Department of Earth Sciences
Durham University

Conference 2015
2nd June

Durham University

AHGS
Arthur Holmes Geological Society

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A welcome from Colin Macpherson, Head of Department

The previous two Department of Earth Science Conferences have been great successes and it is my pleasure to welcome you to the 2015 Conference. This meeting allows our undergraduate and postgraduate students, our postdoctoral researchers and our academic staff to share results of the recent, exciting work they have been undertaking.

Level 4 undergraduates will be completing their summative assessment today by giving talks about their research projects in TR3 (ES230) and TR4 (ES231). Poster presentations in TR1&2 (ES228 and 229) will showcase research and coursework that has been conducted by all 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 work that goes on in the Department throughout the year.

I would like to extend a warm welcome and the Department's thanks to our sponsors and industrial partners for supporting this conference. Many of these will be represented here today so please take the opportunity to meet with all our visitors, especially the exhibitors in TR1&2.

I do hope you enjoy the Conference today and please remember to join us to enjoy refreshments in TR1&2 at 16:30 when we present prizes for the best talks and posters.

Best wishes,

Col

A Brief History of Earth Sciences at Durham

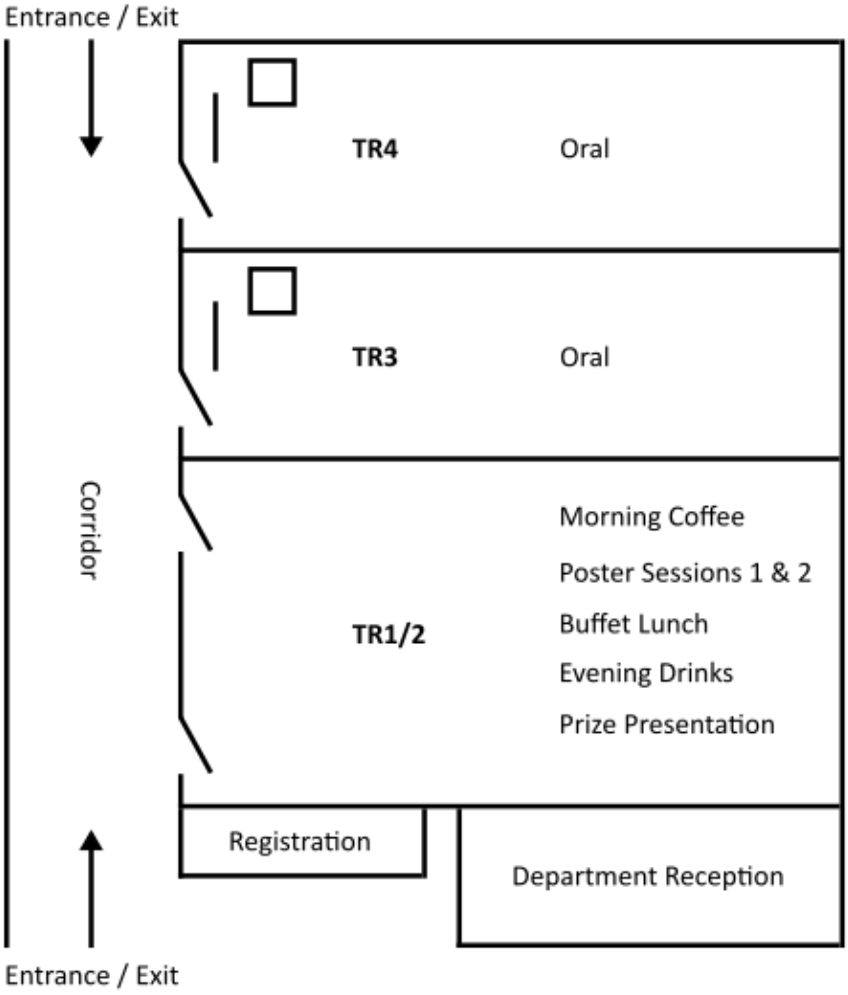
Aspects of the Geological Sciences have been taught at Durham University since its founding, but it was not until 1924 that the Geology Department was created, with Dr (later Professor) Arthur Holmes appointed as its head. Holmes developed a strong department, which produced a succession of distinguished 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 – 11:00	Oral presentations	TR 3 / TR 4
10:30 – 11:00	Coffee break	TR 1 / 2
11:00 – 12:30	Oral presentations	TR 3 / TR 4
12:30 – 14:00	Poster session 1 & buffet lunch	TR 1 / 2
14:00 – 15:30	Oral presentations	TR 3 / TR 4
15:30 – 17:00	Poster session 2 & evening drinks	TR 1 / 2
16:30	Awards ceremony	TR 1 / 2
17:00	Close	

Department of Earth Sciences, Floor Plan



Conference Logistics

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

- **Oral presentations**: To listen to the oral presentations, PLEASE ONLY ENTER TR3 OR TR4 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).

Awards

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

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

Two awards for the best Level 4 oral presentations: Vouchers for an outdoor shop (£100 per award)

These shall be awarded by a panel consisting of both AHGS and BP representatives. Awards will be presented at 16:30 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.

AECOM. AECOM was created to design, build, finance and operate the world's infrastructure in a broad range of markets, including Oil & Gas, Energy, Environment and Water.

Northumbrian Water. Northumbrian Water provides water and waste water management services to millions of people in the North East of England and Essex and Suffolk. With clear vision and values, our aim is to be the leading performer in the industry.

SRK Consulting (UK) Limited. SRK Consulting is an independent international consulting practice providing focused advice and solutions to the natural resource industry.

Neftex. Recognised as industry leaders in the provision of web-based sequence stratigraphy products and their global application.

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

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

2015 Conference Organising Committee:

Cat Moody

Ryan Northam

Izzy Ashamn

Stephen Hirst

Emma Gregory

Claire Horwell

Oral Presentations

Room	TR 3	TR 4
09:15	**Kitteringham, J.D.** Studying transit times in rivers to correct Manning's Equation.	**Bray, P.E.** Fold-related faulting in the Qaidam Basin: controls on variations in fault orientation and the implication for the oblique convergence.
09:30	**Greener, J.W.** Estimating the Oxidative Ratio for UK Biomass and the UK as a whole: How does this affect the UK Carbon Sink?	**Brett, J.A.N.** A Reassessment into the Structural Complexity of the Southern Northumberland Basin.
09:45	**Barnard, O.M.** Constructing a Continuous Energy Budget for an Upland Peat Catchment.	**Wille, J.E.** Developing a new conceptual model for fault zones in thick shale-dominated successions.
10:00	**Whild, H.** A potassium budget for the terrestrial biosphere of Great Britain from 1993 to 2012.	**Edey, A.J.** The Origins of Fold-and-Thrust Belt Curvature.
10:15	**Pratt, N.** Submerged forests and tree-ring stable isotopes: a preliminary study.	**Robson, R.E.M.** Syn-rift Reservoir Development in the Brent Province of the North Viking Graben.
	COFFEE	
11:00	**Rosin, T.** Water Table Dynamic in a Pennine Peat Bog	**White, S.** Modelling Mechanical Stratigraphy Controls on Fracture Networks.
11:15	**Bartholomew, J.** Evaluating the Relationship between Precipitation and Volcanic Activity.	**Sanderson, H.C.** An investigation into whether gas extraction beneath the Storegga Slide could cause subsidence, and the consequences of this potential subsidence.

	TR 3	TR 4
11:30	**Taylor, J.** Trace element concentrations in an aragonite stalagmite as proxies for precipitation based climate change in Belize	**Murray, R.P.** The frictional properties of shale-bearing fault gouges at subseismic and seismic slip rates: an unconventional shale reservoir analogue.
11:45	**Emerson, H.** An investigation into the correlation between temperature, sea level and carbon dioxide in caves.	**Stillings, M.D.** Constraining the frictional properties of shale faults up to the point of unstable sliding: Implications for earthquake nucleation.
12:00	**Landon, E.N.U.** Reconstructing Late Neoproterozoic and Early Palaeozoic ecosystems: implications for the evolution of the modern food chain.	**Unwin, R.H.** The evolution of frictional properties in fault rocks during the seismic cycle.
12:15	**Smith, H.E.** Modelling Panderodus dental function: Implications for coniform euconodont taxonomical classification.	

Poster Session I / LUNCH

14:00	**Boughey, S.S.** A study of the geochemistry of the marine successions at Bowlees Quarry, Teesdale: palaeoenvironment implications.	**Cole, R.P.** Nature and significance of pyroclastic deposits from 29th December 2013 San Miguel eruption, El Salvador.
14:15	**D'Souza, B.** Computer Modelling of the Delaware Basin to Assess the Compaction Characteristics of Mudstone/Carbonate Sediment Mixtures.	**Cromwell, E.J.** Host Rock Characteristics and Controls on Cu-Au-Ag Mineralization at Copper Mountain Porphyry Deposit, Southern BC, Canada.

	TR 3	TR 4
14:30	**Gale, W.J.** The nature and development of zeolite mineralisation and gouges in reactivating shear zones within the Adamello Massif, Southern Italian Alps.	**Dey, S.M.** Quantifying Crystal Mush Structure in Slumped Gabbros, Tugtutoq, SW Greenland.
14:45	**French, G.R.** Seabed mud volcanoes the result of diapir driven focused fluid flow on the Mauritania continental shelf.	**Haddock, D.G.** Sintering and processes during kimberlite eruption: evidence and implications from the youngest known kimberlitic volcanoes on Earth, the Quaternary Igwisi Hills, Tanzania.
15:00	**Santamas, A.A.** Tight Gas in the Southern North Sea.	**Sharp, M.J.** New or re-used crust from arc-collision in the Western Bismarck arc: An analysis through oxygen isotope geochemistry.
15:15	**Shorey, J.E.** Identifying controls on carbonate-rich mudstone porosity using petrographic analysis within the Delaware Basin, Texas.	**Plumstead, J.** High precision seawater strontium measurements over the last 360 Kyr: Can glacial-interglacial fluctuations in $^{87}Sr/^{86}Sr$ be resolved?

Studying transit times in rivers to correct Manning's Equation.

Kitteringham, J.D. **TR3** 09:15

In-stream residence time is used to estimate the amount of carbon dioxide (CO_2) entering the atmosphere from rivers, and is therefore essential in understanding their greenhouse gas impact. In-stream residence times were analysed by measuring transit times and stream velocities between fixed points.

The River Trent was the focus of this study, and six monitoring stations on the Trent were used. Data was collected between each monitoring station, and 16,458 events were considered. The Environment Agency (EA) collects 15-minute data measuring the river discharge between adjacent monitoring stations on UK rivers; 15-minute records from the last 40 years were analysed to give transit times over a range of river flow conditions, and were combined with a knowledge of stream morphology (e.g. slope) to estimate stream velocities over a range of discharges. Transit times were found to be far higher at lower discharges.

Previously, stream velocities have been estimated using Manning's Equation and the roughness constant (*n*) has been assumed to be constant at all flow exceedences, but this study shows that n varies with river level (*d*). For flows less than the 95th percentile, Manning's roughness coefficient n for the River Trent was found to be ~0.0035, but at extreme low flows (less than 5th percentile), n increased to 0.07.

A corrected Manning's Equation in terms of *d* is proposed.

This implies that the amount of CO_2 entering the atmosphere at low river flows is currently vastly underestimated.

Estimating the Oxidative Ratio for UK Biomass and the UK as a whole: How does this affect the UK Carbon Sink?

Greener, J.W. **TR3** 09:30

Since the industrial revolution, anthropogenic sources of atmospheric carbon have become increasingly more significant. Understanding what happens to this excess addition of carbon into the atmosphere requires us to look at the terrestrial biospheres oxidative ratio (OR), which is the mass of CO_2 sequestered in the terrestrial biosphere for each mol of O_2 produced (Worrall et al., 2014). Previous studies have found the global OR value to be 1.1 (Severinghaus, 1995). This study looked at the OR for the UK to establish a more accurate value, which could be used to calculate the flux of carbon to land in the UK. This study yields a UK biomass OR value of 1.15±0.006 and a UK OR value of 1.065±0.01 and 1.137±0.001 depending on how one weights each individual biome. This finds that the flux of carbon to land for the UK has been miscalculated by up to 21% with the flux of carbon land being 2.93 million tonnes C/yr using an area weighted OR value and 2.73 million tonnes C/yr when OR is weighted by carbon stock.

Constructing a Continuous Energy Budget for an Upland Peat Catchment.

Barnard, O.M. **TR3** 09:45

Peatland systems represent ~15-30% of the world's soil carbon storage and are the largest terrestrial carbon store in the UK, hence understanding how peatlands carbon systems will respond to a changing climate is imperative. This study has estimated the long term evapotranspiration for a peat covered catchment in northern England using the Turc and Priestley-Taylor methods. Using a 19 year dataset daily evaporation was estimated and compared to that found by Worrall et al (2015) who used White's method for the same catchment. Solar radiation, net radiation and temperature were measured over the study period, and values of soil heat flux were obtained from Worrall et al (2015); the sensible heat flux was calculated to close the energy budget of the system. The variables were examined to determine how the system reacted to days with anomalous temperature and radiation. This study this study showed that evaporation increased over the time period, while sensible heat flux decreased indicating that sensible heat energy was used to meet the evaporative demand.

On days with anomalously high net radiation the system was found to not respond by avoiding a change in evaporation by a lowering the water table, instead it is hypothesised that anomalous days in Rn caused the system to react by absorbing sensible heat and becoming a heat sink.

A potassium budget for the terrestrial biosphere of Great Britain from 1993 to 2012.

Whild, H. **TR3** 10:00

20 year long records of fertiliser application, atmospheric deposition, food and feed transfers and fluvial flux of potassium were brought together to generate a potassium budget for Great Britain for the years 1993 to 2012. The study found that over the twenty years studied, there was a net loss of 802 ktonnes of potassium from the terrestrial biosphere. The main control on this was found to be the fluvial flux of potassium out of the system. It was concluded that the likely reason for this was down to the losses of potassium from the soil by soil erosion and waste effluent directly discharging into rivers. The effects of a potassium deficit within the terrestrial biosphere involve the reduction of plant growth rates and quality due to decreased availability of mobile potassium which has a strong influence on many biochemical reactions within the plant. Intense agriculture experienced in Great Britain relies on stable levels of nutrients to maintain sustainable growth rates. Therefore, it is important to understand how the potassium budget of Great Britain is changing over time. The report summarises that although there is not currently an issue surrounding potassium levels in agricultural soils due to adequate fertiliser application, this may become a problem in the future as the stores of potassium within soils begin to adapt and change with the budget. Therefore, it is important to carry out localised studies to produce an appropriate plan of action if any potassium deficit symptoms were to become apparent.

Submerged forests and tree-ring stable isotopes: a preliminary study.

Pratt, N. **TR3** 10:15

Submerged forests, former Holocene coastal woodlands inundated by rising sea levels, are found in various locations around the coast of the British Isles, with some being uncovered recently as a result of heavy storms. Due to the quality of wood preservation and the links to the timing and pacing of deglacial sea level change they are a valuable, yet underutilised, source of palaeoclimate information. They occur in terrestrial, temperate regions which suffer from a lack of palaeoenvironmental coverage. Submerged forests are often re-buried or eroded shortly after their exposure, so are often described anecdotally but not thoroughly investigated in scientific literature. Thus far studies have paved the way for stable isotopic investigations of subfossil tree rings, by relating modern tree-ring isotope curves to records of environmental parameters, but relatively few have attempted to apply these relationships to palaeoclimate reconstructions. This preliminary study utilises subfossil wood collected from submerged forests sites on the west coast of the UK and combines whole-wood stable isotope analysis with site stratigraphy, radiocarbon dating and other palaeoclimate proxies to investigate local palaeoenvironmental change and deglacial sea level history. The four sites describe a transect from north to south along which submerged forest age decreases, demonstrating the effect of heterogeneous glacio-isostatic rebound. At each site a complex interplay of coastal morphology and land- and sea-level change is exhibited. Floating oxygen and carbon isotope curves from three radial transects of trunks provide insight into the long-term physiological changes and short-term climate fluctuations that occurred through the lives of the trees. Currently, the potential of stable isotope dendroclimatology of these submerged forests as a palaeoclimate proxy is limited by a lack of overlapping chronologies, but further strategic sampling at sites such as the ones

described, and more well-known sites, will prove fruitful if records can be correlated.

Fold-related faulting in the Qaidam Basin: controls on variations in fault orientation and the implication for the oblique convergence.

