used as a substitute for green rust. The ability of Mg_2Al-LDH to uptake amino acids via ion-exchange is investigated, as this method of intercalation is most relevant to prebiotic synthesis.

Here, the first study on the effect of temperature (30, 60, 90°C) and competition on the uptake of amino acids via ion-exchange is reported. Four different amino acids were successfully intercalated into Mg_2Al-NO_3 LDH at alkali pH and it has been demonstrated that both temperature and competition affect amino acid uptake. Additionally, the use of proton nuclear magnetic resonance (^1H NMR) as a novel quantitative measure of uptake is investigated, although further refinement of the method is required. The ability of LDHs to intercalate amino acids via ion-

exchange at alkali pH could be relevant to prebiotic peptide formation at alkaline settings on the primordial Earth; thus, highlighting the important role that these layered minerals may have played in the origin of life.

Implementation of trace elements behaviour in the numerical modelling of magmatic processes

Cornet, J., Grigorova, V. Riel, N., Bouilhol, P., & van Hunen, J.

MSc Student 10

Trace element analysis of rocks and minerals can provide valuable insight in geochemical differentiation processes, and therefore may offer fundamental insight into geodynamical processes such as melt migration in the mantle or crust. But such processes often involves a multitude of magmatic, metamorphic, or metasomatic thermodynamic reactions, and the trace element behaviour during each of these reactions is complex, which makes interpreting the trace element composition of the end product difficult or impossible.

Here, we present a novel numerical tool for the prediction of trace element behaviour during melting processes. To develop such tool, we used the following approach. First, we compiled the predictive models of partition coefficient based on the lattice strain model (LSM) available in the bibliography. Next, we built our own predictive models by applying statistical regressions on large dataset of trace element partition coefficients when the LSM is not suitable for their prediction. The predictive models were then gathered in an easy-to-use Matlab program TEPM. In our study, we focused on the phases that play an important role in trace elements fractionation within mafic system such as garnet, olivine, pyroxenes, plagioclase and amphibole.

We combine this tool with a state-of-the-art thermodynamic database called Perple_X. This allows us to model the major element composition, the mode and the behaviour of the mafic minerals in given P-T conditions. This offer new perspective in term of numerical modelling since our work give the opportunity to model the major and trace elements composition in geodynamic systems.

The role of deformation bands controlling reservoir quality in a salt-walled mini-basin, Central North Sea, UK

Davies, P.

MSc Student 11

This study focusses on the Triassic Skagerrak Formation, of the Central Graben, North Sea, where abundant deformation bands have been observed near the margins of the salt-walled mini-basins in which the fluvial facies of the Skagerrak Formation was deposited.

Sediments are typically poorly consolidated and subject to low pressures and confining stresses at shallow depths (<1000 m) and dilatant fractures that form under these conditions would be unable to remain open. However, the resultant increase in pore space would allow for processes such as grain sliding and grain rolling to occur, producing deformation bands. In thin section, these deformation bands have been observed to not show any grain breakage or significant abundances of phyllosilicate minerals along the bands and some bands have been observed with a small offset along their length. These observations would kinematically classify the deformation as dilation bands or dilatant shear bands. These deformation bands would become preferential conduits for fluid flow, which could lead to the precipitation of clay minerals and diagenetic material along the band. These minerals would subsequently decrease permeability perpendicular to the bands, acting as baffles or temporary barriers to fluid flow.

The results presented here highlight the importance of constraining how dilation and dilatant shear bands allows for the better understanding of the kinematics of the salt movement adjacent to the sediments.

Furthermore, this study identifies the importance of how early formed deformation bands can later influence the petrophysical properties of sediments in a salt-walled mini-basin.

Contribution of volcanic forcing to the initiation of the Black Death Epidemic

Fell, H.

MSc Student 12

The 14th Century bubonic plague epidemic, commonly termed the Black Death, is known to have coincided with the tumultuous climatic shift from the relative stability of the Medieval Climate Anomaly (MCA) to the initiation of the Little Ice Age (LIA). The plague is predominantly a vector borne disease that is spread through the transmission of the *Yersinia pestis* bacteria. This bacterium is thought to have originated in the rodent populations of the Tibetan Plateau and later spread rapidly westward though Eurasia after Vector transmission to humans. Several studies have determined that Asian rodent and vector populations are highly sensitive to climatic perturbations. The Samalas eruption of 1257 was the largest injection of aerosols in the Common Era and as such can be anticipated to have significant climatic effect. Through a range of proxy records across Eurasia we reconstruct the climate for the period immediately preceding the outbreak of plague. This study investigates the interaction between the Samalas eruption of 1257, the climatic response to the event and the potential effect on the initiation of the Black Death epidemic which shaped population and culture across Eurasia for centuries.

Earth's late veneer and its link to volatile delivery

Findlay, A.R.W.

MSc Student 13

Water rich carbonaceous chondrites may be a significant contributor to the highly siderophile element (HSE) budget of the Earth's mantle through the late veneer - the addition of primitive material and small planetesimals after core formation had ceased. The late veneer provides possible answers to two major questions in the earth sciences: (1) why the HSE budget of the mantle is higher than expected post core formation; and (2) the origins of Earth's water.

On the contrary, current work on Os isotopes (one of the HSEs) suggest that carbonaceous chondrites are too unradiogenic to be a viable source for the excess HSEs within the mantle, consequently ruling them out as a viable volatile source. However, carbonaceous chondrites are known to have undergone early hydrous alteration, which may have mobilised Re, resulting in a lower ingrowth of ^{187}Os over time.

We present a combined ^{187}Os -^{186}Os isotope study of several carbonaceous chondrites (CV, CO, CK, and CM groups) at the whole-rock scale. The Allende meteorite (CV3) has been further crushed and picked for study at the component scale, namely for chondrules of varying size, matrix, sulphides, metal and calcium aluminium rich inclusions (CAIs). We assess the reliability of the Os record, by comparing the $^{187}Os/^{188}Os$ and $^{186}Os/^{188}Os$ results of chondrites and their components to observe any systematic variations. In addition, Os data is analysed alongside HSE data to better understand the relationship between ^{187}Os -^{186}Os and their parent isotopes, and Zn data to trace any elemental loss due to volatility

A New Appraisal of the Hydrocarbon Prospectivity of the Melville Basin, Southwest Approaches

Ottaviani, A., Stricker, S., Lee, J., Imber, J., & Jones, S.

ERASMUS+ Trainee 14

The Melville Basin lies ca. 250 km southwest of Land's End. Durham University, in collaboration with Keele and Leicester Universities, Trace Editors, Geospatial Research and Applied Petroleum Technology, is re-evaluating the hydrocarbon

prospectivity of the Melville Basin on behalf of the Oil & Gas Authority. The first and only phase of exploration took place in the 1970s and 80s, with 14 wells (including re-spuds) drilled in an area of ca. 9000 km^2. Thus, the Melville Basin is a real "frontier exploration" region.

Our evaluation of historic well reports demonstrates that source rock presence and maturity is the primary exploration risk. The Lower Jurassic (Liassic) is the most likely source rock interval, but preservation is patchy due to erosion along the "Cimmerian" (base Cretaceous) unconformity. Where drilled, the Liassic was found to be immature or marginally mature for oil generation.

We present a burial history analysis encompassing all wells within the Melville, St Mary's and Plymouth Bay Basins. Thermal histories have been calibrated to present-day temperature and vitrinite reflectance data. The most likely scenario for Mid to Late Jurassic deposition and Cimmerian erosion indicates that maximum burial – hence the main phase of oil generation – occurred during the Late Jurassic. The preservation of hydrocarbon accumulations therefore depends on: traps having developed during, or prior to, the Late Jurassic; and seal integrity being maintained throughout Cimmerian exhumation and subsequent Alpine inversion. Reservoir quality is an additional risk. Petrographic observations show that widespread carbonate cementation has reduced the porosity of potential Permo-Triassic sandstone reservoirs.

Treatment of domestic wastewater using Anabaena variabilis

Abedi, S.