Bray, P.E. **TR4** 09:15

This study aims to investigate why folds in the same region of the Qaidam Basin, display faults at various orientations. Folds must generate faults to accommodate a lengthening and thinning in response to crustal shortening. The three folds of Heiliangzi, Dafengshan and Jiandingshan each display different fault orientations to the expected trend, with faults orientated perpendicular to the fold axis, parallel to the fold axis and at an oblique orientation to the fold axis, respectively. This study uses high-resolution satellite imagery to interpret the dominant fault set, and derives a relationship between fault dip-direction, hanging wall motion and the three-dimensional surface of the fold to resolve the apparent offset of fault segments. A reversal in apparent offset sense occurs on faults which cross-cut the hinge line and the use of an analogous experiment replicates these patterns to determine that faults on Heiliangzi and Jiandingshan are extensional dip-slip faults that dip towards the west and south west respectively. Axis-parallel faults on Dafengshan also display a reversal but simply extend into the fold core. Fold shape drives limb curvature and hinge tightness, and so governs the dominant direction of outer-arc extension and the geometry of faults generated. Fold aspect ratio is therefore the main factor controlling fault orientation. Where fold shape is domed and relatively uniform, in the case of Jiandingshan, fault orientations develop in response to a basin-wide influence; linking previous works to a suggested eastward rotation in the oblique convergence of Qaidam.

A Reassessment into the Structural Complexity of the Southern Northumberland Basin.

Brett, J.A.N. **TR4** 09:30

My aim of this study was to clarify the sequence of tectonic events having taken place across the Northumberland Basin which has been in dispute. The basin has provided recent evidence for far-field Variscan compression in the form of minor E-W oriented thrust faults. As a result of this compressive stress, an extensional relaxation period followed with the release of compression. An early episode of North Sea rifting is believed to have re-activated selective conjugate strike-slip and normal faults under its associated dextral component. N-S oriented extension is recognised to have initiated rifting whilst reactivating the underlying ancient Iapetus suture during the Early Carboniferous through to the Mid-Carboniferous. However, events which occurred from the late Carboniferous into the Permian have been associated with multiple orientations and magnitudes. Authors portrayed the basin as a classic example for basin inversion, sourced from the ESE trending Variscan belt in Late Carboniferous times. De Paola et al., (2005) noted that NE and NNW shortening structures described by previous authors as indicators of inversion are non-parallel to the Variscan front. An alternative model was proposed by De Paola et al., (2005) who inferred the structures formed during a single phase of right-lateral oblique extension during the rifting of the North Sea which coincided with the intrusion of the Whin Sill at ca. 195 ± 6 Ma. A window of 15 Ma is associated with this event, concluding that the structures are of the same age. A number of key structures were observed during preliminary field work which give way to reactivated processes and others which are representative of Variscan inversion. Documentations made within the Southern Northumberland Basin question the model proposed by De Paola et al., (2005) and lead into re-working the interpretations made by previous authors based on personal observations.

Developing a new conceptual model for fault zones in thick shale-dominated successions.

Wille, J.E. **TR4** 09:45

The structural characteristics of fault zones in shale-dominated successions are studied from a quantitative perspective of fracture distribution and extension within the Lower Jurassic Lias Group of the Cleveland Basin, Northeast England. Data were collected at various stratigraphic levels throughout the succession and analysed, and show consistent results of a laterally-extensive uniform fracture distribution, uninfluenced by the development of faults. Extension accommodated by calcite veins is highly localised adjacent to faults, however, and thus points towards localised strain in the same regions. Fault-strain is found to vary little between the faults studied.

The studied damage zones differ greatly from the widely-cited conceptual fault zone models that are based on high-porosity sandstones, yet display similar characteristics to those of low-porosity sandstones and high-porosity carbonates, indicating both pore space and lithology type will influence the manner in which extensional faulting deforms the host rock.

Ultimately this report concludes that damage zones in shale-dominated successions may be characterised by increased tensile stress up to 20m from the fault core, enabling the reopening of pre-existing tensile fractures, and subsequent fluid flow and mineral deposition.

The Origins of Fold-and-Thrust Belt Curvature.

Edey, A.J. **TR4** 10:00

Fold-and-thrust belts are often curved in plan view. To determine the kinematics of curvature, earthquake slip vectors and GPS data were compared from four fold-and-thrust belts. The Zagros, Himalayas, Tian Shan and Andes were all studied as they are actively deforming in the present day. Each differs with respect to their age, size and extent of curvature. The comparison of GPS data with earthquake slip vectors enabled analysis of strain distribution. Results showed that in the majority of areas, overall convergence is accommodated by both a lateral and a compressive component of slip. Unusually, slip vectors revealed an absence of strike-slip movement in the south-east Zagros Fars Arc; here strain is accommodated by two compressional slip components. Findings support vertical-axis block rotations in the south-east Fars Arc, facilitating curvature. In regions with a high plateau, thrust slip vectors fan out around the convex shape of the fold-and-thrust belt. This indicates that curvature is the result of gravitational spreading and/or pinning. A plateau's height or the degree of pinning may control the extent of curvature.

Syn-rift Reservoir Development in the Brent Province of the North Viking Graben.

Robson, R.E.M. **TR4** 10:15

The Brent Province in the North Viking Graben has been extremely underdeveloped in the Upper Jurassic syn-rift interval. This is despite the predicted erosion of the Middle Jurassic Brent Group, which is a well-known reservoir, during rifting. Key horizons were mapped on a new PGS seismic dataset using IHS Kingdom software. The volume of pre-rift rock that was eroded during rifting and fault-block rotation was then calculated. This was carried out by creating an isopach map of the difference in thickness of the rocks between the Base Cretaceous Unconformity and the top of the Brent Group. Four fields were studied in detail: Cormorant, Hutton, Northwest Hutton and Ninian. Successful production from the Brent Group has occurred in these fields over recent decades.

The erosional volume varies between faults, with the fault bounding the east of Ninian Field producing the most erosion per unit length of all the faults studied. The Cormorant fault blocks have also been heavily eroded, whilst erosion from the Hutton fault block was much less voluminous. Bulk rock volumes were multiplied by net to gross values for the Brent Group to give the likely volume of reservoir-quality rock that was

eroded and therefore deposited either side of the fault block axis. The sedimentation patterns can be inferred from observing the syn-rift succession, and depend on sediment yield as well as the geometry of the fault block. Ultimately, it is likely that the net to gross of the syn-rift succession will be lower than that of the Brent Group. This is due to the addition of background sedimentation, the fining of grains, differing petrology of the upper Brent Group and diagenesis. It is predicted, however, that there might be isolated sand bodies within the syn-rift mudstones, in line with similar analogues in the East Shetland Basin.

Water Table Dynamic in a Pennine Peat Bog

Rosin, T. **TR3** 11:00

In order to adequately manage peat environments it is essential that their hydrological processes are understood. A numerical Richards equation is constructed to simulate the water table dynamics in a peat bog. A simple bucket equation is constructed in order to investigate the water table dynamic taking place. Simulations indicate the existence of significant layering in the peat profile which has a great effect on the water table of the peat bog. The models were tested using a data set collected from the Moor House Peat bog in the North Pennine. Results show very good model performance for the bucket model. The Richards equation model is able to model water table height, however, it is too limited to provide informative simulations of the processes taking place.

Evaluating the Relationship between Precipitation and Volcanic Activity.

Bartholomew, J. **TR3** 11:15

An analysis of the relationship between precipitation and volcanic eruptions over the last 2,000 years reveals that precipitation may act as a trigger for the onset of volcanic activity. To achieve this, we have utilised the Smithsonian Institution's Global Volcanism Programme database. Regions where climate is controlled by the Intertropical Convergence Zone (ITCZ) may be more sensitive to this relationship. In order to trigger increased volcanic activity, we observed that precipitation rates need to be sufficiently high enough during the months of maximum precipitation. Andesite volcanoes in island arc settings are more responsive to changes in precipitation, suggesting an intrinsic link between tectonic setting and climate. A positive, statistical significant relationship has been observed in Southeast Asia. Our findings will strengthen our understanding of the external processes that trigger volcanic activity. In addition, the outcome of this study may result in improved hazard prediction. Hazard prediction of volcanic regions is key to preventing the loss of life.

Trace element concentrations in an aragonite stalagmite as proxies for precipitation based climate change in Belize

Taylor, J. **TR3** 11:30

A stalagmite sampled from southern Belize was analysed for the trace elements Mg, Sr, Ba, Al, Cd, Cu, Y, Rb, Pb, Th and U through sampling at 100 micron intervals. The trace element record was compared to the stable isotope record for the stalagmite, assembled prior to this study, in order to identify precipitation based signals. The aragonite stalagmite has a precise, high resolution U-Th chronology which allows comparison to historical climate records including hurricanes, precipitation and volcanic eruptions. Analysis of Mg, Sr and Ba concentrations within the stalagmite reveal that these elements are derived from both bedrock and soil leaching within the stalagmite, based on their response to seasonal precipitation changes. Concentrations of U in the stalagmite demonstrate a very strong signal reflecting precipitation due to the effect of prior aragonite precipitation on U incorporation. U and δ13C can identify the relative drying trend observed due to the southward shift in the ITCZ position as a result of sulphur emissions from major northern hemisphere volcanic eruptions; the opposite effect is observed for southern hemisphere eruptions. The sensitivity of both of these datasets to precipitation variations and the

effect of sulphur aerosols on the position of the ITCZ has also resulted in the identification of a long term drying trend in both the U and δ13C records from ~1850, as the result of increased anthropogenic sulphur aerosol emissions.

An investigation into the correlation between temperature, sea level and carbon dioxide in caves.

Emerson, H. **TR3** 11:45

Stores of carbon dioxide (CO^{--}_2) are able to influence climate globally and locally. Understanding the variation in atmospheric CO^{--}_2 with relation to temperature and sea level is important in understanding the global carbon cycle and potential changes in climate. It has been seen throughout geological history that periods of higher sea level occurred alongside correspondingly higher levels of atmospheric concentration of CO^{--}_2 and temperature.

The data used in this study was obtained from four different caves in differing locations across the world (Ireland, Belize and the Turks and Caicos Islands). For each of the caves Grapher was used to analyse CO^{--}_2 concentrations, the cave air temperature and the local sea level.

In addition, laboratory experiments were conducted to evaluate the amount of CO^{--}_2 produced with differing amounts of organic material at a constant temperature.

Temperature and sea level have individual impacts on the concentration of CO^{--}_2 that is produced and the rate at which the concentration changes. There are several external factors that may have influenced the results; these factors are not linked to either temperature or sea level.

Reconstructing Late Neoproterozoic and Early Palaeozoic ecosystems: implications for the evolution of the modern food chain.

Landon, E.N.U. **TR3** 12:00

The Cambrian Lagerstätten are a powerful tool for studying the evolution of complex ecosystems due to the exceptional preservation of the soft-bodied components of the biotas and the preservation of gut contents. Analysis of five Cambrian biotas, as well as three biotas from the terminal Neoproterozoic, show that ecosystems with complex food webs and including extensive infaunal and nektonic activity, appeared abruptly as a result of the Cambrian Explosion, and bear little resemblance or connection to the simple, stable ecosystems that characterise the biota of the terminal Neoproterozoic. These Cambrian biotas were also unusually predator dominated, possibly due to abrupt opening of a wide range of niches caused by the biotic upheaval of the Cambrian Explosion.

Modelling Panderodus dental function: Implications for coniform euconodont taxonomical classification.

Smith, H.E. **TR3** 12:15

Conodonts were primitive jawless vertebrates found from the Early Ordovician until the Late Triassic that bore phosphatic tooth-like elements, whose diversity of form was comparable with other vertebrate dentition. These mineralised oral elements are the only common fossilised remains of which many became disarticulated during the process of death and decay due to the soft bodied nature of conodonts. In some cases, however, the feeding array is preserved insitu after post mortem collapse and so conserves evidence of the apparatus architecture.

A paradigm approach is utilised to constrain the taxonomy, phylogenetic classification and functional morphology of a less derived order of ecologically diverse coniform euconodonts. The architecture of the coniform euconodont feeding apparatus is reconstructed by building conceptual models based on actualistic data, microstructural information and the established gross morphology of the Panderodus conodont.

The results of this report suggest a new hypothesis as to the interrelationships of conodont taxa in the gradual evolution of multi-element conodont lineages to reveal the systematic position and evolutionary significance of mineralised feeding elements in coniform euconodonts. This could

develop a stable suprageneric classification system for all conodonts and hence macroevolutionary models for development in the evolution of vertebrate oral apparatus. These results could, essentially, reconstruct phylogenies to determine the true ancestry of all stem group vertebrates.

Modelling Mechanical Stratigraphy Controls on Fracture Networks.

White, S. **TR4** 11:00

This research project looks at the relationship between mechanical layer thickness and fracture connectivity, length and spacing in discrete fracture network models (DFNs). The program used was FracMan^{TM} version 7.0. Seven different models were created containing 5 mechanical layers. The type of fractures, whether they terminate at both beds, just one bed, or grow beyond the bed, was varied for each model to test the effect of fracture type on length intensity, spacing distribution and connectivity within 2 of the mechanical units of the model. The fractures in these models were tested with pseudo wells. Each Model had 2 wells emplaced perpendicular to each fracture set at the mid-level of each mechanical layer. The data was then exported in order to analyse length intensity distribution and spacing distribution. The results show that mechanical layer thickness has no effect on the spacing distribution of fractures, except those that terminate at both bed boundaries. It was also found that within the models fracture length would follow the input distribution to a maximum length where the slope would break and then the longer fractures followed a different distribution. The maximum length for which this occurred varied depending on mechanical layer thickness and the type of fracture. Fracture connectivity was tested by analysing the shortest pathway in each model. Both vertical and horizontal connectivity was tested. As the fracture sets are also steeply dipping, few, if any fractures in any of the models, were intersected by a well at 90°. By inclining the vertical wells so the angle of the well was 16.6° it was found that the well intersected a much higher percentage of fractures and therefore had an increased probability of discovering a connected fracture pathway. This has implications for the fracture connectivity of complex reservoirs in the hydrocarbon industry, as well as any other stratigraphically fractured unit.

An investigation into whether gas extraction beneath the Storegga Slide could cause subsidence, and the consequences of this potential subsidence.

Sanderson, H.C. **TR4** 11:15

The Ormen Lange gas field lies beneath the scar of the Storegga Slide, a headwall off the NW coast of Norway created by a major submarine landslip 8000 years BP. This field provided the UK with 20% of its gas. Petroleum extraction has been known to cause subsidence on the surface and in some North Sea fields, such as the Valhall field, it has led to difficulty in the production of the field. The Storegga slide was caused by an increase in pore pressure in the seafloor sediment, the nature of the glacial sediments creating a slip plane along which the slide occurred and a trigger for the slide, most likely an earthquake. Two models are here presented to estimate how much subsidence will occur with gas extraction, one using the percentile decrease in the porosity of the reservoir unit and the other using predicted pore pressure changes combined with beam theory. Both models come to the conclusion that subsidence will be less than ~5m on the sea floor. This amount is not enough to increase the slope angles of the nearby headwalls enough to decrease the slope stability. It is also unlikely to lead to an increase in pore pressure sufficient enough to create the same condition last seen before the slide. Earthquake activity in the area may increase but not enough to significantly decrease the slope stability of the nearest sediments. Whilst a large slide is unlikely this level of subsidence could lead to issues in the pressure regime of the rocks, which in turn could lead to issues in producing the field.

The frictional properties of shale-bearing fault gouges at subseismic and seismic slip rates: an unconventional shale reservoir analogue.

Murray, R.P. **TR4** 11:30

Unconventional reservoirs may represent the future for sustaining world petroleum demand. Hydraulic fracturing is an unconventional process of inducing micro-fractures to extract tight reserves of petroleum from the sub-surface. There are several risks associated with hydraulic fracturing, in particular the potential for seismicity. This study aims to determine the frictional properties of shale-bearing fault gouges from a reservoir analogue, at both subseismic and seismic slip rates, in order to understand the effect of seismic propagation. To characterise the fault zone architecture and deformation mechanisms of a shale-reservoir analogue, fieldwork has been undertaken in the Cleveland Basin, North Yorkshire. Protolith and slip zone gouge samples were selected for further investigation. A series of laboratory experiments was designed to test the variation in frictional properties after a seismic slip event (1.3 m/s). The experiments were performed on the high to low velocity rotary shear apparatus in the Rock Mechanics Laboratory, Durham University. The results obtained from this study reveal that the shale-reservoir analogue samples exhibit only velocity strengthening behaviour coupled with negative healing rates. The implications of these results for the hydraulic fracturing industry are favourable, as the frictional properties of the shale-bearing fault gouges limit seismicity.