PhD Student 15

Fresh water is fast becoming a high demand scarce resource for domestic use, industrial processes, and irrigation-fed agriculture. Recycling wastewater is therefore an essential part of fresh water budgeting for cities and urban conurbations. To enable wastewater recycling or release into the environment, it has to undergo treatment to remove high levels of nutrients and toxic heavy metals. In addition to addressing fresh water demand, wastewater treatment is vital for environmental protection by reducing pollution of river systems. By harnessing the ability of microorganisms to deftly adapt to new chemistries never encountered before in their evolutionary history, this project aims to develop algal strains capable of treating specific wastewater streams in collaboration with an industrial partner - Northumbrian Water Ltd. In this study, we are investigating the use of Anabaena variabilis strain 29174 in pollutant removal. Gradual adaptation of the alga for growth in the domestic wastewater stream is being achieved via sequential inoculation of an increasing gradient of wastewater strength. We noted that growth in the wastewater is attended by very remarkable morphological changes in the alga, which manages to attain maximal multiplication within 72 hours of inoculation. Water quality parameters, including measurements of nitrate, sulphate and phosphate content, are monitored before and after algal proliferation. In addition, the efficacy of algal treatment on BOD, COD, EC and heavy metal ion composition is evaluated. Our results demonstrate successful deployment of biological adaptation in rapid development of "bespoke" algal strains for treatment of specific wastewater streams.

Lithospheric Stress Control on the Distribution of Mariana Arc Volcanoes

Harisma, A.

PhD Student 16

Volcanoes distribution has been described as a small circle and used to understand the melting process regarding the mantle wedge thermal structure in a subduction zone. Using Hough Transform analysis on a more comprehensive dataset, consisting 37 volcanoes, five lineaments were recognised with 3 km overall misfit, better than 8.43 km misfit from the best fit small circle.

Variography analyses agree with the typical segmentation length in Mariana arc as it shows a strong correlation between volcanoes' spacing and volume within 400 km distance.

Ellipticity analysis on the volcanoes morphology shows significant changes of trench-relative stress regime between the northern and southern segments. The northern segments are dominated by trench-relative compression while the southern segments by trench-relative extension. The lateral changes of stress regime can be explained by the different source of the force that affected the segmentations. The southern segments are also controlled by the normal spreading from the southernmost area, not only from the spreading in the back-arc and subduction process which also occurs in the northern segments. Furthermore, the analysis of the back-arc faults explained the lines generated from Hough Transform are representing the same extensional features but in the deeper crust below the arc.

Interpretation models were constructed based on all observation result and tested by the earthquake focal mechanism within the area. The strain field agrees with the interpretation model where the overriding plate stress is partitioned. It suggests that the control of upper plate structure play an important role in the distribution of volcanoes.

The potential for spills and leaks of hydraulic fracturing related fluids on well sites and from road incidents

Clancy, S., Worrall, F., Davies, R., & Gluyas, J.
PhD Student 17

The potential growth of shale gas developments within Europe has raised concerns of the possibility of spills and leaks from shale gas sites and from liquid transportation via roads and pipelines. Data from a range of sources has been examined to estimate the likelihood of an incident. From the US, the Texas Railroad Commission and the Colorado Oil and Gas Commission have maintained records of the quantity; reasons for the spill; and reported impacts. For the UK, the Environment Agency pollution incident database and transport statistics from the UKs Department for Transport have also been analysed and used as an analogy to determine the likelihood of an incident or spill on the road. Data were used as an analogue to predict the potential number of spills and leaks that might occur at a well site, or in transport operation, under different shale gas development scenarios if fracking was to go forward in the UK.

The evolution of shallow crustal structures in early rift-transform interaction: a case study in the northern Gulf of California

Farangitakis, G.P., van Hunen, J., Kalnins, L.M., Persaud, P., & McCaffrey, K.J.W.
PhD Student 18

The Gulf of California represents a young transtensional plate boundary in which all the transform faults are actively shearing the crust, separated by active rift segments. In the northern Gulf of California, relative plate motion between the Pacific and North American plates is distributed between: a) the Cerro Prieto Fault (CPF) in the NE b) the Ballenas Transform Fault (BTF) in the SW and c) a pull-apart structure located between these two faults consisting of a number of extensional basins. A plate boundary relocation occurred at approximately 2 Ma, creating the 200x70 km2 NE-SW pull-apart structure located northeast of the BTF.

Here we use seismic stratigraphy analysis of the UL9905 high resolution reflection seismic dataset to build on previous structural interpretations and seek to further understand the processes that formed the structural and sedimentary architecture of the pull-apart basin in the northern Gulf of California. We examine the formation of depositional and deformation structures in relation to the regional tectonics to provide insight into the development of structural patterns and

related seismic-stratigraphic features in young rift-transform interactions. Using bathymetric data, characteristic seismic-stratigraphic packages, and seismic evidence of faulting, we confirm the existence of a number of major structural domains in the northern Gulf of California and examine the interaction of the seismic stratigraphy and tectonic processes in each zone. These patterns can be compared with seismic stratigraphy facies and structural patterns in mature transform margins and potentially give insight into their early history.

Quantitative controls of pore systems in carbonate-rich shales: the Eagle Ford, Texas

Gaiani, I.

PhD Student 19

Shales are clastic sedimentary rocks that, if found to be rich in organic matter, may generate significant quantities of hydrocarbons. However, as they mostly present sub-nanometer to micron-scale pore sizes, the flow of hydrocarbons through the system at relatively low pressures is impeded.

Due to the advent of pioneering developments in the recovery methods, it is now possible to economically extract hydrocarbons from these source rocks. Yet, the success of extraction is given by a good prediction of the flow pathways and the potential sites for hydrocarbon storage. Given the high textural and mineralogical heterogeneity of this type of reservoir, a quantitative understanding of the porosity system is required.

This project focuses on the Eagle Ford Formation, a carbonate and organic-rich shale that trends across Texas.

A set of samples of variable maturity and facies from different locations was provided by Shell, Houston. At first, the factors that influence the mineralogy and the diagenetic processes that have occurred in the samples have been interpreted by means of XRD, transmitted and reflected light optical microscopy, EDX and SEM analysis. Secondly, pore sizes and pore connectivity have been measured by means of state-of-the-art techniques such as microCT, Gas Adsorption (He, CO_2 and N_2) and MICP. As a future analysis, the chemistry of the surface pores will be analysed chemically by means of AFM together with nanoIR-spectroscopy. In particular, this will provide information on the wettability of the samples and therefore on the flow behaviour of oil and gas at the nano-scale.

3D P- and S-wave Velocity Structure and Anisotropy of 6.9 Ma Oceanic Crust at ODP Borehole 504B

Gregory, E., Hobbs, R.W., Peirce, C., & Wilson, D.J.

PhD Student 20

Faults and fracture networks within the oceanic crust influence the pattern of hydrothermal circulation. This circulation changes the primary composition and structure of the crust as it evolves, particularly the upper crust (layer 2), through the secondary alteration of minerals and infilling and 'sealing' of cracks. Processes influencing the extent and the depth within the crust of these changes are currently not well known. Alteration can be investigated by observing changes in the seismic velocity structure of the crust, while analysis of seismic anisotropy within the upper crust reveals the nature of aligned faults and fractures acting as fluid pathways.

Here we show 3D Vs and Vp models for 6.9 Ma crust at ODP borehole 504B, situated ~200 km south of the Costa Rica Rift, derived from an active-source wide-angle seismic survey in the Panama Basin conducted in 2015. The P-wave seismic structure reveals relatively homogeneous, ~5 km thick oceanic crust with upper crustal velocity boundaries coincident with alteration fronts observed in 504B. A correlation between basement highs and faster upper crustal velocity suggests a shallowing of the layer 2b/2c transition in these locations, potentially linked to more

intense hydrothermal alteration of the upper crust. Upper crustal azimuthal anisotropy is present with a strong cos(2Θ) pattern, indicating aligned open fractures with a ridge-parallel fast direction.

The calculation of Poisson's ratios details variations in fracturing and alteration and, combined with anisotropy analysis, relationships are drawn between hydrothermal alteration, basement topography, fracturing, and the velocity structure of layer 2 as a whole.

The nucleation of laboratory earthquake and the influence of the loading conditions

Guerin-Marthe, S.

PhD Student 21

The slow slip prior to rupture is a key observation to study the precursory phase of earthquakes. Although most of the field studies of nucleation focus on foreshocks sequences recorded at seismic stations, recent GPS observations of the 2014 Chile megathrust evidence a slow slip phase where a significant portion of the moment release is aseismic. Here we present laboratory observations of this slow slip preceding a rupture. The setup composed of two polycarbonate plates in a biaxial machine enables to visualize the stress field at the interface, and track the rupture tips. A high-speed camera records at 300000 frames per seconds the events. The results of our laboratory experiments are in accordance with the theory, showing a slow slip followed by an acceleration up to a constant rupture velocity, generally the Rayleigh wave speed. It also shows that varying the loading conditions, including initial normal stress or loading rate strongly influences the rupture behavior.

Infiltration of a syenitic crystal mush evolved, late-stage and volatile-rich melts

Hughes, J.W., Humphreys, M.C.S., Cooper, G.F., & Holness, M.B.