Constraining the frictional properties of shale faults up to the point of unstable sliding: Implications for earthquake nucleation.

Stillings, M.D. **TR4** 11:45

Shale gas reservoirs are now being exploited by pumping fluids at high pressures into thick low permeability shale units to induce hydraulic fracturing. With the onset of new hydrocarbon developments there is a requirement for an in-depth understanding of the structural stability of pre-existing fractures and faults at reservoir conditions. By analysing analogous Mid Jurassic organic rich shale outcrops (Jet Rock, Port Mulgrave, Cleveland Basin) and their natural structures, samples from natural fault are used to perform rotary shear experiment using low to high velocity rotary shear apparatus (Durham University) to constrain the frictional properties of gouge samples at sub-seismic slip rates (1.3 µm/s – 13 mm/s). Experiments are carried out at a constant σ_n under Dry, Wet and Brine saturated condition. A series of experiments are performed on samples of undeformed protolith and slip zone gouge samples, where induced velocity steps are imposed with variable displacement and increasing velocity. Experiments demonstrate increasing velocity strengthening behaviour in dry conditions with increasing slip rate, whilst both wet and brine saturated conditions show a constant velocity strengthening behaviour with increasing slip rate and displacement. The effect of this velocity strengthening behaviour, promotes stable sliding conditions, at near seismic slip rates. Slide hold slide tests determine the time dependence of friction showing a dramatic time dependent weakening in wet and brine saturated samples and a transition from healing to weakening in dry conditions, with increasing hold time. These experiments give incite into the frictional behaviour of organic rich shales, showing steady state frictional velocity dependence (a-b) remains velocity strengthening - acting to inhibit earthquake nucleation under all conditions. The result of introducing fluids does not significantly reduce the velocity dependence of friction, so stable sliding occurs. Weakening behaviour implies that the standard stick-slip model does not apply as stress cannot build up due to the weakness of the fault plane. Conditions are not suitable for the nucleation of an earthquake. In this study I report the field and frictional experimental results, and provide a speculative view of the potential deformation mechanisms;

however further microstructural analysis of deformed samples is required to constrain the deformation mechanisms and characteristics.

The evolution of frictional properties in fault rocks during the seismic cycle.

Unwin, R.H. **TR4** 12:00

Synoptic fault models assume the shallow parts of active crustal faults are aseismic and a barrier to earthquake propagation. The frictional properties of fault gouges can control whether earthquake nucleation and propagation can occur within a gouge. Incohesive gouges at shallow depths are thought to be velocity strengthening, and thus should quickly arrest earthquake propagation due to the stress drop. Contrary to this, recent earthquakes, such as the 2011 Tohoku-Oki earthquake, have had unexpectedly large amounts of near-surface slip.

Synoptic models are based on rate and state friction experiments on undeformed granular gouges; in nature, however, frictional heating during seismic slip could trigger physical-chemical reactions which have unknown effects on the frictional properties of fault gouges. Here, I show frictional properties evolve after sub-seismic and seismic slip for five typical fault gouges in different tectonic settings.

Strain localisation and dynamic weakening cause a transition from velocity strengthening to velocity weakening behaviour in granite gouges, promoting earthquake nucleation and propagation. Gabbro, calcite and dry and wet illite-smectite gouges become more stable with slip, resulting in greater stress drops and a more rapid arrest of earthquake propagation. The degree of strain localisation affects the healing rate in granite and gabbro, but not calcite or dry or wet illite-smectite. Dynamic weakening processes affect the healing rate in granite, gabbro and wet illite-smectite, but not calcite or dry illite-smectite. These results indicate a gouge's frictional stability and healing rate are influenced by its slip history, in terms of strain localisation and if dynamic weakening has occurred. It can also depend upon mineralogy and fluid presence. These findings suggest popular synoptic fault models are overly simplified, and those for continental crustal faults do not accurately represent the frictional properties of granite gouges with a slip history. This has implications for seismic hazard analysis, and thus understanding the slip history and distribution of fault gouge types along a fault is important.

A study of the geochemistry of the marine successions at Bowlees Quarry, Teesdale: palaeoenvironment implications.

Boughey, S.S. **TR3** 14:00

15 Dinantian samples from the Bowlees marine succession have undergone a variety of geochemical analysis in the first geochemical investigation of this area. Petrographic analysis indicates that the succession was deposited on the boundary between the mid and outer sections of a carbonate ramp resulting in limestone units with abrupt shale interbeds. Carbon isotope data ($\delta^{13}C$) for these samples highlights fairly stable environmental conditions, suggesting the presence of shale interbeds is purely related to where they have been laid down rather than linked to any changes in climate. Rock Eval Pyrolysis data indicates the shale units are unlikely to have any potential as a source for hydrocarbon production. Organic matter contents (TOC) are generally very low, with the highest value being 4.32 wt.% and an average value of 1.33 wt.%. for the succession as a whole. This study provides some insight into the environment in which the sediments were deposited and the implications with regard to the potential for petroleum. However, it is clear this is the initial stage of what could be a larger-scale future study determining precise details of palaeoclimate in this region.

Computer Modelling of the Delaware Basin to Assess the Compaction Characteristics of Mudstone/Carbonate Sediment Mixtures.

D'Souza, B. **TR3** 14:15

The Delaware Basin in northwest Texas is a Palaeozoic sedimentary basin which is significantly overpressured at depth. Well pressure tests have shown that overpressures up to 50 MPa above hydrostatic pressures exist in an overpressured zone, overlain and underlain by hydrostatically pressured sediment. Mudstone/carbonate sediment mixtures are abundant in this basin which makes accurate predictions about subsurface porosities, permeabilites and pore pressures difficult as the compaction characteristics of these sediments are generally understudied. Computer modelling will attempt to shed some light on the compaction of mudstone carbonate mixtures by modelling permeability controlled disequilibrium compaction in the basin as the core mechanism for generating the overpressure measured in the Delaware Basin. This modelling has predicted that a permeability of 0.004 nD is the minimum permeability required to produce the amount of overpressure measured in the Delaware Basin. This is significantly lower than any permeability ever recorded in a sedimentary rock. This suggests that disequilibrium compaction is not the only process generating overpressure in the Delaware Basin. It is likely that both hydrocarbon generation and smectite to illite diagenesis are also contributing factors in the generation and maintenance of overpressure in the Delaware Basin. In order for these processes to effectively produce overpressure it is likely that permeabilities of the order of 0.1 nD are needed to keep the overpressured zone a closed system.

The nature and development of zeolite mineralisation and gouges in reactivating shear zones within the Adamello Massif, Southern Italian Alps.

Gale, W.J. **TR3** 14:30

The Adamello Massif of the southern Italian Alps is host to one of the most extensive networks of zeolite bearing faults in the world. Through its exhumation, it has experienced an extensive progressive down-temperature history of structural deformation, with the formation cooling joints, shear zones, cataclasites and late zeolite veining. Previous work has highlighted how these deformation structures were reactivated and reworked by late episodes of fluid overpressure. These late fluids are responsible for the precipitation of the secondary silicate mineral zeolite; which forms an extensive network of mineralisation and gouges within the reactivated joints and shears in the Adamello. These aluminosilicate minerals form in low pressure and temperature environments and are hosted along an interconnected network of variably orientated, pre-existing structures throughout the region. Samples of zeolite bearing structures are studied from a $1km^2$ area within the Gole Larghe Fault Zone. Hosted by the Val d'Avio-Val di Genova Tonalite, these samples reveal a range of types of zeolite mineralisation, gouges and gouge injections (and associated deformation structures). Continuing work from Dempsey et al., 2014, this study focuses on the microstructural features of these vein types, aiming to determine the characteristics of each structure; but more importantly to determine the sequence of events that lead to their formation. The results of this study reveal five main controls on the formation of the structures: pressure of the system, volume of fluid, composition of the fluid and wall rock, the degree of reworking and the relative age of the structure. It is hypothesised that the intricate relationships and variations of these factors encompass what controls the formation of the wide range of zeolite-bearing structures in the Adamello.

Seabed mud volcanoes the result of diapir driven focused fluid flow on the Mauritania continental shelf.

French, G.R. **TR3** 14:45

Analysis of 3D seismic data from a gas hydrate province offshore Mauritania reveals the presence of seabed mounds and pockmarks, an underlying diapir, and a complex fault network. The seafloor features include two seabed mounds (PM1-2) with moats, a smaller mound (PM3) without a moat, and a pockmark (PM4) without a mound. Slight changes in pressure and temperature on the continental shelf may cause gas hydrates to dissociate. The bottom simulating reflector (BSR) corresponds to the base of the gas hydrate zone (BHSZ) and is marked by a negative polarity seismic reflection. The BHSZ domes above a NW-SE orientated salt diapir and is connected by a fault network that strikes in the same orientation. The fault network grew over time with the progressive intrusion of the diapir and acts as a deep rooted plumbing system for the migration of fluids and gas in the subsurface. Higher heat flux above the diapir causes gas hydrate dissociation at the BHSZ, triggering it to dome and trap free gas. BSR seismic amplitude anomalies display the regions of high gas accumulations. Gas is predominantly trapped in the eastern side of the dome closely following the intersection of the faults with the BHSZ. Acoustic wipe-out zones on the fault planes beneath the mounds are evidence for the migration of sediment, fluid and gas to the surface. Low seabed seismic amplitude anomalies suggest the mounds are gas charged mud volcanoes that undergo episodic expulsion events. High seabed seismic amplitudes adjacent to PM1 and PM3 suggest gas hydrates or carbonates may have formed in the upper sediments. Subsurface volume loss associated with the removal of material results in the formation of the pockmarks adjacent to the mounds. The locations of the mud volcanoes are controlled by the vertical flux rate of fluid, gas and sediment. The seabed features observed here are the surface expression of diapir driven focused fluid flow on the continental shelf and are indicators of active hydrocarbon seepage. This study highlights the vulnerability of the gas hydrate zone to small changes in temperature and pressure and helps us to understand the role gas hydrate provinces may play in past and future climate change.

Tight Gas in the Southern North Sea.

Santamas, A.A. **TR3** 15:00

With our ever-increasing need for energy in the United Kingdom, we are extending our search to unconventional fuel sources. Tight gas from the Carboniferous interval of the Southern North Sea could provide a solution to this energy crisis. In this report, the depositional environments of the Carboniferous are assessed for their viability in producing reservoir, source and seal rocks and a definition of tight gas in the Southern North Sea is established. Through the detailed analysis of 8 well cores of the Carboniferous interval, there is new insight into the reservoir quality of the Visean and Namurian. Additional petrographic analysis of well core 43/22-2 supports the existence of secondary porosity and microporosity in the Namurian, Millstone Grit formation. The primary control on reservoir quality is thought to be quartz cementation and compaction, whereby quartz overgrowths act to protect primary porosity by lessening the effects of compaction. Although permeability values of the Visean and Namurian interval are low, estimated flow rates for the 8 wells analysed reach up to 63 MMSCF/D. Well 43/22-2 and the other wells analysed, support the concept of tight gas in the Carboniferous interval of the Southern North Sea, whilst acknowledging the associated risks and the need for further research.

Identifying controls on carbonate-rich mudstone porosity using petrographic analysis within the Delaware Basin, Texas.

Shorey, J.E. **TR3** 15:15

Carbonate-rich mudstone samples of various Palaeozoic formations were collected from four drilling wells within the Delaware Basin, Texas, in

order to identify the controls on porosity. The samples are drill cuttings, amalgamated with resin into thin section, impregnated with blue dye and polished. Drill cuttings show excess fracturing and a loss of preserved hydrocarbons within pore spaces, but are the most representative samples for the basin rocks at depth. The samples were analysed using a combination of transmitted light microscope and scanning electron microscope (SEM) point counting, well log calculations, jPOR software and mercury injection experiments. These various techniques are used to produce a full rock composition, porosity, pore size and pore type distribution, with transmitted light microscope and SEM images.

Samples porosity values vary between data collection method. This is explained by the poor resolution of jPOR software and SEM point counting and effects of fracturing on the Density and sonic log data. Evidence of mechanical and chemical compaction with depth is observed as point and long grain contacts, dissolution, suturing of grains and stylolites. Porosity reducing processes identified within the samples include, carbonate and clay cements, formation of authigenic quartz and feldspar, dedolomitization, smectite to illite diagenesis and ductile clay compaction. Porosity is increased by fibrous partial pore-filling clay cement and dolomitization. The initially small porosity between clay minerals and the effects of carbonate cementation will reduce porosity greatly at shallow depths, reducing the effects of deep burial compaction and transformation processes. While temperature and pressure drive the processes affecting rock porosity, the mineralogy determines the effect the processes have on porosity. Based on strong correlations between carbonate content and rock porosity, carbonate content is found to be the primary control on porosity in carbonate-rich mudrocks.

Nature and significance of pyroclastic deposits from 29th December 2013 San Miguel eruption, El Salvador.

Cole, R.P. **TR4** 14:00

The 2013 eruption at San Miguel volcano, El Salvador was characterised by two small explosions, the second generating a pyroclastic density current (PDC) that flowed ~ 1 km from the summit vent. This type of eruptive activity had been considered rare at San Miguel, but it offered a good opportunity to sample fresh tephra. In this study, I estimate ~ 1.4 x 10^5 m^3 of pyroclastic material was carried in the flow, 2-5 x 10^4 m^3 of which was magma. The first granulometric and componentry analysis is carried out on tephra fallout and flow deposits, collected 4 months after the eruption. A detailed morphological study of the juvenile ash is also presented to constrain the cause of this eruption. I find that the eruption occurred in two or three phases. The initial Vulcanian explosions blew a vent-sealing plug and the resulting eruption column collapsed to produce the dilute PDC. The fragmentation mechanism transitioned from phreatomagmatic to magmatic during the course of the eruption. Water-magma interaction took place in a shallow aquifer and resulted in a fine-grained, lithic-rich deposit, with blocky and moss-like juvenile ash fragments, covered in adhering particles. Ash morphology and surface features, show that a low-degree of water-magma interaction took place and the groundwater body was probably exhausted. The last magmatic phase was more sustained and produced a coarse, very juvenile-rich fall deposit, containing highly vesicular fragments with smooth surfaces. San Miguel city lies only ~12 km NE of the volcano and farm land occupies the lower flanks. These types of explosive eruptions, therefore, pose a very significant hazard to the local population, but until now, have been poorly studied. The results of this study should be included for complete hazard assessments in future.

Host Rock Characteristics and Controls on Cu-Au-Ag Mineralization at Copper Mountain Porphyry Deposit, Southern BC, Canada.

Cromwell, E.J. **TR4** 14:15

This study assesses the relationship between host rocks and mineralization at a silica saturated copper-gold-silver alkali porphyry deposit; Copper Mountain, British Columbia, Canada. Mineralization is predominantly associated with units of the Lost Horse Intrusive Complex (LHIC). New field, petrographic and geochemical observations show at least 3 texturally and compositionally distinct phases of the LHIC: LH1 diorite, which displays no close relationship to mineralization, exhibiting equigranular plagioclase feldspars (300-600µm), augite (200-400µm), disseminated apatite (<50µm), very fine (<50µm) titanite (trace) and low Th, Zr and Nb. LH2 porphyritic monzonite, which displays a close spatial relationship to chalcopyrite-bornite-chalcocite mineralization, characterized by plagioclase (200-500µm) and high relief augite phenocrysts (50-200µm) in a fine (<50µm) K-feldspar groundmass, with a sporadic geochemical distribution attributed to pervasive sodic and potassic alterations. LH2a porphyritic monzonite displays no close relationship to mineralization, has coarse euhedral plagioclase phenocrysts (1-9mm), anhedral augite (50µm – 1mm) and high Th, Zr and Nb. These observations allow us to identify characteristic features associated with pre, post and syn-mineralization intrusions. This study documents several occurrences of structurally controlled molybdenite with mineralization. Re-Os geochronology of molybdenite allows us to constrain an age of mineralization to 203.3 ± 1.0Ma, confirming an age of the LHIC after the intrusion of the Copper Mountain Stock (CMS) (205.5 ± 1.1Ma; Milhalynuk et al., 2009). Study on the CMS intrusive unit indicates 3 mineral phases, syenite, monzonite and an equigranular diorite containing plagioclase feldspars (100-300µm), augite (100-200µm), 5% biotite (200-700µm) and fine-grained disseminated magnetite (~50µm), displaying high-grade chalcopyrite-bornite mineralization on the peripheries of the diorite. Our new data provides an improved understanding of the intrusive evolution and associated mineralization at Copper Mountain and will provide a framework for magmatic complexity of similar known porphyry camps in British Columbia, Canada.