PhD Student 22

Located in the Gardar Igneous Province of South Greenland, the 3 x 4 kilometre Klokken gabbro-syenite intrusion (1166 ±3 Ma) shows evidence of infiltration of syenitic crystal mush by evolved, late-stage, volatile-rich melts. The core of the intrusion comprises a laminated syenite (LS) series that hosts large fragments of the roof cumulate sequence (granular-textured syenite, GS) that repeatedly delaminated during crystallisation. Ultramafic residual melts from the LS form a suite of filaments or 'wisps', comprising cpx + bi + ol + ox + afs + amph + apatite, infiltrating the GS.

The morphology of the infiltration textures varies systematically with stratigraphic position relative to the inferred paleo-roof zone. This is interpreted as a reflection of systematic changes in the deformation behaviour of the GS crystal mush. GS in proximity to the roof zone contains extensive, planar-sided fractures that have been exploited by both the LS and the late-stage melts. In comparison, stratigraphically lower GS sheets are infiltrated by an interconnected network of irregular wisps, generally up to 3-4 cm in width. The spacing and the number of wisps appears to be influenced by grain size and crystal orientation of the GS crystal mush, the width of the individual GS sheet and the nature of the GS-LS contact. The lowermost sheets of GS appear to be hybridised; here infiltration and deformation of the mush is characterised by disaggregation. We interpret this progressive variation in rock fabrics as a manifestation of changes in rheology of the GS crystal mush, from brittle to ductile, with changing temperature and crystallinity.

Magmas within the Gardar Igneous Province are typically enriched in LILE, HFSE and F. The region hosts a number of Tier 1 REE-Nb-Ta-Zr ± U deposits (e.g. Kvanefjeld, Kringlerne and Motzfeld). Better characterisation of the migration of late-stage, evolved melts such as those identified at Klokken has wider implications for our understanding of ore forming processes in magmatic environments.

Where has all the porosity gone?: Linking pore pressure evolution and reservoir quality in the Taranaki Basin, New Zealand

O'Neill, S.R.
PhD Student 23

The Taranaki Basin (TB) lies onshore and offshore in central-west New Zealand. The basin has undergone rapid subsidence and burial, accumulating up to 8km of sediment since the Late Cretaceous with many overpressured regions of up to 4000psi/28MPa above hydrostatic. It has been shown that shallow early onset of high pore fluid pressure (low vertical effective stress) can inhibit pressure dissolution driven by mechanical compaction; thereby reducing the load borne by intergranular grain contacts and maintaining high primary porosities. This study has focused on the Palaeocene Farewell Formation which is dominated by high N/G multi-stacked multi-lateral fluvial sandstones. Kapuni Deep-1 well was drilled onshore to test the reservoir potential of the deep Farewell (>5000m TVD), which was found to be significantly overpressured (3000psi/21MPa) but displayed very poor reservoir quality with measured porosity and permeability of 2.88% and 0.095mD respectively.

1D basin modelling has shown that the Farewell Formation has experienced initial rapid burial leading to porosity loss through mechanical and subsequently chemical compaction. Rapid burial beginning in the Pliocene drove the formation of significant overpressure through disequilibrium compaction, but was too late to act in arresting porosity loss. Degradation of feldspars has led to precipitation of pore filling kaolinite and pore bridging illite which has further impacted the reservoir quality. Although the overall reservoir quality is poor, the deep Farewell Formation could still be an attractive exploration prospect if secondary porosity and connected fractures are charged with movable hydrocarbons.

Does Vertical Effective Stress Influence Quartz Cementation?

Oye, O.J., Aplin, A.C., Jones, S.J., & Gluyas, J.G.
PhD Student 24

It is well established that the development of shallow overpressure within sedimentary basins reduces vertical effective stress (VES) and inhibits mechanical compaction, thus preserving porosity and economic reservoir quality. However, the influence of vertical effective stress on chemical compaction ("pressure dissolution") and related quartz cementation in sandstones has been de-emphasized in several clastic reservoir studies that have favoured temperature as the control on quartz cementation. These models suppose that quartz cementation is controlled by temperature-related precipitation kinetics and that supply through dissolution of quartz at grain contacts, which may be influenced by VES, is largely irrelevant. This study is targeted at understanding the relevance of VES to quartz cementation by investigating the shallow marine sandstone of the Upper Jurassic Fulmar in the UK Central Graben. Samples have been chosen from upper shore face sands from Clyde (30/17B), Elgin (22/30C) and Fulmar (30/16) fields. These sands are essentially same facies, but have had different VES-temperature histories. All are at maximum burial depth with present day temperatures and VES as follows: Fulmar 127^{o}C& 30MPa; Clyde 147^{o}C& 40MPa; Elgin189^{o}C and 10MPa. Point count data from transmitted light and SEM-CL petrographic analysis show that sands from Elgin – the highest temperature and lowest VES sample set has a lower average quartz cement content (2.0 ± 1.4%) than both Fulmar (2.8 ± 1.7%) and Clyde (3.6 ± 1.6%). The occurrence of e.g. clay coatings and micro-quartz cannot account for the differences in quartz cement. Since Elgin has been in the classic quartz cementation window (i.e. > ca. 80^{o}C) for over 90Ma,we suggest that chemical compaction at quartz-quartz contacts and related cementation has been limited by low VES from high pore fluid pressure through much of Elgin's burial history.

The Rovuma Transform Margin: the enigmatic continent-ocean boundary of East Africa

Phethean, J.J.J., Kalnins, L.M., van Hunen, J., McCaffrey, K.J.W., & Davies, R.J.

PhD Student 25

The N-S trending Davie Fracture Zone (DFZ) is often assumed to form the continent-ocean transform margin (COTM) of the Western Somali Basin. However, multiple plate tectonic reconstructions favour a pre-breakup location for Madagascar that crosses the DFZ, incompatible with its interpretation as the COTM (e.g., Lottes & Rowley, 1990; Reeves, 2014; Phethean et al., 2016). For the first time, we have identified classic COTM features in seismic reflection data from the Southern Rovuma Basin, to the west and inboard of the DFZ. These suggest a NNW trend to the margin, consistent with the tectonic reconstructions. 2D gravity models, with the seabed and top basement constrained by seismic data, are used to investigate the Moho structure across the Rovuma margin and are best fit using steep 'transform style' geometries, confirming the nature of the margin. We thus model generic COTM geometries elsewhere along the East African and Madagascan transform margins to locate best-fitting positions for these conjugate COTMs. This analysis confirms that the COTMs follow a NNW trend along the Rovuma Basin and Southern Madagascar, respectively, and allows a restoration of the conjugate COTMs. We believe that this study finally provides conclusive evidence that Madagascar originated from within the Tanzania Coastal Basin, inboard of the DFZ, after some 30 years of debate regarding this matter.

CFM study of brine effect on adhesion of silica face kaolinite

Santha, N. & Cubillas, P.

PhD Student 26

The interaction between oil, clay, and brine plays a crucial role in increasing the oil yield from low salinity enhanced oil recovery (LSEOR) in sandstone reservoirs. LSEOR is driven by a change in the wettability state of the reservoir (from oil to water wet), but the underpinning mechanisms behind it are not fully understood. It has been hypothesized, however, that the reduction in "adhesion" of oil to clay minerals present in the reservoir is one of the main drivers in the change of wettability. We have set to study the adhesion of representative oil molecules to clay surfaces at the nanoscale by means of chemical force microscopy using at various brine concentration and pH conditions. In our experiments, the polar crude oil is represented by functionalized tip which are carboxylic acid (-COOH), amide ($-NH_2$), and alcohol (-OH) terminated Kaolinite is selected as a representative clay mineral (silica face). Adhesion measurement is performed in NaCl and $CaCl_2$ with concentrations of 0.001 M, 0.01M and 1 M, and with pH ranging 5 to 9. Results show that the concentration effect produced three different trends for the three functional group categories. At pH close to neutral, changes from low to high $CaCl_2$ concentration resulted in an inverse low salinity effect for -COOH tips (i.e. adhesion increased at lower concentrations), whereas the opposite was true when the pH of the solution was 8 (i.e. adhesion decreased with decreasing concentration).