Quantifying Crystal Mush Structure in Slumped Gabbros, Tugtutoq, SW Greenland.

Dey, S.M. **TR4** 14:30

Qualitative descriptions of thin section samples using a petrographic microscope are well developed. However quantitative methods are needed to provide information about the physical processes occurring during the crystallisation of igneous rocks. This report focuses on slumped peridotite samples from different heights on the slopes of troll's mouths in Tugtutoq, South West Greenland. Currently no size analysis has been made for the minerals within samples from this area. Statistical techniques from the Spatstat package are applied to investigate crystal size distributions and textural features. Results show olivine crystals are sorted according to their sizes depending on their height above the base of the troll's mouth. A greater abundance of smaller (0.5-1.25mm) olivine crystals are present further above the base, while a higher abundance of larger (>1.25mm) olivine crystals occur closer to the base. Preferential settling of larger olivine crystals and clusters of smaller olivine crystals occurs due to their faster sinking velocities. It is proposed synneusis of crystals is responsible for the characteristic textures in the peridotites including clustering of smaller (0.5-1mm) olivine crystals.

Sintering and processes during kimberlite eruption: evidence and implications from the youngest known kimberlitic volcanoes on Earth, the Quaternary Igwisi Hills, Tanzania.

Haddock, D.G. **TR4** 14:45

The Igwisi Hills of Tanzania are the youngest

known kimberlites on the planet and are thought to have erupted during the late Pleistocene-early Holocene. They are unique in that their young age has exceptionally preserved extra-crater deposits that have been previously unseen or been too heavily altered in other kimberlites. Petrographic and scanning electron microscope (SEM) analysis of several samples, particularly lithic-rich IH10, has revealed several intriguing features of the Igwisi Hills eruption. It is characterised by highly irregular pyroclasts in comparison to those from other kimberlite eruptions. This irregularity stems from the rapid quenching the pyroclasts upon formation most likely due to eruption in a likely phreatomagmatic setting. All pyroclast types show strong evidence of sintering over the scale of hours - even quenched pelletal lapilli. This may contradict previously hypothesised methods of pelletal lapilli formation and sintering processes in ultrabasic magmas which may be different or perhaps even not apply at Igwisi Hills. Evidence points towards a post-eruptive phase of sintering in already deposited fallout beds.

New or re-used crust from arc-collision in the Western Bismarck arc: An analysis through oxygen isotope geochemistry.

Sharp, M.J. **TR4** 15:00

New oxygen-isotopic data obtained through laser-fluorination is presented for the Western Bismarck arc. The data from within the clinopyroxene phenocrysts phase is analysed in conjunction with the model presented by Woodhead et al. (2010), which is based primarily on changes in the radiogenic isotopic values and trace element concentrations along the arc to establish the effect that the arc-continent collision has had upon the subduction system. Oxygen provides an isotope system that is a very sensitive indicator of magma mixing, whereas element abundances are much more easily obscured. The oxygen isotope data obtained from clinopyroxene phenocrysts is applied alongside radiogenic strontium ratios from the same samples, to James' (1980) binary mixing model in order to place constraints upon Woodhead et al.'s model. This allows the mode of contamination by sialic material to be deduced and the amount of detrital material involved in the genesis of the lavas erupted along the Western Bismarck arc to be estimated. $\delta^{18}O$ values along the Western Bismarck arc range between 5.31‰ – 5.89‰, peaking in the centre of the arc along with geochemical tracers presented by Woodhead et al. (2010). The crustal component end-member values used in the mixing model is derived from a range of sediment samples collected from the Solomon Sea, these are highly enriched in Strontium in comparison to the mantle resulting in the model strongly predicting that the contamination of the arc lavas is the result of source contamination. The $\delta^{18}O$ values are indistinguishable from those estimated for the typical depleted mantle so the predicted volume of material from the subducting slab involved in the genesis of the lavas is <1%.

High precision seawater strontium measurements over the last 360 Kyr: Can glacial-interglacial fluctuations in $^{87}Sr/^{86}Sr$ be resolved?

Plumstead, J. **TR4** 15:15

The $^{87}Sr/^{86}Sr$ ratio of seawater is generally regarded as a proxy for the rate of chemical weathering of the continents. Existing foraminiferal $^{87}Sr/^{86}Sr$ measurements over the late Pleistocene provide no evidence for glacial-interglacial variability in the Sr composition of seawater at the ±4.9 - 13 ppm level of precision. However present day chemical weathering studies, other isotope systems and modelling suggest that fluctuations in seawater $^{87}Sr/^{86}Sr$ might exist even if they cannot be detected by current analytical techniques. This study presents very high precision $^{87}Sr/^{86}Sr$ isotope data from each of the major oceans and a seawater $^{87}Sr/^{86}Sr$ record from Ocean Drilling Project (ODP) Site 758 in the Bay of Bengal. $^{87}Sr/^{86}Sr$ measurements for modern seawater from the Indian, Pacific and Atlantic Oceans are indistinguishable from one another (average $^{87}Sr/^{86}Sr$ composition =

0.7091735 ± 0.0000029; n = 15) at the level of precision achieved in this study (±4.06 ppm; 2σ; n = 15). This observation is entirely consistent with the long residence time of Sr in the ocean (~2.5 Ma). The long-term trend over the last 360 kyrs based on the best fit trend to the data obtained here and that of Mokadem *et al*. (2015), constrains the rate of change of seawater $^{87}Sr/^{86}Sr$ with time to 5.2 ppm 100 kyr^{-1}. This trend is well within error of previous long-term calculations of seawater $^{87}Sr/^{86}Sr$ evolution. The seawater $^{87}Sr/^{86}Sr$ record covering glacial termination II (114 - 142 ka), III (236 - 257 ka) and IV (332 – 364 ka) shows no resolvable glacial-interglacial fluctuations, and limits the maximum response of seawater $^{87}Sr/^{86}Sr$ to variations in the chemical weathering flux and/or composition to ±6.52 ppm (2σ). Calculations suggest that a variation of <±15% around the steady state weathering flux can be accommodated by the uncertainties obtained here. The new data cannot accommodate a short-term weathering pulse during de-glaciation, although a more diffuse weathering pulse accompanying gradual ice sheet retreat is permitted. These results still indicate that modern riverine fluxes are potentially higher than the Quaternary average, this non-steady state behaviour during successive glacial terminations in the Quaternary can also account for the long-term rise in $^{87}Sr/^{86}Sr$ over this time interval.

Poster Presentations

Level 2 Undergraduate

001	**Edwards J.D.**	Assessing the Implications of a Cumbra Vieja Tsunami on New York, Washington DC, and Miami Dade
002	**Garvey, C.J.**	"Do Impact Craters On Mars Serve As A Good Proxy For The Age of The Martian Surface?"
003	**Graham, S.P.**	The Structure and Tectonic History of the Scremerston Region, Northumberland
004	**Hodges, Z.V.**	A GIS analysis of arsenic contamination of groundwater in Bangladesh
005	**Katz, O.**	A GIS-based DRASTIC method assessment of groundwater vulnerability in the Lower Weber Sub-basin watershed, Utah
006	**King, J.J.**	The structure and tectonic history of the Scremerston region, Northumberland
007	**King, J.J.**	Which parts of California are most at risk from major earthquakes?

Level 3 Undergraduate

008	**Hirst, S.J. & Smailes, N.J.**	Near-surface geophysics using a multiple method approach at Brancepeth Castle, County Durham
009	**Leung, N.S.J. et al.**	Effect of pH on Pesticide-soil-mineral Interactions: Molecular Modelling Study of Glyphosate-clay Hydrated Interfaces

Level 4 Undergraduate

010	**Cromwell, E.J.**	Host Rock Characteristics and Controls on Cu-Au-Ag Mineralization at Copper Mountain Porphyry Deposit, Southern BC, Canada.
011	**French, G.R.**	Seabed mud volcanoes the result of diapir driven focused fluid flow on the Mauritania continental shelf.

MSc Student

012	**Alves-De-Matos, M.**	Evidence for active faults in SE Brazil
013	**Dobrzański, A. et al.**	Can iron-making and steelmaking slag products be used to sequester CO2? Passive weathering and active carbonation experiments
014	**Erdogan, A.R.**	Swelling Behaviour of Bentonite in Different Organic Solvents
015	**Freeburn, R.**	Numerical modelling of slab breakoff to assess the potential for generating post-collisional magmatism.
016	**Mahony, J.**	MiST – Microalgae in Sewage Treatment
017	**Racionero Gómez, B.**	Rhenium uptake and distribution in Phaeophyceae macroalgae, *Fucus vesiculosus*

PhD Student

018	**András, P. et al.**	Diagenesis and chemical compaction in Lower Cretaceous mudstones on the Halten Terrace, offshore mid-Norway
019	**Atar, E.F.L.**	Inorganic geochemistry and palaeoenvironments of the Early Jurassic Cleveland Basin.
020	**Barnes, J.M.**	Simple models of ocean circulation driven by volume fluxes through the sea bed.
021	**Danabalan, D. et al.**	Noble gases: the new frontier for helium exploration.
022	**Gregory, E.P.M.**	Geophysical analysis of fractured crust at mid-ocean ridges: The Costa Rica Rift
023	**Horan, K. et al.**	Controls on the molybdenum isotope composition of river water: Insights from Iceland and New Zealand.
024	**Inglis, E.C. et al.**	Iron stable isotope variations accompanying prograde metamorphism of basalts & gabbros from Alpine ophiolites
025	**Jones, T.J. et al.**	Pulling the plug on a Hawaiian fissure eruption.
026	**Maunder, B.**	Delamination of the Mafic Subducting Crust.

027	**Nanne, J.A.M.**	Stable osmium isotopes: A new geochemical tool.
028	**O'Neill, S. et al.**	Overpressure as a control on reservoir quality: the Taranaki Basin, New Zealand.
029	**Phethean, J.J.J.**	Offshore East Africa: Will breaking the geodynamic convention break the petroleum system?
030	**Snell, T.A.**	Fluid Overpressure and Earthquake Nucleation.
031	**Sproson, A.D. et al.**	Evidence for glaciation or an exogenic system shift across the Silurian-Devonian boundary: Insights from osmium isotopes.
032	**Strang, K.M.**	The Sirius Passet black shale Lagerstätte: The taphonomy of the Cambrian Explosion.
033	**Stricker, S. et al**	Enhanced porosity Preservation in Triassic Skagerrak, CNS.
034	**Underwood, T. et al.**	Molecular Dynamics Simulations of Low-Salinity Enhanced Oil Recovery.
035	**Wang, X. et al.**	Development and evolution of overpressure in the offshore Bohai Bay Basin, China.
036	**Zhang, J.**	Developing volcanic amphibole as a magma archivist.

Postdoctoral Research Assistant

037	**Agrusta, R., et al.**	Advantages of a conservative velocity interpolation (CVI) scheme for particle-in-cell methods with application in geodynamic modelling.
038	**Baldini, L.**	A speleothem-based trace element reconstruction of westerly wind strength during the Younger Dryas in northern Iberia.
039	**Boothroyd, I.M. et al.**	Fugitive emissions of methane from abandoned oil and gas wells and A study of the potential of major basin-bounding faults as a source of thermogenic methane.
040	**Bouilhol, P.**	Redefining the Trans-Himalayan batholith in the frame of the India-Eurasia collision.
041	**Clark, S.J.**	Cosmic-Ray Muons; the future of monitoring CO2 storage.

042 **Magni, V.** Slab dehydration and deep water recycling through time.

043 **Nunn, C.** Mount Etna: 3D and 4D structure using seismic tomography

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044 **Tang, Q. et al.** Markov Chain Monte Carlo inversion of temperature and salinity of solitons from marine seismic reflection records.

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045 **Adams, C.A.** BritGeothermal: Plumbing the Depths

046 **Allen, A.** Crustal processes cause adakitic signatures in syn-collision magmatism from SE Iran.

047 **Baldini, J.U.L.** Using high-resolution monitoring data to identify the effects of cave and surface conditions on cave drip water hydrochemistry

048 **Foulger, G.R.** The Yellowstone 'hot spot' track results from migrating Basin Range extension.

049 **Harper, D.A.T.** An enigmatic large discoidal fossil from the Pennsylvanian (Upper Carboniferous) rocks of County Clare.

050 **Humphreys, M.C.S.** The validity of plagioclase-melt geothermometry for decompression-driven magma crystallisation.

051 **Imber, J. & Wille, J.** The spatial distribution of fractures and extension in oil-mature and immature shales.

052 **Kalnins, L.M.** The morphology of the Tasmantid Seamounts: Interactions between tectonic inheritance and magmatic evolution

053 **Macpherson, C.G.** Segmented magmatism in the Mariana Arc.

054 **McCaffrey, K.** Slip rate determination in Active Normal faults, central Apennines, Italy.

055 **Niu, Y.** The nature of the lithosphere-asthenosphere boundary (LAB) beneath ocean basins

056	**Williams, H.M.**	Iron stable isotopes, magmatic differentiation and the oxidation state of Mariana Arc magmas.
057	**Worrall, F. et al.**	A 19-year long energy budget of an upland peat bog, northern England
058	**Worrall, F. et al.**	Understanding multiple element budgets of peatlands – stoichiometry, enthalpy and entropy

Assessing the Implications of a Cumbra Vieja Tsunami on New York, Washington DC, and Miami Dade.

Edwards, J.D.

Level 2 Undergraduate 001

Changes in the strain regime of the Western flanks of the Cumbra Vieja volcano on La Palma over the past several thousand years has led to the prediction of a lateral slope collapse induced tsunami (Day et al., 1999). This tsunami has been mathematically modelled in detail (e.g. Abadie et al., 2012), however no comprehensive hazard assessment of high risk regions of the USA has been made. This study aims to understand the social and physical implications of such an event on New York, Washington DC and Miami Dade, based upon worst case scenario circumstances outlined in Moss et al., 1999. Data was acquired from various sources, notably the USGS, and processed using ArcGIS. Inundation zone mapping was achieved using a custom built model and spatial data was analysed using these zones. Influence on population, structures, hospitals, metro networks, and tourist attractions have been studied and appropriate evacuation routes and zones assigned. Miami Dade is most adversely effected with ~$2bn worth of damages to the residential sector, 100% of the population effected, with no feasibility for evacuation zones within the county. New York experiences moderate impact with 84% of the population effected and ~7.2 million structures damaged. Washington DC is least effected with 52% of the population living within inundation zones. Important limitations and assumptions are noted including the lack of hydrodynamic data which cannot be processed in ArcGIS.

"Do Impact Craters On Mars Serve As A Good Proxy For The Age of The Martian Surface?"

Garvey, C.J.

Level 2 Undergraduate 002

The majority of planetary bodies show scars of impact bombardment, whether they be from asteroids or meteorites, Mars is no exception. Without being able to absolute date rocks linked to specific locations, these visible impact features have long been used to determine cratering rates thus providing age ranges for the emplacement of major geologic units.

This study uses ArcGIS as an analytical and illustrative tool in assessing the use of the relative abundances of craters to relatively date the surface of Mars. Crater abundance will primarily be used alongside potassium concentration data in order to answer the study question.

The Structure and Tectonic history of the Scremerston region, Northumberland

Graham, S.P.

Level 2 Undergraduate 003

The work presented here represents the result of fieldwork carried out as part of the second year *Structural Geology and Tectonics* module. The work concentrates on the strata exposed at Cocklawburn beach, near the village of Scremerston, Northumberland (around 4 miles south of Berwick upon Tweed). The exposures consist largely of a deformed sequence of limestones, sandstones and mudstone from the Visean stage of the Lower Carboniferous. The work carried out focused on characterising the stratigraphic order (way-up) of the deformed beds, the nature of their structures (brittle or ductile) and determining the orientation of the paleo-stress and strain fields, their relationship to each other, and quantifying these where possible. Strain analyses were carried out on three antiforms, quantifying the shortening due to

folding, and extension due vein emplacement along the fold axes. Conjugate joint sets exposed on some folds were used to infer the orientation of the paleo-stress field. The Wilcoxon Ranked Sum test (also known as the Mann-Whitney U test) was applied to strike data take from fold traverses to test the coaxiality of the deformation on a local scale. It is concluded that deformation was predominantly due to NNW – SSE trending shortening, accommodated by folds and minor faulting (fold accommodation faults). The result of the statistical analysis points to the deformation being locally coaxial.