Challenges with Seismic Imaging in Volcanic Margins

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PhD Student 27

Volcanism associated with continental breakup and the formation of the North Atlantic covers much of the Faroe-Shetland Basin, causing a major problem in geophysical exploration of margin basins. The extrusive basalt sequences on the Atlantic margins can be in excess of 3 km thick, and

are highly heterogeneous, which causes complex scattering and attenuation of the seismic wavefield during exploration surveys, resulting in poor intra-basalt and sub-basalt seismic imaging. Sequences contain a range of lavas, intra-basaltic siliciclastic and volcaniclastic sediments, and the high acoustic impedance contrasts between units results in the generation of multiples and mode conversions. In addition, lavas exhibit a high impedance contrast between the dense flow cores and the lower density unit crusts, as well as rough interfaces, which leads to additional wave scattering. Wide-angle refraction acquisition is often preferred to traditional reflection techniques, however results can still be unreliable, as will be shown. Furthermore, igneous sills, which typically have a high velocity and density relative to the surrounding sedimentary country rock, result in strong seismic reflections. This becomes problematic in stacked sill networks, where thick sills mask the appearance of thinner sills below. Many intrusions are below the level of the vertical seismic resolution, meaning they are missed during the interpretation of seismic data. We use synthetic seismograms, generated from models based on field analogues from Utah, USA, and well-log data from the Faroe-Shetland Basin, to highlight some of the challenges faced using seismic techniques along volcanic margins

Magmatism in numerical models of continental collision zones

Schliffke, N., van Hunen, J. Allen, M., Magni, V.
PhD Student 28

Magmatism in continental collision zones still is poorly understood due to the diversity of possible subduction dynamics and petrological processes. Particularly in continental collision zones, where small amounts of magma with a diverse composition are produced, magmatism might provide unique insight in the underlying dynamical and chemical processes. The thickness and rheology of the colliding continent are key parameters influencing subduction dynamics. The two parameters control delamination or slab breakoff which in each case would differ in the magmatic response. This setting may be applied to the central Mediterranean subduction zone where the subducting plate seems to be delaminating beneath the younger and thinner Apennines but not beneath the cratonic Nubian plate.

In this study, we develop numerical models that can provide new insight in this topic, by combining previously developed 2D geodynamical models with thermodynamical databases and software. With this approach, we are able to trace the temporal and spatial evolution of the magmatic composition of arcs during subduction and the subsequent continental collision. We vary the rheology and continental thickness to study the effect on position and degree of melting. Preliminary results suggest small amounts of melting after slab break-off compared to models with delamination due to deep break-off compared to more shallow delamination.

Surface uplift of the Andes constrained by radiogenic isotopes of arc lavas

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PhD Student 29

The timings and mechanisms of orogenic plateau formation are not fully understood, yet are necessary to decipher the interplay between climate and tectonics. Currently-used paleo-elevation proxies for orogenic plateau have debated calibrations for past climate conditions, leading to large uncertainties. We propose a new approach to constrain plateau surface uplift, which is independent of paleo-climate changes. By comparing radiogenic isotope compositions of Quaternary Andean arc lavas to crustal thickness and present day elevation, we have established that $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios are effective paleo-elevation proxies and plateau discriminants

along the Andean arc. We use this relationship, and a new compilation of published age-corrected isotope compositions, to constrain 200 Myr of surface uplift history for the Andean arc. We show that by 23 Ma, the Andean arc had already attained elevations similar to present day (4200 ± 260 m) between at least 16-28°S. From 23-10 Ma, the elevated surface propagated south of 28°S by ~400 km. Our new, climate-independent model of surface uplift will have significant impact for studies on tectonic-climatic interactions. Our study of orogenic plateaux further suggests that regional uplift occurs via crustal thickening and isostasy, rather than localised, pulsed uplifts caused by lithospheric delamination.

Oil mixture adsorption and selectivity for aluminol and silicate kaolinite surfaces

Tian, S., Erastova, V., Greenwell, C., & Underwood, T.

PhD Student 30

Shale oil is currently of a major interest in the unconventional resource exploration and development. Understanding of the mechanism of interaction between oil and reservoir will assist in better recovery of the oil. In this paper, molecular dynamics simulation is used to study adsorption character of oil mixture within nanoscale kaolinite pore of shale rocks. To better understand the effects of oil composition, temperature and pressure on adsorption character of oil mixture, we modelled the six-component oil mixture (CH4, C6H14, C12H26, C18H38, C10H8, C18H36O2) on the kaolinite with the pore size of 8 nm at the range of temperatures (298 K, 323 K, 348 K and 373 K) and pressures (1 bar, 50 bar, 100 bar and 200 bar). It is demonstrated that shale oil density oscillates from the slit surface to the bulk region. Polar compounds are more likely to be adsorbed on the aluminol interface of kaolinite, oppositely, alkanes are more likely to be adsorbed at the silicate interface. In addition, the number of adsorption layers, density of adsorption phase and total adsorption amount at silicate interface are bigger than those on the aluminol surface. On the basis of our molecular simulation, we show the adsorption rate of shale oil on the surfaces of kaolinite sheets and the potential to assess the moveable capacity of shale oil.

How is the Clay Composition of the Bowland Shale affecting the Adsorption of a Basic Fracking Fluid?

Ward, C.

PhD Student 31

Fracking fluids in the US can contain up to 25 additives, but in 2011 the first UK onshore well was fracked using a very basic fracking fluid called slickwater, containing only salt, polyacrylamide, two types of proppant and mains tap water. Polyacrylamide, used as a friction reducer, is likely to be a common additive. At present there is no published information on how polyacrylamide will behave in the environment. Samples of Upper and Lower Bowland Shales, along with stratigraphically similar sandstones and limestones, have been obtained from outcrop and boreholes in NW and NE England. Literature states that the Bowland shale is dominated by clays, specifically illite/mica and kaolinite, in concentrations ≤38%. It is these clays, with high surface areas and very good sorption properties, that are expected to remove some polyacrylamide from solution. The samples obtained were powdered for use in XRD, XRF and TOC to assess mineralogy. Powdered 1g samples of each lithology were reacted under room conditions over a 24 hour period with a simple 0.1% polyacrylamide fluid. After 24 hours, the N-bromination method was applied to determine the total concentration of amide groups of the polyacrylamide and any dissolved organic matter spectophotometrically at 570 nm. Preliminary results show the shales, with higher clay content, adsorbing ≤28% of the polyacrylamide from solution whereas lithologies with less clay, cleaner sandstones, are only adsorbing ≤8% with some showing no adsorption.

Controls of Reservoir Quality in Namurian Tight Gas Sandstones, Copernicus discovery (Quad 44), Southern North Sea Tight Gas Sandstones

Wasielka, N.
PhD Student 32

Carboniferous sandstones under the North Sea are largely unexplored tight gas prospects. Reservoir effectiveness remains, however, a key exploration risk. This is caused by differences in reservoir quality between depositional facies and by small variations in diagenetic style, which can result in permeability differences of several orders of magnitude over small areas of reservoir. It is therefore important to be able to identify sandstones with sufficient reservoir quality to optimize the drilling and gas recovery process and minimize exploration costs. Both primary (i.e. sedimentological) and secondary (diagenetic) controls on porosity and permeability distribution are investigated, to develop predictive reservoir quality distribution models.

Initial results from three wells from Copernicus discovery show that fluvial facies association displays the best porosity values. These are mainly controlled by the amount of detrital clay. Permeability appears to be largely controlled by diagenetic processes, with the highest permeabilities recorded within quartz cemented sandstones. There is, however, a correlation between diagenetic alterations and depositional facies.

Shallow aquifer vulnerability from subsurface fluid-injection at a proposed shale gas hydraulic fracturing site

Wilson, M.P., Worrall, F., Davies, R.J., & Hart, A.
PhD Student 33

The groundwater flow resulting from a proposed hydraulic fracturing (fracking) operation was numerically modelled using 91 hydrogeological scenarios. Scenarios were chosen to be a combination of hydrogeological factors that *a priori* would control the long-term migration of fracking fluids to the near-surface. These factors were: induced fracture extent; cross-basin groundwater flow; deep low-permeability strata; deep high-permeability strata; fault hydraulic conductivity and overpressure. The study considered the Bowland Basin of northwest England, with fracking of the Carboniferous Bowland Shale at ~2000 m depth and the shallow aquifer being the Sherwood Sandstone at ~300 - 500 m depth. Of the 91 scenarios, 73 scenarios resulted in tracked particles not reaching the shallow aquifer within 10000 years and 18 resulted in particle travel-times less than 10000 years. Four factors proved to have a statistically significant impact on reducing travel-time to the aquifer: increased induced fracture extent; absence of deep high-permeability strata; relatively low fault hydraulic conductivity and magnitude of overpressure. Modelling suggests that deep high-permeability formations can be more effective fluid barriers to vertical flow than low-permeability formations. Furthermore, low-permeability faults can result in subsurface pressure compartmentalisation, reducing the chances of horizontal groundwater flow and encouraging vertical fluid migration. The modelled worst-case scenario, using unlikely geology and induced fracture lengths, maximum values for strata hydraulic conductivity and with conservative tracer behaviour had a particle travel-time of 130 years to the base of the shallow aquifer. This study has identified hydrogeological factors which lead to aquifer vulnerability, or invulnerability, from shale gas exploitation.

Biocides in hydraulic fracturing: A comparison to agricultural and assessment of hazard and vulnerability with respect to groundwater pollution

Wilson, M.P., Worrall, F., & Davies, R.
PhD Student 34

Biocides are one possible chemical additive to frack fluids and their role is to control bacterial

growth. Since biocides are designed to be toxic to particular organisms, their accidental or deliberate release into the environment has become a growing topic of concern, especially with regards to fracking. The objective of this study was to consider whether biocides proposed for use in fracking, could be a threat to English groundwater based on past groundwater monitoring data. The study considered all groundwater samples analysed for biocides in English groundwater between 2005 and 2014. The monitoring records were compared to: records of application (both amount and area); and chemical and molecular data for the biocides. The study did not use traditional adsorption and degradation data as these parameters are prone to variability and are not pure molecular parameters. The study showed that of the 110 biocides tested for in English groundwaters in the decade 2005 – 2014. The total number of detections was 2234 out of 1475000 observations of 95 compounds, and 38 were compounds that were not applied during the period of record. The detection of these 38 compounds did not decline over the 10 year period implying very long residence times and that once compounds do pollute an aquifer, then they will be a persistent problem. The study was able to develop binomial regression models of the probability of detecting pesticide in groundwater based upon molecular and application variables; and solely upon molecular properties. The solubility of the range of biocides used in frack fluids would imply a potentially higher hazard than for most agricultural biocides, but molecular modelling implied that one compound could be safer than others.

Assessing fugitive emissions of CH_4 from high-pressure gas pipelines

Boothroyd, I., Almond, S., Worrall, F., Davies, R.K., & Davies, R.

Postdoctoral Research Assistant 35

The impact of unconventional natural gas production using hydraulic fracturing methods from shale gas basins has been assessed using life-cycle emissions inventories, covering areas such as pre-production, production and transmission processes. The transmission of natural gas from well pad to processing plants and its transport to domestic sites is an important source of fugitive CH_4, yet emissions factors and fluxes from transmission processes are often based upon out of date measurements.

This study considers CH_4 emissions from the UK National Transmission System (NTS) of high pressure natural gas pipelines. Mobile surveys of CH_4 emissions using a Picarro Surveyor cavity-ring-down spectrometer were conducted across four areas in the UK, with routes bisecting high pressure pipelines and separate control routes away from the pipelines. A manual survey of soil gas measurements was also conducted along one of the high pressure pipelines using a tunable diode laser.

Accounting for wind direction, 92 km of high pressure pipeline and 72 km of control route were driven over a 10 day period. Methane fluxes were significantly greater on routes with a pipeline than those without. The smallest leak detectable was 3% above ambient (1.03 relative concentration), with any leaks below 3% assumed to be ambient. The number of leaks detected along the pipelines correlate to the estimated length of pipe joints, inferring that there are constant fugitive CH_4 emissions from these joints.

The sulphur budget of a peatland - constraining the carbon budget

Boothroyd, I., Worrall, F., Clay, G.D., Moody, C.S., Burt, T.P., & Rose, R.

Postdoctoral Research Assistant 36

This study considered the stoichiometry and energy content of organic matter reservoirs and fluxes through and from a peatland. The stoichiometry and energy content were used to constrain the carbon budget of the peatland and the stoichiometric constraints showed that the transition to deep peat was limited by the

availability of electron acceptors. The stoichiometry suggests there is insufficient energy available in the organic matter to produce CH4. The alternative pathways need either to use sulphate as a terminal electron acceptor or to use the DOM present in the peat pore water as the energy source. To test these explanations this study considered the sulphur budget of this peatland and the composition of the DOM in the peat profile pore water.

Samples of each organic matter reservoir and flux were collected and analysed for their elemental content including S. The samples analysed were: aboveground, belowground, heather, mosses and sedges, litter layer, a peat core, and monthly samples of stream particulate and dissolved organic matter. The dissolved organic matter included samples from the stream water and two depths within the peat profile. The composition of the organic matter was viewed in the context of ongoing measurement of inorganic S within the catchment which included precipitation, pore waters and stream water.

A new robust numerical water diffusion model with applications to rhyolitic volcanism

Coumans, J.P.

Postdoctoral Research Assistant 37

Volcanic eruption behaviour is strongly influenced by mechanisms of volatile exsolution and escape from magma. Of particular importance are the rates and timing of bubble growth and the development of gas escape pathways which, in turn, control eruption dynamics. Bubble growth in magma is controlled by diffusive transport of dissolved volatiles (predominantly water) and viscous deformation of the melt, whilst both the melt viscosity and the water diffusivity are themselves strongly dependent on the melt water content. Consequently, an accurate, quantitative description of the behaviour of water in silicate melt is an essential pre-requisite for modelling of many eruptive processes.

Water is present in silicate melts as both molecular (H_2O_m) and hydroxyl (OH) species. Diffusion of molecular water is much faster than hydroxyl because H_2O_m is a small molecule that moves relatively easily while OH is bonded to the silicate network. Diffusion of 'total water' (H_2O_t = H_2O_m + OH) can be described by a process where H_2O_m diffuses and the two species re-equilibrate as defined by the equilibrium constant (K_{eq}). The equilibrium constant and the kinetics of the speciation reaction are strongly temperature dependent; consequently, the quench rate of a melt strongly influences the final species abundances. To address these problems we have developed new numerical models that determine both H_2O_m diffusivity and K_{eq} simultaneously from the same experimental dataset. Using species data from diffusion-couple experiments on rhyolites, we have determined both quantities as functions of pressure and temperature, while eliminating uncertainties associated with disequilibrium speciation arising from quench.

Understanding surface interactions in aqueous miscible organic solvent treated layered double hydroxides

Erastova, V.[1], Degiacomi, M.[2], O'Hare, D.[2], & Greenwell, C.[1].

[1]Durham University; [2]Oxford University

Postdoctoral Research Assistant 38

Layered materials are of interest for use in a wealth of technological applications, many of which require a high surface area for optimal properties and performance. Recently, an industrially scalable method to create high surface area layered double hydroxide (LDH) materials, which may be readily dispersed in non-polar solvents, has been developed. This method involves treatment of LDHs with aqueous miscible organic (AMO) solvents. Here, molecular modeling is exploited to elucidate the AMO solvent-LDH interactions to understand how the dispersion process is facilitated by the AMO treatment. The

simulations show how hydrogen-bond networks within the LDH interlayer are disrupted by AMO solvents, leading to delamination.

Mineral surface chemistry considerations for prebiotic polymer formation: peptides on layered hydroxides

Erastova, V.[1], Degiacomi, M.[2], Fraser, D.[2], & Greenwell, C.[1].

[1]Durham University; [2]Oxford University

Postdoctoral Research Assistant 39

The role of clays in the origin of life, first proposed by John Desmond Bernal some seventy years ago, has been the subject of much research. While majority of clays carry negative charge, layered double hydroxides are positive, making them an ideal host for amino acids in early Earth's reducing environment. In this work we examine the role layered hydroxides could have played in prebiotic peptide formation. We demonstrate how highly ordered layered double hydroxides can concentrate, align and template amino acids and, during wetting-drying cycles, promote peptide bond formation. We propose a mechanism for peptide growth, supported by layered double hydroxides in an early Earth environment. Our work provides new insights into the potential role of mineral surfaces in mimicking aspects of biochemical reaction pathways.

Seismic anisotropy in subduction zones: numerical modeling and infinite strain axis calculations

Rodriguez-Gonzalez, J.

Postdoctoral Research Assistant 40

Subduction zones show significant variability in shear wave splitting, both above and below the slab, and along-strike. In the Peruvian flat slab region, shear wave splitting shows complex patterns that indicate that the anisotropic structure varies both laterally and vertically. Above the flat-slab, fast directions measured on shear wave splitting of local S phases are dominantly trench-parallel north of the Nazca Ridge, but become more complicated towards the south as the slab steepens. For SKS phases that sample the whole subduction zone, there is an intriguing and pronounced region of nulls measurements, which could indicate seismic anisotropy with a vertically aligned symmetry axis. Seismic anisotropy is often interpreted as the result of lattice preferred orientation (LPO) of olivine due to flow in the mantle. We provide some insight into the relationship between mantle flow and seismic anisotropy using 3D numerical modeling and infinite strain axis (ISA) calculations. Our models include a slab with along-strike variable geometry that changes rapidly with time. The changing geometry of the slab induces a complex mantle flow with both vertical and trench-parallel components. Trench-parallel flow is intense in broad regions in the mantle wedge and in the sub-slab mantle. In some regions, the ISA is trench-parallel in the supra-slab mantle, compatible with observations. However, below the slab, the ISA is mostly vertical, with trench-parallel ISA present only in narrow regions. Vertical ISA in broad regions could potentially offer an explanation for the null SKS splitting measurements found below the Peruvian flat-slab region.