A GIS analysis of arsenic contamination of groundwater in Bangladesh.

Hodges, Z.V.

Level 2 Undergraduate 004

In the 1960s and 1970s, millions of tube-wells were dug across Bangladesh to provide safe drinking water and reduce fatalities from water-borne diseases. However, as a result, Bangladesh has seen the worst case of mass poisoning in history due to naturally occurring arsenic in groundwater. Using GIS software, the distribution of arsenic contamination was examined in relation to population, geology and depth. Unlike other cases of arsenic contamination, spatial analysis revealed no significant control on arsenic distribution by population, thus supporting a natural, rather than an anthropogenic, cause. Recent studies have attributed the existence of naturally occurring arsenic in groundwater to reductive dissolution of iron oxides by microbial action; as such, this process is thought to occur where there is high organic content, such as in peat deposits. This GIS analysis found that high groundwater arsenic concentrations correlated with the distribution of alluvial and deltaic deposits of the Ganges-Brahmaputra-Meghna delta plain; these deposits contain numerous peat layers, which accrued during the Mid-Holocene. Inverse distance weighting revealed a relationship between depth and arsenic concentration, in that higher concentrations were found at shallower depths, thus implying that the younger Holocene deposits contained more peat layers than older deposits. Stratigraphic log evidence confirmed this, suggesting that the apparent depth control is simply an artefact of the geology, which inherently changes with depth and time. Overall, the findings suggest that deeper groundwater reserves within Bangladesh may provide a safer source of drinking water, though further tests on this potential source should be conducted.

A GIS-based DRASTIC method assessment of groundwater vulnerability in the Lower Weber Sub-basin watershed, Utah

Katz, O.

Level 2 Undergraduate 005

Groundwater pollution can have detrimental social and economic effects on regions such as Utah, which have sensitive aquifer reserves. In this investigation, I use a DRASTIC method approach to analyse the Lower Webber Sub-basin's vulnerability to groundwater pollution. The DRASTIC method uses a combination of aquifer properties, vadose morphology and environmental factors to form a low cost vulnerability analysis on a large scale, for which further investigation can be carried where needed.

I use GIS software and a more suitable modified DRASTIC equation, incorporating land use and population density factors. This allows me to assess the human interference with an agricultural and urban bias, which is especially relevant with the watershed's proximity to Salt Lake and the salt flats to the north. Incorporating population density into the equation allows for the creation of a pseudo risk map where vulnerability hotspots are isolated in conjunction with areas of high population density.

We discover that while the eastern provinces of the watershed, with the exclusion of the fertile valleys, present a low vulnerability to pollution, the western areas give over to a much higher overall vulnerability. This may be of some concern

as the majority of the population live in this sector, giving rise to an increased risk of generating pollution in the most vulnerable areas. Thus, raising questions for the water outlook in this area of Utah, with a large proportion of its agricultural and domestic water being sourced from groundwater reserves.

The structure and tectonic history of the Scremerston region, Northumberland.

King, J.J.

Level 2 Undergraduate 006

Scremerston, Northumberland, is located on the North East coast of England, approximately 3 miles south of Berwick-Upon-Tweed. A highly deformed Lower Carboniferous sedimentary sequence is exposed at Scremerston with rocks belonging to the 'Middle Limestone Group' comprising limestones, sandstones, mudstones, siltstones and coal. Field sketches, measurements, and observations collected on a one-day field trip, alongside aerial images, were used to interpret the area's tectonic history. Observing the region at different scales shows the strain ellipsoid to be heterogeneous. Spatial and temporal variations in the stress field are apparent and the heterogeneity of deformation indicates the region was subjected to phases of differing orientations and magnitudes of stress. N-S trending asymmetric folds, formed from E-W compression, are accommodated by limestone and thin shale layers which provide a strong mechanical anisotropy for flexural-slip folding to occur. The more competent limestone beds accommodate both brittle thrust faults, and ductile folding. I propose the folds exposed are second-order folds on the eastern limb of a larger scale antiform to the west, however more field data is required to test this hypothesis. The deformation most likely occurred in the upper crustal brittle regime, where the bedding surfaces act like faults. Looking at folds and veins in isolation, simple shear and elements of pure shear could explain the deformation, however roughly E-W trending dextral strike-slip faults (in sandstone beds) at the northern limit of the study area, and perpendicular extension suggests a more plausible mechanism is wrench-dominated transtension, due to strain partitioning of the anisotropic rocks.

Which parts of California are most at risk from major earthquakes?

King, J.J.

Level 2 Undergraduate 007

California is located on the West Coast of the United States of America, covering 423,970 km^2, with a population of 38.8 million. California lies on the Eastern edge of the Pacific 'Ring of Fire' and is subject to regular natural seismic activity. The tectonic transform plate boundary between the North American and Pacific plates runs through California posing a major natural hazard to areas of high population density such as San Francisco and Los Angeles. Using data freely available on the internet I have created several illustrated maps displaying; a seismic overview, ground shaking intensity and population density distribution, and where is most at risk. California's geological units have been classified based on shear-wave velocity into five groups of ground shaking intensity (A-lowest shaking intensity to E-highest shaking intensity). The mean recurrence intervals of California's main faults (from UCERF 3) have been used to forecast the predicted rupture years of the sub-sections of California's main faults. Combining ground shaking and population density data highlights areas at high risk to potential severe damage and fatalities from major earthquakes. Selecting the combined data with an attenuation factor of 50km proximity to major fault sub-sections with predicted fault rupture within the next 50 years highlights the areas most at risk from major earthquakes in the near future based on the UCERF 3 models.

Near-surface geophysics using a multiple method approach at Brancepeth Castle, County Durham.

Hirst, S.J. & Smailes, N.J.

Level 3 Undergraduates 008

Multiple geophysical methods have been used in a study area surrounding the outer walls of Brancepeth Castle, County Durham, in order to interpret the bedrock geometry and assess the presence of a hypothesised moat. Interpretations of two surveys, carried out along the western and eastern sides of the castle, are presented to give an overview of findings from Seismic Refraction, Electrical Resistivity Tomography (ERT) and Vertical Electrical Sounding (VES) surveying. Borehole records used in conjunction with the data collected show that bedrock beneath the site dips towards the northeast. This observation correlates with the interpretation of Seismic Refraction and VES data, whilst ERT data from the western side of the castle identifies potential fault offset, which may explain the original construction of the castle on shallow bedrock at the south of the site. The presence of a fault is supported by VES data collected along the eastern side of the castle; calculated offset errors indicate the presence of deep lateral resistivity variations, potentially caused by a step in bedrock. The hypothesis of a moat surrounding the castle walls remains plausible. ERT data highlights a shallow resistivity anomaly adjacent to the castle walls, showing a discontinuity between material of higher resistivity (~200 Ωm) close to the castle walls separated from a material of a lower resistivity (~30 Ωm) further from the castle. The presence of a moat has been proposed as a cause of subsidence on a turret built outwards from the outer walls of the castle.

Effect of pH on Pesticide-soil-mineral Interactions: Molecular Modelling Study of Glyphosate-clay Hydrated Interfaces.

Leung, N.S.J., Erastova, V., Underwood, T.R., Greenwell, C.H.

Level 3 Undergraduate 009

Glyphosate (GPS), the active ingredient of the widely used herbicide Roundup®, has recently been identified as a possible cause of human health problems. Because of its large-scale application in modern agriculture, it is important to understand its fate in the environment. The behaviour of GPS has been widely studied at macroscopic level, yet a molecular-level explanation has been lacking. In this study, the effect of pH on Glyphosate–clay interactions was studied using molecular dynamics simulations to obtain molecular level insights of the adsorption processes of GPS to clay minerals in soil. The systems being studied include sodium-saturated (NaMMT) and calcium-saturated (CaMMT) montmorillonites hydrated with fresh water and 0.1M $CaCl_2$ simulated soil solution. In the NaMMT systems, whereas GPS adsorption decreased as pH increased, GPS were always adsorbed on CaMMT but the associated mechanism was pH dependent. Generally, at very low pH (< 2.2) GPS was directly hydrogen bonded to the clay surface. As pH increased GPS were adsorbed through electrostatic interactions with the surface Ca^{2+}. It was also found that the $CaCl_2$ solution enhanced GPS adsorption on NaMMT as Ca^{2+} replaced some Na^{+} on the clay surface. The increase in adsorption thus became more notable as pH increases. Since Ca^{2+} were already saturated on CaMMT surface, $CaCl_2$ solution, did not give a significant effect on GPS adsorption on CaMMT. These results can have important implications for the development of retention time model and thus a more accurate transport model for the prediction of the fate of GPS in soil.

Host Rock Characteristics and Controls on Cu-Au-Ag Mineralization at Copper Mountain Porphyry Deposit, Southern BC, Canada.

Cromwell, E.J.

Level 4 Undergraduate 010

This study assesses the relationship between host rocks and mineralization at a silica saturated copper-gold-silver alkali porphyry deposit; Copper Mountain, British Columbia, Canada. Mineralization is predominantly associated with units of the Lost Horse Intrusive Complex (LHIC). New field, petrographic and geochemical observations show at least 3 texturally and compositionally distinct phases of the LHIC: LH1 diorite, which displays no close relationship to mineralization, exhibiting equigranular plagioclase feldspars (300-600µm), augite (200-400µm), disseminated apatite (<50µm), very fine (<50µm) titanite (trace) and low Th, Zr and Nb. LH2 porphyritic monzonite, which displays a close spatial relationship to chalcopyrite-bornite-chalcocite mineralization, characterized by plagioclase (200-500µm) and high relief augite phenocrysts (50-200µm) in a fine (<50µm) K-feldspar groundmass, with a sporadic geochemical distribution attributed to pervasive sodic and potassic alterations. LH2a porphyritic monzonite displays no close relationship to mineralization, has coarse euhedral plagioclase phenocrysts (1-9mm), anhedral augite (50µm – 1mm) and high Th, Zr and Nb. These observations allow us to identify characteristic features associated with pre, post and syn-mineralization intrusions. This study documents several occurrences of structurally controlled molybdenite with mineralization. Re-Os geochronology of molybdenite allows us to constrain an age of mineralization to 203.3 ± 1.0Ma, confirming an age of the LHIC after the intrusion of the Copper Mountain Stock (CMS) (205.5 ± 1.1Ma; Milhalynuk et al., 2009). Study on the CMS intrusive unit indicates 3 mineral phases, syenite, monzonite and an equigranular diorite containing plagioclase feldspars (100-300µm), augite (100-200µm), 5% biotite (200-700µm) and fine-grained disseminated magnetite (~50µm), displaying high-grade chalcopyrite-bornite mineralization on the peripheries of the diorite. Our new data provides an improved understanding of the intrusive evolution and associated mineralization at Copper Mountain and will provide a framework for magmatic complexity of similar known porphyry camps in British Columbia, Canada.

Seabed mud volcanoes the result of diapir driven focused fluid flow on the Mauritania continental shelf.

French, G.R.

Level 4 Undergraduate 011

Analysis of 3D seismic data from a gas hydrate province offshore Mauritania reveals the presence of seabed mounds and pockmarks, an underlying diapir, and a complex fault network. The seafloor features include two seabed mounds (PM1-2) with moats, a smaller mound (PM3) without a moat, and a pockmark (PM4) without a mound. Slight changes in pressure and temperature on the continental shelf may cause gas hydrates to dissociate. The bottom simulating reflector (BSR) corresponds to the base of the gas hydrate zone (BHSZ) and is marked by a negative polarity seismic reflection. The BHSZ domes above a NW-SE orientated salt diapir and is connected by a fault network that strikes in the same orientation. The fault network grew over time with the progressive intrusion of the diapir and acts as a deep rooted plumbing system for the migration of fluids and gas in the subsurface. Higher heat flux above the diapir causes gas hydrate dissociation at the BHSZ, triggering it to dome and trap free gas. BSR seismic amplitude anomalies display the regions of high gas accumulations. Gas is predominantly trapped in the eastern side of the dome closely following the intersection of the faults with the BHSZ. Acoustic wipe-out zones on the fault planes beneath the mounds are evidence for the migration of sediment, fluid and gas to the

surface. Low seabed seismic amplitude anomalies suggest the mounds are gas charged mud volcanoes that undergo episodic expulsion events. High seabed seismic amplitudes adjacent to PM1 and PM3 suggest gas hydrates or carbonates may have formed in the upper sediments. Subsurface volume loss associated with the removal of material results in the formation of the pockmarks adjacent to the mounds. The locations of the mud volcanoes are controlled by the vertical flux rate of fluid, gas and sediment. The seabed features observed here are the surface expression of diapir driven focused fluid flow on the continental shelf and are indicators of active hydrocarbon seepage. This study highlights the vulnerability of the gas hydrate zone to small changes in temperature and pressure and helps us to understand the role gas hydrate provinces may play in past and future climate change.

Evidence for active faults in SE Brazil

Alves-De-Matos, M.

MSc Student 012

This masters project is focused on active faults in a passive margin. We will be analysing the data collected to study the controls of intraplate seismic activities. It is still unknown what the cause is for the neo-tectonic structures in the area, induced seismicity and natural seismicity cannot be discerned from each other at environments where reservoirs are built, which is the case in SE Brazil. This project will be an outline for a more in- depth study of the influence of farfield and/or local stress pertubations for the area, thus adding to the debate on the influence of the Nazca plate in the Andes to the compressional regime of the South American plate and its seismicity in SE Brazil.

Can iron-making and steelmaking slag products be used to sequester CO_2? Passive weathering and active carbonation experiments.

Dobrzański, A., Worrall, F.[1], Gluyas, J.[1]

[1]Department of Earth Sciences, Durham University

MRes Student 013

The high calcium content of iron and steel-making slags has been highlighted as providing a suitable feedstock material and medium with which to sequester CO_2 into geologically stable carbonate phases. Optimisation of the natural carbonation process provides the potential for increasing the degree of carbonation above that possible via passive weathering.

This study has assessed the baseline passive carbonation potential of several different slag products (graded steel slag aggregate, pellite, GBFS) within the climate of the northern UK. This baseline was then used as a comparison to the carbonation values achieved by the same products when actively reacted in a CO_2-rich environment. The active carbonation phase of the project involved a factorial experimental study of materials reacted at 1MPa/10MPa CO_2 pressure and 25˚C/125˚C.

This study has shown:

1) That active carbonation of these products can successfully sequester additional CO_2.
2) Carbonation potential in general is highly dependent upon grain size within material types,
3) There is a material-dependent cost-benefit issue when using different active carbonation conditions as well as the choice to use active vs. passive carbonation.

The median sequestration potential of the slag products in this study is equivalent to the total

emissions from 910 people from the UK; the CO_2 emissions from 10000 tonnes of cement production; or 340000 tonnes of steel production.

Swelling Behaviour of Bentonite in Different Organic Solvents

Erdogan, A.R.

MRes Student 014

In this study the swelling behaviour of compacted "Wyoming Bentonite" was examined to gain fundamental understanding into the stability of shales during oil drilling operations. The swelling of clay tablets were analysed by a novel non-contact linear displacement meter. First, different organic solvents were chosen depending on their dipole moment, dielectric constant and surface tension. The swelling rate was calculated by measuring the time that the displacement due to swelling reached the sensor limit. The results were tabulated against each solvent parameter and correlations between swelling rate and each solvent parameter were made. Swelling rate was also correlated between linear alcohols as a function of the number of carbon atoms in the molecule chain. Second, different interlayer cations were used in certain solvents to see the effect of the cation on inhibition in different solvents. Linear swelling experiments were carried with the same procedure. After linear swelling tests, in ongoing work, X-ray diffraction (XRD) techniques will be used to examine the interlayer swelling of bentonite clay by measuring the *d*(001) interlayer spacing of the silicate layers of the clay. By using this technique, the role of interlayer swelling in total swelling will be monitored, and the role of the focused parameter on interlayer swelling and pore swelling will be determined. To observe the *in-situ* interlayer expansion in organic solvents wet-cell XRD procedure will be applied. Specific surface area and pore size distribution will be analysed by Brunauer–Emmett–Teller Analysis (BET) via adsorption and desorption isotherms of N_2.