Time-dependent changes in magmatic and hydrothermal activity at the Costa Rica Rift recorded by variations in oceanic crustal structure

Wilson, D.J., Peirce, C., Hobbs, R.W., & Gregory, E.P.M.

Postdoctoral Research Assistant 41

Geophysical studies of crustal structure at a diverse range of ridges have provided evidence that the balance between spreading rate and magma supply determines whether spreading predominantly occurs by magmatic accretion of new oceanic crust or through tectonic stretching

of the whole lithosphere. Asymmetric spreading, patterns of on- and off-axis volcanism, the evolution of oceanic core complexes and the distribution of hydrothermal systems all indicate that the process of spreading is not constant over geologically short timescales. Studies along flow-lines across ridges spreading at intermediate rates suggest variations in topographic style and crustal structure have periodically occurred, controlled by the interplay between magmatic accretion and tectonic stretching, and coupled to the degree of hydrothermal activity. Seismic reflection images and tomographic models derived from wide-angle seismic data have enabled a detailed examination of the oceanic crust that formed at the fast-to-intermediate-spreading (36 mm yr^{-1}) Costa Rica Rift over the last 6 Ma, to look for any temporal variation in basement topography, upper crust (layer 2) P-wave velocity/density structure and crustal thickness. Collectively our analyses allow us to investigate the timescale and cyclicity of crustal structure variations and, by comparing to variations in the spreading rate over time, consider how this may reflect changes in magma supply and/or hydrothermal activity at the Costa Rica Rift, using borehole 504B as the ground-truth. This research is part of a major, interdisciplinary NERC-funded collaboration entitled: Oceanographic and Seismic Characterisation of heat dissipation and alteration by hydrothermal fluids at an Axial Ridge (OSCAR).

3D and 4D tomography for volcanic and magmatic materials: recent successes & future directions

Dobson, K.[1], & Garwood, R.[2].

[1]Durham University, [2]University of Manchester

Academic Staff 42

Recent advances in laboratory and synchrotron X-ray tomography now mean we can produce 3D images of the internal structures of rocks at high spatial and phase resolution faster than ever before. This allows us to use in situ apparatus to perform observations under realistic conditions. Here we present a series of case studies highlighting the latest high speed real-time x-ray tomography methods, with acquisition rates now reaching 20 3D frames per second at spatial resolutions of a few microns. When these frame acquisition rates are applied to volcanic and magmatic processes, we can capture the phase interactions in magma flows: from bubble growth and coalescence to crystal network formation and disruption, and the extraction of melts from crystal mushes. We will also discuss some of the other recent laboratory and synchrotron techniques, and those under development (correlative microscopy, helical scanning, hyperspectral imaging, XRD tomography etc.) and how these may transform our understanding of volcanic and magmatic processes.

Nearshore-shallow marine mixed sedimentation response to sea level and paleoclimate change: a case study from Carboniferous in Tarim Baisn

Fu, M.

Academic Visitor 43

The characteristics of siliciclastic-carbonate mixed sedimentary environment are still obscure, resulting in poor understanding of distribution of mixed rocks. In this study, the sedimentary environments and environmental parameters of Carboniferous mixed rocks in Tarim Basin are studied, using observation of thin sections, measurement of minerals and trace elements composition. Mixed rocks deposited on the tidal flat, carbonate restricted platform and open platform. The concentrations of Ti, Rb, K, Al are used to divide the degree of mixed sedimentation into four levels, for their good relationship with contents of mixing terrigenous detrital within carbonate rocks. The salinity was reflected by Na content and Na/Ca. The depth of water was discussed by Mn/Fe and Sr content. V/(V+Ni) was used to indicate the redox condition. And the paleoclimate was analyzed using Ti/Al and Mg/Sr.

Results show the mixed sedimentation beyond level 2 occurred at a humid climate, while there was no obvious mixing at an arid climate. Meanwhile, most mixed sedimentation was accompanied by sea level fall. On the carbonate open platform, the mixed sedimentation was only of level 1, while mixed sedimentation of level 3-4 developed on the tidal flat and carbonate restricted platform. The mixed sedimentation in each environment all can record the change of sea level and paleoclimate.

OSCAR – Oceanographic and Seismic Characterisation of heat dissipation and alteration by hydrothermal fluids at an Axial Ridge

Hobbs, R.W.
Academic Staff 44

The interdisciplinary OSCAR project is examining the heat and mass fluxes in the solid Earth and overlying ocean at the Costa Rica mid-ocean Ridge (CRR) in the Panama Basin. The basin is isolated from the Pacific Ocean below ~2000 m by the Cocos and Carnegie Ridges except for a deep water channel along the Ecuador trench. This channel supplies cold abyssal water into the Basin at a rate of 0.35 Sv at a temperature of 1.75°C. Within the basin the water is heated to ~2°C.

The principal geophysical transect for the survey links the CRR with the ODP 504B borehole which is drilled 2111 m into 6.9 Ma oceanic crust. Changes in the solid Earth properties are mapped using a combination of seismic refraction and reflection. Results show that the crust older than 5.6 Ma has a higher velocity and lower topography when compared with younger crust. Also the heat-flow over the older crust is largely through conduction whereas in the younger crust it is largely by advection.

Physical oceanography data show that the inflowing water along the Ecuador trench initially mix with with the warmer water. Heating continues as the water circulates into the western part of the basin. We estimate that the geothermal contribution is over 70% to the abyssal water heating. This is the largest contribution yet observed in abyssal basins and is in line with a growing number of studies arguing that geothermal heating plays a significant role in driving the abyssal and global circulation.

Cracked and full of sand: microstructural insights into how fractures enable ingress of oil into crystalline basement

Holdsworth, B., Dempsey, E., McCaffrey, K., & Roberts, N.
Academic Staff 45

The fractured Precambrian gneisses of the 200km long Rona Ridge form the SE margin of the Faroe-Shetland Basin (FSB). Uplifted during Cretaceous-age normal faulting, it is flanked and immediately overlain by Devonian to Cretaceous cover sequences. Basement-hosted oil is known to occur in substantial volumes in at least two fields (Clair, Lancaster). Re-Os dating of bitumen and new U-Pb dating of calcite fills suggests that mineralization and oil charge occurred over a period of 20-30 Ma during the Upper Cretaceous.

A new study of basement cores was carried out to assess the mechanisms and timing of oil charge and other fracture-hosted mineralization. Oil charge is everywhere associated with quartz-adularia-calcite-pyrite mineralization and is hosted in meshes of interconnected shear/tensile fractures that formed during a single protracted, episode of brittle deformation. This association is recognized in all basement cores containing oil and also in locally overlying well-cemented Devonian and Upper Jurassic clastic sequences.

Mineralization and oil charge is everywhere associated with clastic sedimentary material which occurs either as vein-hosted injected slurries or as laminated infills in mm to dm-scale open fractures. The latter preserve delicate way-up criteria and geopetal structures. The largest accumulations of oil are found either in the poorly-cemented sedimentary infills or in fracture-hosted vuggy cavities up to (at least) several cm across. All

these features, together with the widespread development of zoned mineral cements and cockade textures suggest a near surface (<1-2km depth) low-temperature hydrothermal system. Highly dilated, open fractures developed in strong basement and overlying well cemented sedimentary rocks and were able to act as long-lived fluid channel-ways. There is no evidence for reactivation. Oil saturation likely periodically shut down fracture cementation.

The widespread preservation of dilational pull-apart features, together with the development of injected sediment-mineral slurries, and possible silica gels along faults, suggests that Upper Cretaceous seismogenic faulting drove fluid flow through the basement fracture systems. This may have also helped to drive oil migration from the Jurassic source rocks located to the west in the FSB, through the basement ridge and up into the overlying cover sequences. The significance of these findings for fractured basement reservoirs worldwide will be discussed.

Apatite as a tool to investigate the changing pre-eruptive volatile compositions of magmas

Humphreys, M., Brooker, R., Riker, J., Smith, V., Cees, J.H., & Stock, M.
Academic Staff 46

Apatite can provide new insights into the volatile compositions of magmatic systems, as it accommodates all the major volatile species (H, C, F, Cl and S). Apatite crystallises relatively early in many magmas, and is commonly trapped as inclusions within phenocrysts, thus preserving a temporal record of changing magmatic volatile compositions prior to eruptions.