Numerical modelling of slab breakoff to assess the potential for generating post-collisional magmatism.

Freeburn, R., van Hunen, J., Maunder, B., Magni, V., Bouilhol, P.

MPhil Student 015

Slab breakoff is often proposed as a mechanism for generating observed post-collisional magmatism in continental settings. Previous modelling studies suggest breakoff occurs at depths shallower than the overriding lithosphere, which could lead to partial melting through the decompression melting of upwelling asthenosphere through the slab window and the thermal perturbation of the overriding lithosphere. Interpretations of geochemical data which invoke slab breakoff as a means of generating magmatism mostly assume these shallow depths. However more recent modelling results suggest that slab breakoff might occur deeper.

2-D numerical models are designed to investigate the dynamics of continental collision and resulting slab breakoff and to study whether partial melting can be induced. To that end, the oceanic plate age, continental crustal and lithospheric thickness and crustal rheology are varied systematically. The shallowest breakoff, although always occurring at depths greater than the overriding lithosphere, is achieved when subducting a thick continental crust relative to the total lithospheric thickness. The post-processing application of a dry mantle solidus shows no melting would occur in this setting. We therefore model the hydration of the mantle wedge above crustal material and include the depletion of mantle material through time. Results show for an atypically thin continental lithosphere, a short-lived (<0.5 Myr) period of mantle melting can occur where hot asthenosphere flows through the slab window into a region hydrated by the detached slab.

MiST – Microalgae in Sewage Treatment

Mahony, J.

MRes Student 016

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

Scenedesmus obliquus was chosen as a suitable microalgal species and cultured in diluted autoclaved, ADL in sterile conditions. It was found that microalgae grown on the ADL was dually inhibited by high ammonia (NH3) concentrations and limited trace element availability. Trace element limitation decreased the microalgae biomass productivity to 1/3 of cultures with trace element supplementation. It was also found that NH3 concentrations > 17-23 mg/l NH3-N completely inhibited growth. A long time lag observed in 10 % ADL solutions was found to be due to the pH decreasing in ADL flasks over time (from 9.30 to 8.60), leading to a decrease in NH3 concentration until the toxicity threshold was crossed (approximately 20 mg/l NH3-N at pH 8.80), after which exponential growth occurred. Using 17.62 mg/l NH3-N as an inhibition threshold, it was calculated that the highest concentration of total ammonia nitrogen TAN that could be remediated at pH 7.0 was 400 mg/l TAN (a 3.75 x dilution of neat ADL).

Rhenium uptake and distribution in Phaeophyceae macroalgae, Fucus vesiculosus.

Racionero Gómez, B.

MSc Student 017

Owing to rhenium (Re) having no known biological role, it is not fully understood how Re is complexed by marine organic matter. A commonly held assumption is that Re is incorporated into the organic biomass during deposition and burial. However, brown macroalgae (Phaeophyceae) is known to concentrate Re up to several thousand times that known in seawater.

This study, utilizes *Fucus vesiculosus* (brown macroalgae) to assess Re uptake, abundance and distribution in the modern environment. Re abundance of *F. vesiculosus* structures were determined by Inductive coupled plasma mass spectrometry. Our data demonstrate that Re is not located in one specific structure within macroalgae, but is found throughout the organism. However, the relative Re abundance varies within the macroalgae, e.g., Re in the non-fertile thallus tips has a concentration four times higher than in all other structures.

We also evaluate the ability of Re uptake and tolerance of the *F. vesiculosus* tips via individual cultures grown in seawater of different Re(III) concentrations. The Re abundance of the non-fertile tips cultures show a positive correlation between the concentration of Re doped seawater to the abundance of Re accumulated in the tips. Rhenium uptake by non-fertile tips continued until a seawater Re concentration of ~1000 ppb.

In addition, we establish that dead *F. vesiculosus* does not accumulate Re, which indicates Re uptake is by a non-diffusive pathway.

Our data suggests that Re in organic matter occurs predominantly via bioabsorption (syn-life enrichment) and not bioaccummulation (post-life enrichment), and that macroalgae may provide a valuable source for Re phytomining.

Diagenesis and chemical compaction in Lower Cretaceous mudstones on the Halten Terrace, offshore mid-Norway

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Funded by GeoPOP3 Industry Research Consortium

PhD Student 018

The Cretaceous mudstones on the Halten Terrace, offshore mid-Norway are ideal to study the processes of chemical compaction in an overpressured regime. They are at maximum burial depth at the present day. The Cretaceous mudrocks are overpressured, with pore pressure showing very little lateral variation from well to well.

We used a set of different methodologies to characterize the composition, texture and physical properties of 53 shale samples from the Lower Cretaceous Lange Formation. X-ray powder diffraction (XRD) shows consistent mineralogy with little variation between the samples. The average clay content is 52%, with mixed layer illite-smectite being the dominant clay mineral phase (40%). Cation exchange capacity (CEC) measurements of the bulk fraction show a continuous decrease in smectite content in the mixed layer illite-smectite with depth, from 60% smectite at 2700 m rkb and 20% smectite at 4600 m rkb. The fabric anisotropy measurements (HRXTG) show a range of MRD (multiples of a random distribution) values from 2.2 to 7.7, but overall the results indicate a well-developed fabric alignment, also observed using SEM.

Porosity decreases from 25% at 2500m rsl to 5% at 4600m rsl. This porosity loss cannot be explained by classical mechanical compaction models, requiring chemical compaction related to smectite illitization and associated processes. The broad range of observed alignment values can be explained by the depositional silt/clay ratio of these rocks. Ongoing smectite illitization above 100◦C is a result of the time-temperature history – these rocks reached the temperature where chemical compaction started during recent, rapid burial.

Inorganic geochemistry and palaeoenvironments of the Early Jurassic Cleveland Basin.

Atar, E.F.L.

PhD Student 019

The palaeoenvironmental conditions leading up to and during the Toarcian Oceanic Anoxic Event (T-AOE) are still unclear. We use geochemical data from a core in the Cleveland Basin to investigate the depositional controls on this succession. Organic carbon isotopes reveal the c. 6‰ negative excursion in the Whitby Mudstone Formation which defines the T-OAE. A c. 2‰ negative excursion occurs at the top of the Cleveland Ironstone Formation, which we correlate to the Sulphur Band and the Pliensbachian–Toarcian boundary. Total organic carbon values are generally <2% before, 5–20% during, and c. 3% after the T-OAE. Detrital proxies suggest sediment supply before the T-OAE was cyclical and related to orbital pacing of either relative sea level changes or variations in the hydrological cycle. Published oxygen isotope data are consistent with 'freshening' of surface waters that elevated productivity in the photic zone during the T-OAE. Detrital proxies further suggest that siliciclastic sediment supply was shutoff during the T-OAE, a consequence of relative sea-level rise, which promoted trapping of sediment in nearshore environments, and led to the deposition of palimpsest sediment. Redox proxies alongside published Mo isotope data indicate sediment-pore water anoxia during the T-OAE, which enhanced organic matter preservation. Climate simulations for other OAEs indicate increased

rainfall with higher pCO_2 and global warming. We therefore suggest that elevated pCO_2 during the T-OAE resulted in higher global temperatures and sea levels and more intense precipitation. This led to enhanced biological productivity, water column stratification, basin anoxia and enhanced organic matter preservation.

Simple models of ocean circulation driven by volume fluxes through the sea bed.

Barnes, J.M. & Morales Maqueda, M.A.

PhD Student 020

As part of the OSCAR project (Oceanographic and Seismic Characterisation of heat dissipation and alteration by hydrothermal fluids at an Axial Ridge), the effects of geothermal and hydrothermal systems on deep ocean circulation are being studied. This poster introduces the oceanographic side of the project and presents some of the preliminary work; a selection of scenarios modelled using analytical techniques and computation in Matlab and Fortran. The situations modelled here are limited to the effects of volume fluxes through the sea bed in different configurations. Future work will add greater complexity to models, including the heat fluxes which will be a central focus of the project.

Aspirations for future work are discussed, along with the place this work has in the broader context of the OSCAR project.

Noble gases: the new frontier for helium exploration.

Danabalan, D., Gluyas, J.G., Macpherson, C.G., Barry, P.H., Warr, O., Mabry, J.C., Byrne, D.J., & Ballentine, C.J.

PhD Student 021

Helium is integral to modern society, however, known reserves are declining and there are no viable exploration strategies in place.

Radiogenic helium (^4He), which accumulates in the crust during quiescent periods, is released during periods of active tectonism. In the Hugoton-Panhandle gas field (USA), ^4He is known to strongly correlate with atmospheric-derived ^{20}Ne. This correlation suggests that basement-derived ^4He dissolves in overlying groundwater, migrates laterally and then degasses into a hydrocarbon gas phase.

To test whether this mechanism is common to other helium-rich natural gas fields, we have collected 22 natural gas samples from Kansas, the Harley Dome field in Utah, and two wildcat wells in Montana and Saskatchewan, Canada. Preliminary helium concentrations vary between 0.009 cm^3 STP and 0.080 cm^3 STP, greatly in excess of air values (5×10^{-6} cm^3 STP). The helium isotope ratio, $^3He/^4He$, ranges from 0.08 R_A to 0.66 R_A (1 $R_A = {}^3He/{}^4He_{air}$) indicating a predominantly crustal helium source with a minor mantle input for most samples.

To help characterise the involvement and importance of groundwater within this helium-rich reservoir, neon and argon data are also presented. $^4He/^{20}Ne$ ratios from the Kansas samples range between $3.5 - 7.8 \times 10^4$, indicating a lower degree of water involvement compared with the Hugoton-Panhandle ($^4He/^{20}Ne = 3.5 \times 10^4$). Harley Dome, Montana and Saskatchewan $^4He/^{20}Ne$ ratios range between $1.0\text{-}2.3 \times 10^5$, showing a 3-7 times lower involvement of the groundwater system. This is consistent with the high $^{40}Ar/^{36}Ar$ ratios present for these localities (4586-8963).

Geophysical analysis of fractured crust at mid-ocean ridges: The Costa Rica Rift

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

PhD Student 022

Fracture networks in upper oceanic crust affect its permeability structure and the exchange of fluids with the overlying ocean. Formed by extension at mid-ocean ridges, aligned faults and fractures control patterns of hydrothermal circulation, which causes alteration to the oceanic crust over time and changes to its seismic velocity structure. Seismic data from the Costa Rica Rift, acquired

from the spreading ridge to ~6 Ma crust at DSDP/ODP Hole 504B will be used to investigate this problem, in conjunction with real geology observed in the borehole. The construction of three-dimensional P- and S-wave velocity models from reflection and refraction data, alongside particle motion and anisotropy analysis will aim to constrain estimates of permeability and porosity in the upper crust, and the changes that occur as the crust ages and fractures are sealed through hydrothermal mineralisation. These results will contribute to the NERC-funded project OSCAR, aiding the project's objectives to better understand changes in oceanic crustal structure, namely the boundaries within seismic layer 2; the extent and influence of hydrothermal circulation on the crust; and the behaviour of fluids flowing in fractured rock. When combined with other research streams within OSCAR focussing on heat flow and geothermal heating of the deep ocean, this will integrate geophysical and oceanographic understanding of heat transfer and fluid flow at active mid-ocean ridges, and the potential effects on global ocean circulation and long-term oceanic crustal composition.

Controls on the molybdenum isotope composition of river water: Insights from Iceland and New Zealand.

Horan, K., Hilton, R.G. and Burton, K.W.

PhD Student 023

The molybdenum isotope composition of river water plays a central role in setting the $\delta^{98/95}$Mo of the oceans (Archer and Vance, 2008). Use of $\delta^{98/95}$Mo as a palæo-redox proxy in marine sediments requires quantification of the controls on $\delta^{98/95}$Mo in continental runoff. Molybdenum can be sourced from sulfides and organic carbon and its mobilisation may help quantify oxidative weathering reactions governing the long-term evolution of atmospheric CO_2 and O_2 (Calmels et al., 2007). Here we present measurements of the redox-sensitive trace elements molybdenum and rhenium and $\delta^{98/95}$Mo in rivers with contrasting lithology and differing erosion processes (glacial versus non-glacial).

Existing $\delta^{98/95}$Mo data from glacial rivers in basaltic catchments of Iceland (Pearce et al., 2010) show $\delta^{98/95}$Mo values increase from ~0‰ close to the source to ~1‰ downstream. In contrast, new data from the Skaftá glacial river indicates higher $\delta^{98/95}$Mo values at the source (0.43‰) which decrease downstream (0.23‰). This may reflect a predominance of sulfide weathering in this catchment; an idea supported by high sulfate concentrations. $\delta^{98/95}$Mo data from the Skaftá River also support the premise that glacial systems are isotopically heavy compared with non-glacial systems (Pearce et al., 2010), with a non-glacial tributary having $\delta^{98/95}$Mo=0.08‰.

Preliminary dissolved rhenium concentrations in rivers draining meta-sedimentary bedrock in the western Southern Alps, New Zealand, suggest oxidative weathering efficiency is greater in glacial ([Re]=1.3ppt-1.5ppt) compared with non-glacial catchments ([Re]=0.4-0.7ppt). Application of $\delta^{98/95}$Mo will lend new insights into the role of molybdenum source versus isotope fractionation during weathering in these catchments.

Iron stable isotope variations accompanying prograde metamorphism of basalts & gabbros from Alpine ophiolites

Inglis, E.C.[1], Debret, B.[1], Millet, M-A.[1], Burton, K.W.[1], Nowell, G.M.[1], Dale, C.W.[1] & Williams, H.M.[1]

[1]Department of Earth Science, Durham University, UK

PhD Student 024

During subduction the downgoing slab undergoes progressive dehydration and element loss to the sub-arc mantle. The transfer of iron in slab derived fluids could represent an important geochemical flux, and have a fundamental control on the redox state of the sub-arc mantle. Recent work has demonstrated that prograde serpentinite dehydration may result in the loss of iron from the slab, manifest by a progressive shift in the iron isotope composition with increasing metamorphic

grade.

To determine the mobility of iron in slab derived fluids we have analysed metabasalts and metagabbros from a suite of Alpine ophiolites. These fragments of fossil oceanic crust record prograde metamorphic conditions representative of the P-T path of basaltic crust during subduction. This provides us with a unique opportunity to examine the effect of subduction zone dehydration on the distribution and oxidation state of iron in the subducting slab.

Results show that variations in iron isotope composition does not correlate with Mg# and other indicators of melt depletion. This suggests that the observed variations in isotope composition are not related to protolith heterogeneity, and could be linked to later stage processes. Despite this, there is no systematic correlation between δ^{56}Fe and metamorphic grade. Trace element data reveals varying degrees of sediment and fluid interaction with blueschist facies lithologies but the effect of this on iron isotope systematics is unclear.

Future work will focus on characterising modern altered oceanic crust, in conjunction with ophiolite samples displaying sediment interaction.

Pulling the plug on a Hawaiian fissure eruption.

Jones, T.J.[1], Llewellin, E.[1], Houghton, B.[2], Brown, R.[1] and Vye-Brown, C.[3]

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PhD Student 025

Basaltic volcanoes are responsible for the bulk of the planet's magma output. Their eruptions are often spectacular, but are rarely violently explosive; consequently the hazard that they pose to life is modest. Nonetheless, basaltic eruptions can have serious impacts on a local scale (through lava flows) and regional scale (through emission of toxic gases); Icelandic fissure eruptions are one of the top three risks on the UK National Risk Register of Civil Emergencies. The 1969 Mauna Ulu eruption of Kilauea initiated as a fissure with coeval fire fountaining and lava flows. Despite the exceptional preservation at this fissure, features observed today largely represent lava drain back and spattering during the waning stages of the eruption and little evidence of primary effusion survives. We reconstruct drained lava volumes associated with different fissure segments across the flow field and discuss the dynamic behaviour required to create the surface topography observed today. Using Mauna Ulu as a case study, we explore the role that drainage of dense, relatively outgassed lava back down the conduit plays in controlling the system fluid dynamics, and shutdown of the eruption. This aids our understanding of the evolution and longevity of basaltic fissure eruptions.

Delamination of the Mafic Subducting Crust.

Maunder, B.

PhD Student 026

It is commonly accepted that the building of continental crust is linked to subduction zone processes, but the refining mechanism isolating the felsic product from its basaltic counterpart, leading to a stratified crust, remains poorly understood. Upward delamination of subducting material from the slab, its subsequent melting and segregation, with the felsic part being underplated and added to the overriding crust from below has been suggested to be a viable scenario.