New high-P-T experiments show that apatite can accommodate high CO_3^{2-} concentrations. In halogen-free experiments carbonate is accommodated primarily in the channel site (Type A substitution) but in halogen-bearing experiments it is incorporated onto the phosphate site (Type B substitution). Experimental apatite-melt K_Ds for H_2O-CO_2 exchange are 0.678 ± 0.076 for haplobasaltic andesite and 0.642 ± 0.103 for trachyte. Equivalent K_Ds for OH-Cl and OH-F exchange are in the range 0.08-0.11 and 0.02-0.09 respectively. Our new data, combined with literature data, show a clear dependence of K_D^{OH-Cl} and K_D^{OH-F} on temperature, with increased preference for the OH component at higher temperatures.

Modelling suggests that apatite volatile compositions may be sensitive to the composition of a coexisting magmatic volatile phase and to the onset of volatile saturation. This is a significant advantage over melt inclusion studies and provides additional constraints on the role of volatile exsolution in pre-eruptive processes. We illustrate this using the volatile compositions of apatites from eruptions of Laacher See, Germany and Campi Flegrei, Italy. Apatite chemistry therefore has great potential for investigating temporal variations in magmatic volatiles prior to eruption, and for understanding the nature of exsolved volatile phases.

The challenge of achieving professionalism and respect of diversity in a UK Earth Sciences department

Imber, J., Taylor, M., Callaghan, M., Castiello, G., Cooper, G., Foulger, G., Gregory, E., Herron, L., Hoult, J., Lo, M., Love, T., Macpherson, C., Oakes, J., Phethean, J., & Riches, A.
Athena SWAN Committee 47

The Department of Earth Sciences has one of the lowest percentages, relative to the natural applicant pool, of female academic staff amongst UK geoscience departments. There are currently (April 2017) 9% female academic staff at Durham, compared with a median value (in November 2015) of 20% for all Russell Group geoscience departments in the UK. Despite the fact that the female staff group is relatively senior, the Department's academic management is mainly comprised of men.

The Department has an informal working culture,

in which academics operate an “open door” policy, and staff and students are on first name terms. A positive outcome of this culture is that > 95% of final year undergraduate students deemed the staff approachable (National Student Survey 2016). Nevertheless, a survey of staff and research student attitudes revealed significant differences in the way males and females perceive our working environment. Of particular concern, females agree more strongly than males with the statement that, within the Department, they “have felt uncomfortable because of [their] gender”.

The Department is working to bring about positive changes to our working environments, whether in the office, classroom, or on fieldwork. Achieving such change is a difficult, and we have adopted an approach used by the corporate sector to bring about lasting cultural change. This includes aligning changes with our academic strategy, and attempting to embed a few, key positive behaviours – such as bystander intervention – into our everyday working practices.

Experiments on Carbon Dioxide Ice Sublimation and a Comparison with Contemporary Mars

Mc Keown, L., Bourke, M.C., McElwaine, J.N.
Academic Staff 48

Carbon dioxide is Mars’ primary atmospheric constituent and is recognised as an active and dynamic driver of Martian surface evolution. Having recently gained strength in the literature, CO_2 ice sublimation mechanisms can explain a host of features that are forming in the contemporary Martian climate. However, there is a dearth of empirical evidence to support models of these processes. Here we present the results of laboratory experiments undertaken to understand the interaction between sublimating CO_2 ice blocks and a porous, mobile substrate. We find that CO_2 sublimation can mobilise grains to form (1) pits and (2) furrows, which may be analogous in morphology to those observed on Martian dunes. Based on a survey of Proctor and Russell Crater dunes, we present a new hypothesis for detached pit formation at linear gully termini.

Formation and Maintenance of a Viscous Plug in a Strombolian Volcanic Conduit

Llewellin, E.W., Jenkins, A.P., & Jones, T.J.
Academic Staff 49

Textural studies of pyroclasts have shown that both degassed, crystal-rich magma, and gas-rich, crystal-poor magma may be ejected by a single strombolian explosion. Furthermore, some pyroclasts contain both magma types, intermingled. These pyroclasts have been interpreted as evidence of the presence of a plug of degassed, crystal-rich – and therefore high-viscosity – magma at the top of the volcanic conduit, overlying gas-rich, crystal-poor, low-viscosity magma. Analogue experiments have indicated that the presence of a viscous plug increases the vigour of strombolian explosions by enhancing the build-up of overpressure in the gas slug that drives them. The purported plug material has a higher density, as well as a higher viscosity, than the magma that underlies it. Consequently, the configuration is expected to be unstable, and the plug and underlying magma should convectively overturn. Does this mean that a viscous plug is an ephemeral feature? Or can a plug persist for long periods as a dynamic feature, which is continually created at the same rate at which it is convectively consumed? We conduct laboratory analogue experiments to investigate the formation and maintenance of a viscous plug. We drive thermal convection of a range of Newtonian and non-Newtonian magma analogue fluids in a 20cm diameter vertical pipe by heating the bottom, and cooling the top. The fluids have strongly temperature dependent rheology; both rheology and driving buoyancy are scaled to the volcanic scenario. We present preliminary results which characterize the spatial distribution of viscosity, density and velocity. We find that the hotter, lower-viscosity fluid ascends the core of

the pipe, whilst the cooler, higher-viscosity fluid descends in an outer annulus. The upper region, in which the flow reverses direction, constitutes a dynamic plug.

Continent origins and evolution; New Zealand's disparate crust and mantle?

Riches A.J.V., Nowell G.M., and team

Academic Staff 50

The outer most layer of Earth includes continental masses on which civilisation has grown. Continents are the longest-lived features on the Earth, and their mode of creation is unique among planets in our Solar System. Age information for the upper (crust) and their protective deep roots is key to understanding how such landmasses were created and how the oldest portions have survived and evolved. Crust-mantle relations are a critical part of understanding supercontinent growth and dispersal over Earth history.

Rocks from the deepest parts of continents (the mantle roots) are uncommon at Earth's surface. Though rare, mantle rocks are sometimes carried as exotic fist-sized fragments in volcanic magmas, or emplaced as km-scale blocks pushed up to Earth's surface during mountain building events. A spectacular and little understood region of mantle is found within Zealandia, SW Pacific. Here, mantle xenoliths have shown the largest age-gap (>1.5 Gyrs) between crust and its underlying mantle yet known anywhere on Earth. Some of the globe's largest blocks of mantle material are exposed through the centre of this microcontinent, but little age or geochemical information has been reported. Amy funded and led an expedition to collect mantle samples from the remarkably extensive Dun Mountain Ophiolite Belt thereby providing a ~500 km NNE-SSW transect across New Zealand's South Island. To better understand the nature of Zealandia's crust-mantle relationships osmium-age information has been determined for placer deposits associated with this ophiolite belt. These data provide important new perspectives on Zealandia's history and position in supercontinent reconstructions.

What do students learn from field trips?: An analysis of reflections on fieldwork

Saville, C.

Academic Staff 51

Fieldwork is an important part of the teaching programme within the Earth Sciences department at Durham University. It aims to teach scientific skills within a realistic context and provide educational experiences where multiple techniques must be synthesised into a coherent whole by students. How well students' whole experiences of field work fulfil these aims is not often assessed, as most feedback on fieldwork that is solicited is focused on the experiences of one field trip. The work detailed here encourages students to reflect on the entirety of their field experiences and consider what value they have derived from them. The RSQC^2 (Recall, Summarise, Questions, Connect, Comments) questionnaire style is used to guide students through staged reflection and questionnaires are administered to students while they are undertaking field work. The properties of field work that are valued show a marked variation depending on what stage of their degree students are at. Responses of level 1 students skew towards looking for the strategic value of fieldwork and how it can directly tie in with assessments and subject knowledge of modules they are currently taking. Level 2 students provided responses that skewed more towards considering the holistic usefulness of field work within modern Earth sciences practice and how their learning experiences in the field correlated to this.