In this study we use thermo-mechanical numerical models of subduction to explore the possibility of delamination of the mafic part of the slab crust and determine the conditions that are required by varying key parameters, such as subduction speed and angle, slab age, crustal thickness and density, overriding plate thickness, mantle temperature, depth of eclogitisation and the rheological properties for crustal and mantle material.

Our preliminary models demonstrate that, for present day mantle potential temperatures and average slab crustal thickness, only the uppermost 2-3km of mafic slab crust may delaminate and only for extreme rheologies (i.e very weak crust) or very slow subduction (~2cm/yr convergence), making slab mafic crust delamination unlikely. Contrastingly, in an early earth setting (High mantle temperature potential and thicker mafic slab crust) we find that delamination of the subducting mafic crust is a dynamically viable mechanism for a reasonable rheology under a wider range of subduction conditions and that when it does occur, it can be much more extensive, with the entire crust able to delaminate from the slab in some cases.

Stable osmium isotopes: A new geochemical tool.

Nanne, J.A.M. (Fienke), Millet, M.-A., Burton, K.W., Dale, C.W., Nowell, G.M., Williams, H.M.

PhD Student 027

We present the development of a new method that allows collection of stable osmium (Os) isotope ratios in geological samples to a high precision. Osmium is a highly siderophile (iron-loving) element that is redox sensitive and displays compatible behaviour during mantle melting. The stable isotopes of Os, therefore, have the potential to provide a powerful tool to constrain processes that take place on meteorite parent bodies or during Earths early accretion and differentiation. However, until this date, the stable isotopes of Os have remained unexplored.

We will show the precision and reproducibility that can be attained by the method through a range of analytical tests. In addition, we present, for the first time ever, measurements of the stable isotope composition of osmium in terrestrial and extra-terrestrial samples. Preliminary results on ordinary and enstatite chondrites show no detectable variations, which imply that Os stable isotopes were homogeneously distributed in the solar nebula. Data for terrestrial mantle samples also show little variations and display similar values to that obtained for chondrites. These results are consistent with expected consequence of the Late Veneer scenario where, after core formation, a late addition of chondrites delivered highly siderophile elements, including Os, to the depleted mantle.

Overpressure as a control on reservoir quality: the Taranaki Basin, New Zealand.

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PhD Student 028

The Taranaki Basin (TB) lies partly onshore and mostly offshore in the central-western part of New Zealand (NZ). It is the only basin in NZ with commercial oil and gas production. The TB has undergone a rapid burial history producing many overpressured regions and up to 9 km of sediments having accumulated since the Late Cretaceous. Palaeocene to Eocene Formations can be found normally pressured at out crop and offshore (near or at hydrostatic) and extend to deeper more highly pressured regions (>3000 m, >30 MPa). It is the Farewell Formation that forms the focus of this research, with specific focus on the role of high pore fluid pressures (low vertical effective stress) inhibiting pressure dissolution through burial compaction and maintaining high porosity to depth. Early results from this ongoing research have identified variable reservoir quality across the TB, but early tentative findings appear to demonstrate improved reservoir quality (porosity and permeability) for Farewell reservoirs that are often overpressured. The overpressured reservoir sandstones contain noticeably less quartz overgrowths and can have enhanced porosities especially where chlorite grain coatings also occur. Furthermore, in the producing Kupe fields variable fluid pressures with evidence for lateral drainage and downward hydraulic flow can be identified. The Farewell reservoirs appear to have an enhanced porosity of up to ~30% at 3100

m and lateral drainage may have influenced the mechanical and chemical diagenesis of the sandstones. The results will help to understand porosity preservation and reservoir quality in HPHT reservoirs and assist in developing improved predictive models.

Offshore East Africa: Will breaking the geodynamic convention break the petroleum system?

Phethean, J.J.J.

PhD Student 029

Interpretation of free-air and mantle bouguer gravity anomalies, in addition to their derivatives, from new satellite altimetry data (V23 - Sandwell and Smith) has allowed the identification of the extinct Mid Ocean Ridge, and related fracture zone trends, within the West Somali basin. We present a plate tectonic reconstruction for the drift of Madagascar away from Africa based on these interpretations, and calibrated to herein trusted ocean magnetic anomaly interpretations. The reconstruction supports the tight fit for Gondwana fragments of Reeves (2014), and elucidates as to the nature of the N-S trending Davie fracture zone (DFZ), previously interpreted by Coffin and Rabinowitz (1987) as the Continental-ocean fracture zone (COFZ). We now interpret this structure as a Ocean-ocean fracture zone (OOFZ) which to the north of Pemba formed by the coalescence of several fracture zones during a change in plate motion as Madagascar escaped from Africa. To the south of Pemba the DFZ converges with the NNW-SSE trending Continental-ocean fracture zone that runs along the Rovuma and Mandawa basins to meet the orthogonally and obliquely rifted margins of Tanzania and Kenya north of Dar es Salaam. This shifts the COB landward, by as much as 300km when compared to traditional interpretations, and may have devastating consequences for the petroleum maturation potential in many of the offshore East Africa blocks. These interpretations are supported by onshore and offshore Magnetic and gravity data, in addition to onshore geological observations and the interpretation of offshore seismic reflection data.

Fluid Overpressure and Earthquake Nucleation

Snell, T.A.

PhD Student 030

Understanding how the development of overpressured fluid patches along fault zones can act as nucleation sites and trigger earthquakes is critical.

We deliver a set of numerical models where the strength evolution of fault patterns is predicted as a function of the non-linear variation of their transport properties and pore fluid pressures, assuming natural fracture/fault patterns geometries.

Evidence for glaciation or an exogenic system shift across the Silurian-Devonian boundary: Insights from osmium isotopes.

Sproson, A.D.; Selby, D.; Hladil, J.; Slavik, L.; Ebert, J.; Zhao, W.; John, C.

PhD Student 031

The Silurian-Devonian boundary (SDB; 419.2 Ma) records one of the largest carbon cycle perturbations of the Paleozoic via a marked large positive carbon isotope excursion (2 to 6‰). Although the cause remains elusive it has been postulated that orogenic changes coupled with increased primary production from the expansion of early vascular terrestrial vegetation, led to increased carbon burial, lowering atmospheric CO_2, which drove cooling across the SDB. Subsequently, carbon-rich deposits eroded during Early Devonian sea regressions and a geodynamically active tectonic setting led to organic matter reburial and oxidation causing an abrupt shift in carbon isotope ratios to return to background levels.

Another theory extends periodic end-Ordovician and early-mid Silurian glaciations through the Silurian to the SDB. The Hirnantian glaciation and

the Ireviken Event are punctuated by carbon isotope excursions linked to major southern hemispheric glaciation. Despite a lack of evidence, Late Silurian carbon isotope excursions like the SDB could be related to glaciations induced by CO_2 drawdown from the Caledonian Orogeny.

Utilised here are osmium isotope ($^{187}Os/^{188}Os$) values of organic-rich sedimentary rocks from geological formations that span the SDB. We record an osmium isotope curve similar to that of Finlay et al. (2010) for the Hirnantian glaciation. This reflects changes in the weathering of radiogenic continental crust that occur in tandem with the SDB carbon isotope excursion. This data in combination with future oxygen and clumped isotope data may be the key to deciphering between glaciation and an exogenic system shift as causes for the SDB carbon cycle perturbation.

The Sirius Passet black shale Lagerstätte: The taphonomy of the Cambrian Explosion.

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PhD Student 032

The Sirius Passet Lagerstätte of North Greenland contains the earliest exceptionally preserved fossils of the Cambrian. The fauna include an abundance of bilaterans, particularly arthropods, iconically associated with the Cambrian Explosion. Understanding the taphonomy of these fossils is the key to accurately reconstructing the ecology of these early animal communities and the location of the Cambrian Explosion. Thin sections, Scanning Electron Microscopy and elemental mapping have been carried out on a variety of specimens from the Sirius Passet to determine the exact mode of preservation of the most abundant organisms. Results show that preservation occurred syn-depositionally. Trilobites show a unique death mask preservation, comprising a silica hyporelief, concave external mould (counterpart) and an epirelief convex cast, composed of silicified microbial mat material. *Campanamuta* specimens also show unique preservation but in this case specimens are flattened, muscles external to the guts are silicified and, gut contents are phophatised ($Ca_3(PO_4)_2$). It is hypothesized that: 1) The original seawater composition, changing sediment pore water chemistry and original tissue composition of the animals had a controlling influence on subsequent taphonomy and 2) mineralisation was initiated by crystal seed nucleation processes, controlled by reactions in the microbial mat. Differences between the trilobite and *Campanamuta mantonae* taphonomic pathways are considered due to: 1) the presence of a mineralized exoskeleton in the trilobites, absent in *Campanamuta* and, 2) different feeding styles. We document the first colonization of Cambrian mat grounds and discuss evolutionary links between ecological differentiation and taxonomic diversification in early Cambrian ecosystems.

Enhanced porosity Preservation in Triassic Skagerrak, CNS.

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

PhD Student 033

Current understanding of porosity preservation in sandstone reservoirs tends to be focused on how diagenetic grain coatings of clay minerals and microquartz can inhibit macroquartz cementation. However, where overpressure occurs, reducing vertical effective stress (VES) and arresting the rate of mechanical compaction can allow preservation of high porosities to depths normally considered uneconomic. We have investigated porosity preservation in fluvial sandstone reservoirs of the Triassic Skagerrak Formation, Central North Sea, which are deeply buried, high pressure, high temperature reservoirs (HPHT). Pore fluid overpressures within the Skagerrak Formation can exceed 35 MPa at depths of 4000 mbsf where temperatures are above 150 °C. Retained primary porosity up to 35% can be found in many of the fluvial channel sandstones. This study evaluates the role played by pore fluid overpressure and chlorite grain coatings in porosity preservation in HPHT reservoirs (above

65 MPa and 150°C). Skagerrak sandstones penetrated by wells in J-Block (UK Quad 30), the Heron Cluster (UK Quad 22) and the Norwegian area (Quad 7) demonstrate the controls on reservoir quality and differences in porosity preservation, ranging from 1% to 35%.

Molecular Dynamics Simulations of Low-Salinity Enhanced Oil Recovery.

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PhD Student 034

In an age of increasing energy demand it is clear that we must utilise our energy resources as efficiently as possible. Current oil extraction methods only recover approximately a third of the oil in a reservoir; however, it has been shown that incremental oil recovery can be achieved via using water floods of decreased salinity. The aim of this research is to bring clarity to the fundamental mechanisms behind low salinity enhanced oil recovery, a technique where seawater, partially desalinated, is used to push increasing amounts of crude oil from existing, and future, oil reservoirs. The phenomenon of low-salinity enhanced oil recovery is thought to be due to the complex interactions between the organic oil compounds, inorganic clay particles and the simple salt ions within the reservoir. Using large-scale classical molecular simulations, the presented results elucidate the underlying effects driving low salinity enhanced oil recovery.

Development and evolution of overpressure in the offshore Bohai Bay Basin, China.

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PhD Student 035

The Bohai Basin is a major continental hydrocarbon basin located in eastern China, of which the offshore part of the basin contains more than one-third of the total reserves. The research focuses on two main depressions in the offshore Bohai Bay Basin: the Bozhong and Liaodongwan Depressions. The stratigraphy in the basin is dominated by thick braided river, lacustrine and fan delta sediments of the Eocene Shahejie (Es) and Oligocene Dongying (Ed) Formations . The Eocene and Oligocene syn-rift sediments and Miocene to Recent post-rift sediments record a maximum thickness of 12 km.

The distribution of overpressure in the basin was evaluated by integrating direct pressure measurements and drill stem tests (DST) and pressures calculated from wireline logs. In total, 1433 DST from 143 wells has been incorporated into this study from the overpressured Es and Ed Formations. Overpressure tends to be restricted to the Bozhong and Liaodongwan Depressions that encountered the highest sedimentation rates. Compaction disequilibrium is favoured as the main mechanism to explain overpressure generation in much of the offshore Bohai Bay Basin, primarily due to the rapid sedimentation rates (~500 m/m.y.) of fine-grained sediments. However, our data indicates that the highest-magnitude overpressures are caused by the addition of hydrocarbon generation from the source rocks within the Es Formation. The depth to the top of the overpressure intervals ranges from 2000 to 2800 m and in several portions of the basin bears a close correlation to source rock depth of the Es Formation. All of the overpressured reservoirs and source rocks have a minimum temperature of ~87^{o}C and overpressured source rocks have a vitrinite reflectance (R_o) values of 0.6% or higher. Many of the overpressured source rocks contain microfractures that may be related to episodic expulsion of hydrocarbons or overpressure dissipation.

Overpressure in the sandstone intervals of the ES Formation and to a lesser extent of the younger Ed Formation correspond to anomalously

high porosity of up to 38% compared to the regional porosity-depth trend for the basin. In many cases the overpressured reservoir sandstones reflect an undercompacted state of burial and show a close association with tight calcareous mudstones that form an effective pressure seal in the basin. The distribution of overpressure, vertical effective stress, porosity and general reservoir quality of the reservoir sandstones are investigated as part of this study to more accuately guide exploration in the offshore Bohai Bay Basin, China.

Developing volcanic amphibole as a magma archivist.

Zhang, J.

PhD Student 036

Open magmatic behaviours, such as fractional crystallization and magma mixing, have been revealed as an important way in producing intermediate magmas beneath subduction zone-related volcanoes. These processes are closely related to the physical state of magmas stored in shallow crustal magma chambers, which determines the way of magma ascent and controls the style of volcanic eruption. Recently, investigation of magmatic pressure-temperature (P-T) conditions and open processes under intermediate arc volcanoes have been carried out using volcanic amphibole textures and compositions.

Amphibole is a common mineral phase in wet arc magmas which crystallizes over a large magmatic P-T range, its compositions are sensitive to magma parameters such as pressure, temperature, melt geochemistry and volatile contents. Any changes in those parameters caused by progressive fractional crystallization-driven melt geochemical evolution or disturbed by mafic recharge can be recorded in amphibole geochemical variations. Therefore, a careful examination of amphibole crystal texture combined with detailed geochemical survey over a range of crystal stratigraphy provide the key to reconstruct the pre-eruptive magma evolution history in the magma plumbing system.

In the poster, I will first present textural data and major- and trace element compositions of amphibole crystals from Mt. Lamington (Papua New Guinea). Then, the amphibole thermobarometry is employed to constrain amphibole crystallization P-T conditions. The amphibole-melt trace element partitioning coefficients ($^{amph/L}D$) from literature are evaluated and applied to the reconstruction of compositions of melts. Finally, a model uncovered from the amphibole archivist is proposed to explain how the plumbing system is formed under Mt. Lamington.

Advantages of a conservative velocity interpolation (CVI) scheme for particle-in-cell methods with application in geodynamic modelling.

Wang, H.*, Agrusta, R.*, van Hunen, J.

Postdoctoral Research Assistant 037

The particle-in-cell method is generally considered a flexible and robust method to model the geodynamic problems with chemical heterogeneity. However, velocity interpolation from grid points to particle locations is often performed without considering the divergence of the velocity field, which can lead to significant particle dispersion or clustering if those particles move through regions of strong velocity gradients. This may ultimately result in cells void of particles, which, if left untreated, may, in turn, lead to numerical inaccuracies. Here, we apply a two-dimensional conservative velocity interpolation scheme (CVI) to steady state and time- dependent flow fields with strong velocity gradients (e.g. due to large local viscosity variation), and derive and apply the three-dimensional equivalent. We show that the introduction of CVI significantly reduces the dispersion and clustering of particles in both steady-state and time-dependent flow problems, and maintains a locally steady number of particles, without the need for ad-hoc remedies such as very

high initial particle densities or re-seeding during the calculation. We illustrate that this method provides a significant improvement to particle distributions in common geodynamic modelling problems such as subduction zones or lithosphere-asthenosphere boundary dynamics.

A speleothem-based trace element reconstruction of westerly wind strength during the Younger Dryas in northern Iberia.