A patchwork of pathways: preservation in the Sirius Passet Lagerstätte

Topper, T.P.
Academic Staff 52

The Sirius Passet Lagerstätte represents the earliest Cambrian microbial mat community with exceptional preservation and contains a diverse array of stem-group euarthropods, lobopodians, sponges and the iconic *Halkieria*. Many of fossils that have been described from the Sirius Passet have been preserved as complete, silicified three-dimensional external moulds, similar to Ediacaran-type preservation, but also with phosphatised digestive tracts. The compressed, carbonaceous fossil films characteristic of Burgess Shale-type preservation, although casually mentioned, remain to be documented in detail from the Sirius Passet. Fresh *in situ* material collected during recent expeditions has yielded a range of fossil specimens that are seemingly preserved as two-dimensional, kerogenous films. Here we investigate the taphonomic pathways associated with these films in the Sirius Passet Lagerstätte using Raman spectroscopy and elemental mapping. The majority of kerogenous films are covered to various degrees by an orange veneer that is present over multiple fossil-bearing horizons. The dominant phases of these veneers are iron oxides and oxyhydroxides and it is most likely that they represent pyrite that has been oxidized as a result of modern weathering processes. A key requirement in the exceptional preservation of organic matter is the impedance of decay. We interpret that these veneers represent the absorption of iron onto the organic matter that has prevented the activity of enzymes involved in the decomposition process. Comparisons with Burgess-Shale type preservation and Ediacaran-type preservation suggests that the Sirius Passet represents a unique and complex deposit that encapsulates a number of preservational pathways.

The 2016 Central Italy seismic sequence from geodesy, seismology and field investigation

Walters, R.J., and team.
Academic Staff 53

The destructive 2016 earthquake sequence that struck the central Apennines constitutes the largest semi-continuous release of seismic energy in central Italy in a hundred years, since the 1915 M_w 6.7 Fucino earthquake. The sequence started on 24th August with a M_W 6.2 earthquake, which was followed on the 26th October and 30th October by M_W 6.1 and M_W 6.6 events respectively, as well as by thousands of smaller aftershocks.
Here we use geodesy and body-wave seismology to estimate source mechanisms for each of the major earthquakes in this sequence, and to investigate the spatio-temporal evolution of seismic and aseismic slip throughout the sequence. Slip distributions at depth are estimated from joint inversion of coseismic GNSS data and Sentinel-1 and ALOS-2 InSAR data, whilst inversion of teleseismic body-waves provides independent evidence for the geometry and depth of faulting. Our field measurements of extensive metre and decimetre-scale surface ruptures are used to constrain and to validate our source models. We use our slip estimates to calculate the evolution of Coulomb stress on the causative and surrounding faults throughout the sequence. We find that each of the M_W>6 events primarily involved shallow (<8 km) slip on the Vettore fault, a WSW-dipping normal fault that had not produced earthquakes in the historical record, despite being known to be active over the Holocene. We discuss the implications that our findings have for future seismic hazard in the region and the potential for large normal faulting earthquakes in Italy

The flux of organic matter through a peatland ecosystem – a molecular budget of C in peatlands

Worrall, F., Moody, C.S., & Clay, G.D.
Academic Staff 54

Carbon budgets of peatlands are now common and studies have considered nitrogen, oxygen and energy budgets, but no study has considered the whole composition of the organic matter as it transfers through a peatland. Organic matter samples were taken from each organic matter reservoir and fluvial transfer pathway and analysed the samples by ^{13}C nuclear magnetic resonance (NMR) and thermogravimetric analysis. The samples analysed were: aboveground, belowground, heather, mosses and sedges, litter layer, a peat core, and monthly samples of particulate and dissolved organic matter. All organic matter samples were taken from a 100% peat catchment within Moor House National Nature Reserve in the North Pennines, UK, and collected samples were compared to standards of lignin, cellulose, humic acid and plant protein.

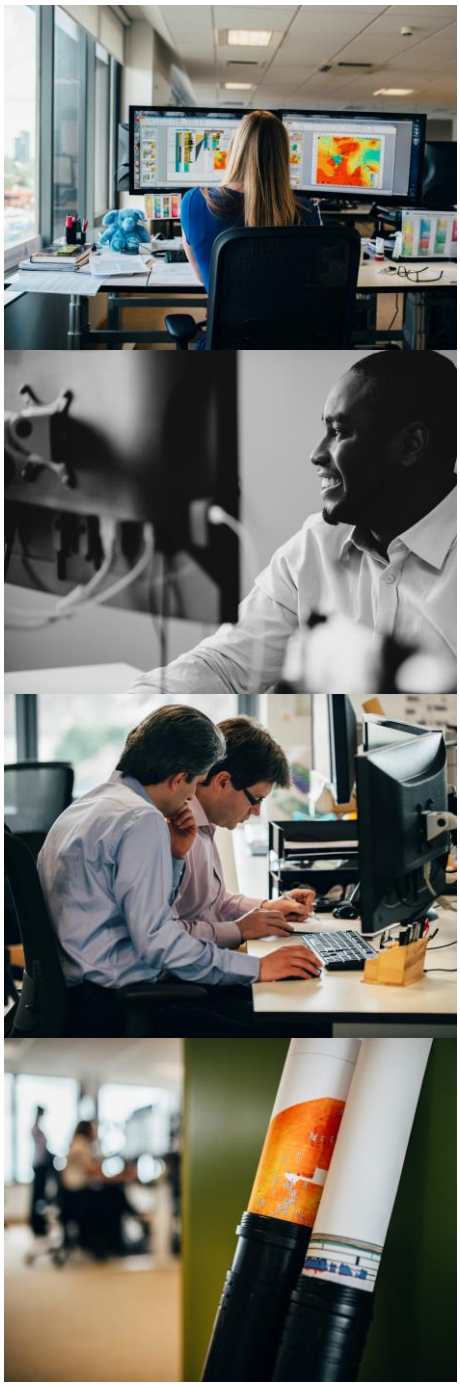
Results showed that the thermogravimetric trace of the sampled organic matter were distinctive with the DOM traces being marked out by very low thermal stability relative other organic matter types. The peat profile shows a significant trend with depth from vegetation- to lignin-like composition. A principal component analysis (PCA) of the NMR data shows that the DOM was a mixture of plant and peat compositions reacting to form a highly evolved composition that perhaps represents autochthonous stream processes. When all traces are weighted according to the observed dry matter and carbon budgets for the catchment then it is possible to judge what has been lost in the transition through and into the ecosystem. By plotting this "lost" trace it possible to assess its composition which is either 97% cellulose and 3% humic acid or 92% and 8% lignin. The "lost" composition shows that peatland processes preferentially remove carbohydrates and retaining lignin compounds reflected. Similarly the NMR traces show that while O-alkyl functional groups were selectively lost in the transition while alkyl groups were selectively enriched.

Thermodynamic constrains on the flux of organic matter through a peatland ecosystem

Worrall, F., Moody, C.S., Clay, G.D., Kettridge, N., & Burt, T.
Academic Staff 55

The transformations and transitions of organic matter into, through and out of a peatland ecosystem must obey the 2nd law of thermodynamics. Beer and Blodau (*Geochimica Cosmochimica Acta, 2007, 71, 12, 2989-3002*) showed that the evolution of CH_4 in peatlands was constrained by equilibrium occurring at depth in the peat as the pore water became a closed system. However, that study did not consider the transition in the solid components of the organic matter flux through the entire ecosystem.

For this study, organic matter samples were taken from each organic matter reservoir and fluvial transfer pathway and analysed the samples by elemental analysis and bomb calorimetry. The samples analysed were: above- and below-ground biomass, heather, mosses, sedges, plant litter layer, peat soil, and monthly samples of particulate and dissolved organic matter. All organic matter samples were taken from a 100% peat catchment within Moor House National Nature Reserve in the North Pennines, UK, and collected samples were compared to standards of lignin, cellulose, and plant protein. It was possible to calculate ΔH_f^{OM} ΔS_f^{OM} and ΔG_f^{OM} for each of the samples and standards. By assuming that each thermodynamic property can be expressed per g C and that any increase in ΔG_f^{OM} can be balanced by the production of CO_2, DOM or CH_4 then it is possible to predict the consequences of the fixation of 1 g of carbon in a peatland soil.



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Programme Summary

Posters/Lunch

Hydrocarbons

Environmental

Geodynamics, Volcanology and Structural Geology

	TR 3
09:15-09:30	Izzy Ashman
09:30-09:45	Alex Hornby
09:45-10:00	Heather Martin
10:00-10:15	Erin Cullen
10:15-10:30	Fiona Rea
10:30-11:00	**Coffee**
11:00-11:15	Catherine Mascord
11:15-11:30	Zoe Hodges
11:30-11:45	Hamish Couper
11:45-12:00	Lewis Li
12:00-12:15	Ellie Desouza
12:15-12:30	Emma Ownsworth
12:30-12:45	Josh Folds
12:45-14:00	**Poster Session I/Lunch**
14:00-14:15	Olivia Adam
14:15-14:30	Josh Currie
14:30-14:45	Daniel Gibson
14:45-15:00	Caitlin Johnston
15:00-15:30	**GUEST SPEAKER – Sue Loughlin**
15:30-17:00	**Poster Session II/Drinks**

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