Baldini, L.[1], McDermott, F.[2,3], Baldini, J.[1], Arias, P.[4], Cueto, M.[4], Fairchild, I.[5], Hoffmann, D.[6,7], Mattey, D.[8], Müller, W.[8], Nita, D.[6], Ontañón, R.[4], Garciá-Moncó, C.[4], and Richards, D.[6]

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Postdoctoral Research Assistant 038

The latitude of North Atlantic westerlies during the Younger Dryas (YD) is constrained using precisely-dated, high-resolution stable isotope and trace element data from a La Garma Cave stalagmite, Northern Spain. In situ laser techniques yield a biennial-scale isotope and subannual-scale trace element record of the YD providing crucial information about the mechanisms that led to the onset, stabilisation, and termination of this important abrupt climate change event. We present high resolution Mg data as a novel proxy of sea spray contributions and therefore wind strength at this coastal cave site. Decadal-scale meridional oscillations in westerly storm tracks during the early YD (12.85 – 12. 15 kyr) resemble the modern NAO. Our records support a northward repositioning of westerlies between 12.15 and 12.10 kyr that persisted until the YD termination consistent with existing central and northern European wind reconstructions (Bakke et al. 2009; Brauer et al., 2008). A correlation between inferred westerly wind position and the low latitude Intertropical Convergence Zone (ITCZ) suggests that strengthened Atlantic Meridional Overturning Circulation (AMOC) resulted in northward migration of the ITCZ and associated atmospheric circulation, including westerlies over Europe. This resulted in break-up of sea ice initially proximal to Scandinavia, followed by the NW European Atlantic margin, and finally along NE North America. The mid-Younger Dryas atmospheric circulation reorganization occurred over just a few decades leading to a stormier northern Europe but a warmer Mediterranean.

Fugitive emissions of methane from abandoned oil and gas wells and a study of the potential of major basin-bounding faults as a source of thermogenic methane.

Boothroyd, I. M., Almond, S., Qassim, S., Worrall, F., Davies, R. J.,

Postdoctoral Research Assistant 039

Abandoned oil and gas wells from four onshore UK basins were surveyed for elevated concentrations of methane at the surface relative to controls with the same land use and soil type within the same basin. Results from a preliminary sample of 48 wells indicated that 26% had CH_4 at the soil surface that was significantly greater than their respective control. Results also suggested that 53 years since the date of well inception, there is a 50% risk of a well having a measurable leak with this probability rising to an 88% chance of a detectable leak after 100 years.

A second study was conducted to determine whether major faults bounding hydrocarbon

basins form natural conduits for methane. This was conducted to establish a baseline set of conditions for shale basins that may be subject to hydraulic fracturing in the future. Two shale basins were compared with the Durham coal measures and a non-hydrocarbon control basin. Preliminary results indicate that biogenic (microbial) methane sources dominate the observed elevations above atmospheric background but localised emissions of thermogenic (natural-gas) methane have been observed in the vicinity of major faults.

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

Bouilhol, P.

Postdoctoral Research Assistant 040

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

Cosmic-Ray Muons; the future of monitoring CO_2 storage.

Clark, S.J., Gluyas, J., Durham Physics, Sheffield Physics, Boulby Underground Laboratory, NASA Jet Propulsion Laboratory

Postdoctoral Research Assistant 041

The regulation of atmospheric greenhouse gas concentrations is required to stabilise the effects of anthropogenic climate change. Levels of atmospheric carbon dioxide could be reduced through CO_2 capture and storage (CCS) technologies. The principle of transporting and sequestering CO_2 in depleted oil and gas fields or in saline aquifers is well understood, however, current methods of monitoring subsurface CO_2 such as repeat seismic surveys are episodic and costly. Muon Tomography offers an innovative new method of passive subsurface CO_2 monitoring.

High-energy muons are created when cosmic rays interact with the Earth's atmosphere. These muons are attenuated by density and therefore it is possible to map the density profile of a large object by observing local variations in the muon flux. Geocellular models have been created using seismic and well data using Jewel Suite ™. These models accurately map the overburden geology and density above potential CO_2 injection sites. A variety of cases from pre-injection through to an unrealistic extreme CO_2 injection scenario (in which pores are 100% saturated by CO_2) were created. Physicists at the University of Sheffield then use them to accurately model the muon flux through the geology. A working prototype detector is currently installed in the Boulby Underground Laboratory within Boulby Potash

mine, Cleveland UK which is being used as a proof of concept.

Recent research has shown that muon tomography may also be able to provide a low cost, continuous, passive, subsurface monitoring technique that could complement existing technologies.

Slab dehydration and deep water recycling through time.

Magni, V., Bouilhol, P., van Hunen, J.

Postdoctoral Research Assistant 042

The fate of water in subduction zones is a key feature that influences the magmatism of the arcs, the rheology of the mantle, and the recycling of volatiles. We use a numerical tool that combines thermo-mechanical models with a thermodynamic database to investigate the dehydration processes in subduction zones and their implications for the water cycle throughout Earth's history.

Our results show that faster slabs dehydrate over a wide area: they start dehydrating shallower and they carry water deeper into the mantle. A hotter mantle (i.e., early Earth setting) drives the onset of crustal dehydration slightly shallower, but, mostly, dehydration reactions are very similar to those occurring in present-day setting. However, for very fast slabs and very hot mantle epidote is involved as a dehydrating crustal phase. Moreover, we provide a scaling law to estimate the amount of water that can be carried deep into the mantle. We generally observe that a 1) 100°C increase in the mantle temperature, or 2) ~15 Myr decrease of plate age, or 3) decrease in subduction velocity of ~2 cm/yr all have the same effect on the amount of water retained in the slab at depth, corresponding to a decrease of ~2.2×10^5 kg/m^2 of H_2O. We estimate that for present-day conditions ~26% of the global influx water, or 7×10^8 Tg/Myr of H_2O, is recycled into the mantle. We illustrate that deep water recycling might still be possible in early Earth conditions, although its efficiency would generally decrease.

Mount Etna: 3D and 4D structure using seismic tomography

Nunn, C.

Postdoctoral Research Assistant 043

We investigate the structure of Etna, an active stratovolcano in eastern Sicily. Recent work suggests that it is possible to detect changes in the elastic parameters of the rocks beneath Etna, and that these changes can be linked to volcanic activity.

Our partners at I.N.G.V - Catania have provided us with both P and S arrival time observations from over 3000 seismic events. These data cover a period which includes several eruptions, from 1st November 2000 to 31st December 2006. We are currently constructing 3D tomographic images to understand the structure and to form a baseline for our 4D work.

In volcanic systems, it is thought that the presence of fluids, cracks and pressurised gases can rapidly and drastically change the elastic properties. Temporal changes are commonly investigated by carrying out separate inversions for different epochs. However, we would expect repeated tomographic inversions of the same area to show some variation, even if the structure itself did not change. This is due to variations in the seismic ray distribution and to observational errors.

Consequently, we will use a new tomography program, **tomo4d**, that inverts multiple data sets simultaneously (Julian, B. R. and Foulger, G. R. Time- dependent tomography. *Geophys. J. Int.* **182**, 1327–1338, 2010). This code imposes constraints which minimise the structural differences calculated for different epochs. The remaining variations are thus truly required to fit the data, and should provide a more accurate picture of the temporal changes. Our work has future applications for the assessment of volcanic risk.

Markov Chain Monte Carlo inversion of temperature and salinity of solitons from marine seismic reflection records

Tang, Q.[1,2], Hobbs, R.W.[2], Biescas, B.[3]

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[2]Earth Sciences Department, Durham University

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Academic Visitor 044

Marine seismic reflection technique is used to observe the strong ocean process of solitons (nonlinear internal solitary waves, ISWs) in the near-surface water. Analysis of ISWs is problematical because of their transient nature and limitations of classical physical oceanography methods. This work explores a Marko Chain Monte Carlo (MCMC) approach to recover the temperature and salinity of ISW field using seismic reflectivity and in-situ hydrographic datasets. The MCMC approach is designed for directly sampling the posterior probability distribution of temperature and salinity which are the solutions of the system under investigation. Comparing to previous methods, the first principle improvement of the MCMC approach is the implicit expression of the intermediate parameters, whose additional assumptions and errors are removed. The second improvement is the capability of incorporating uncertainties in observations and prior models which then provide quantified uncertainties in the output model parameters. We test this method on two acoustic reflectivity datasets synthesized from CTD and derived from seismic reflections. The MCMC approach finds the solutions faithfully within the significantly narrowed down confidence intervals, and nearly equivalent to the conventional linearized inversion. While the former provides us the quantified uncertainties of the inversed model parameters the latter does not. When combined with a low frequency initial model modified from seismic horizons of ISWs, the finescale temperature, salinity and density structures of ISW field are derived, as well as their uncertainties. These results are the first time ISWs have been mapped with sufficient detail for further analysis of their dynamic properties.

BritGeothermal: Plumbing the Depths

Adams, C.A., Gluyas, J.G., Hirst, C.M. & Narayan, N.S.

Academic Staff 045

The UK's low enthalpy geothermal resources were assessed as a whole during the 1980s in response to the oil crisis. The geothermal potential was found distributed amongst deep sedimentary Mesozoic basins and buried radiothermal granites. This survey revealed that the geothermal resource in place could theoretically meet the UK's heat demand for 100 years. The study also identified the potential for modest power generation.

Efforts to ensure security of energy supply for the UK whilst reducing carbon emissions have renewed interest in deep geothermal energy to contribute to future energy demands. Three research wells have recently been drilled by the BritGeothermal partnership into the Weardale Granite (2 wells) at (Eastgate, County Durham) and associated structural features (Science Central, Tyne and Wear) and have provided information about temperature and permeability of strata at depths of between 500m and 2km.

Since the preliminary study additional low enthalpy resources exist associated with the exploitation of fossil fuels. In the UK, over 2000 hydrocarbon wells were drilled onshore between 1902 and 2013. Existing and future wells could be retrofitted with heat exchangers and used to provide several 100kW of heat per well. There are also vast ultralow enthalpy geothermal resources associated with flooded abandoned mines. Using these resources with heat pumps to boost their temperature, offer good potential because of their underlap with centres of population.

Crustal processes cause adakitic signatures in syn-collision magmatism from SE Iran.

Allen, M., Neill, I. & Kheirkhah, M.

Academic Staff 046

We report new elemental and Nd-Sr isotopic analyses for Late Cenozoic intrusive and extrusive rocks emplaced in SE Iran as part of the wider syn-collision magmatic province within the Turkish-Iranian Plateau. The sample sites are near the town of Dehaj. Most of the rocks are from stocks and batholiths, interpreted as the roots of central volcanoes. Age controls are not precise, but the rocks are likely to be Late Miocene-Quaternary in age.

The rocks range from basalt lavas through to rhyolites. Isotopic signatures are similar to Bulk Earth, without any clear evidence for large-scale crustal contamination. There is variable and high La/Yb and Sr/Y, such that the rocks range from calc-alkaline to adakitic compositions depending on the degree of fractionation.

As the 'adakitic signature' is increasingly apparent in more evolved magmas it is likely to have occurred during melt evolution from an initial low Sr/Y and low La/Yb parent. The high Sr/Yb and La/Yb signatures are best explained by the suppression of plagioclase fractionation by high magmatic water contents, promoting incompatible behaviour of Sr. Also, Y and Yb are compatible during amphibole and garnet fractionation, which may have occurred near the base of thickened crust. We argue that magmatism across much of the plateau is linked to small-scale convection beneath the collision zone, as predicted by numerical modelling. Particular compositions such as those at Dehaj are influenced by local sources and differentiation processes, but there is no need for independent triggers for initial melting across different locations.

Using high-resolution monitoring data to identify the effects of cave and surface conditions on cave drip water hydrochemistry

Baldini, J.U.L., Sherwin, C.M.

Academic Staff 047

Hourly-scale cave air PCO2, temperature, barometric pressure, and drip water electrical conductivity and discharge rates were used to demonstrate the effects of prior calcite precipitation (PCP) on drip water chemistry within Crag Cave, Ireland. Lower cave air PCO2 caused more CO2 degassing from drip water and subsequently more PCP, and higher cave air PCO2 reduced PCP, although these effects were minor compared with dilution effects caused by variability in recharge. Calcite growth over the interval of the study was quantified by using an Iceland Spar calcite rhombohedron as a substrate; the total observed calcite growth compared very favorably to values calculated using theoretical calcite growth equations. To our knowledge this is the first study that compares actual and theoretical calcite growth rates calculated using all growth determining variables at a high temporal resolution, and it suggests that equations used to calculate calcite growth rates are valid. The study also demonstrates that PCP is an active process in caves, and is potentially important in modulating drip water chemistry, stalagmite growth rates, and consequently geochemical proxy records contained within stalagmites.

The Yellowstone 'hot spot' track results from migrating Basin Range extension.

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Academic Staff 048

Whether Columbia River Basalts, eastern Snake River Plain and Yellowstone volcanism is related to a mantle plume or plate tectonic processes is a long-standing controversy. There are numerous geological mismatches with the plume model, and logical flaws, including the use of arguments for a deep-mantle origin to support upper-mantle plume models. The sweeping of the USArray seismic network across the continent has recently yielded abundant new seismological results but despite this, the most sophisticated seismic experiment ever staged having targeted the Yellowstone region, seismic analyses have still not resolved the disparity of opinion. This suggests that seismology is fundamentally unable to resolve the plume question for Yellowstone and likely elsewhere. USArray data, have, however, inspired many new models that relate western USA volcanism to shallow mantle convection associated with evolution of the subduction zone to the west. These models assume, however, that all that is required for surface volcanism is melt in the mantle and that the lithosphere is essentially passive. We propose a pure Plate model in which melt is commonplace in the mantle, and its tendency to rise is not the cause of surface eruptions. Instead, it is extension of the lithosphere that permits melt to rise. Eruptions occur where there is extension and not simply where there is melt. The time-progressive chain of rhyolitic calderas in the eastern Snake River Plain-Yellowstone zone formed in response to systematic eastward migration of the axis of most intense Basin Range extension since the province formed at ~ 16 Ma. Rhyolitic volcanism followed migration of the locus of most rapid extension, not vice versa. This model does not depend on seismology to test it, but can be investigated using surface geological observations.

An enigmatic large discoidal fossil from the Pennsylvanian (Upper Carboniferous) rocks of County Clare.

Murray, J.[1], MacGabhann B.A.[2,3,1], Doyle, E.[4] and *Harper, D.A.T.*[5]

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[2]*Department of Geography, Edge Hill University, Lancashire, UK.*

[3]*School of GeoSciences, University of Edinburgh, UK.*

[4]*Burren and Cliffs of Moher Geopark, County Clare, Ireland.*

[5]*Palaeoecosystems Group, Department of Earth Sciences, Durham University*

Academic Staff 049

A rare and unusual, large solitary discoidal fossil, c.130-135 mm in diameter, has been discovered on a paving slab quarried from the cyclothemic Central Clare Group (Kinderscoutian, Pennsylvanian, Carboniferous) of western Ireland. The slab in question was recovered for safe keeping from the pathway at the Cliffs of Moher Visitor Centre in 2009. The fossil impression itself consists of a smooth raised inner discoidal area, c.80 mm across, surrounded by a slightly lower relief outer ring with eight prominent equidistant ovoid raised nodes towards the outermost margin. The specimen is surrounded by a shallow groove.

It is not clear at present precisely how this enigmatic fossil should be classified, although the octoradially symmetrical body plan suggests possible placement within the cnidarians. The specimen is interesting from a palaeoecological perspective: it occurs within the world-renowned Liscannor Flagstone, which consists of thinly bedded, fine-grained sandstones which are extensively covered by prominent, sinuous to

meandering *Psammichnites* (= *Olivellites*) horizontal feeding trails (c. 10-20 mm in width). This particular sedimentary facies is generally interpreted as representing mouth bar sedimentation in a delta front succession. The organism responsible for the discoidal impression was clearly too large to have been the maker of the *Psammichnites* trails and it occurs on a portion of the slab where these burrows are largely absent. Either the *Psammichnites* trace-makers deliberately avoided this larger solitary organism, or this is merely chance preservation, with intensive bioturbation routinely obliterating other impressions of similar discoidal organisms.

The validity of plagioclase-melt geothermometry for decompression-driven magma crystallisation.

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Academic Staff 050

Any quantitative interpretation of the formation conditions of igneous rocks requires methods for determination of crystallisation temperature. Accurate application of such thermobarometers relies on the attainment of equilibrium in the system to be studied. This may be particularly difficult in silicic magmas, where diffusivities are low and crystallisation kinetics sluggish. Moreover, progressive degassing of volatile-rich magmas can result in continuous changes in effective undercooling, causing particular problems in achieving equilibrium between melt and crystals that grow in response to decompression. We consider these problems in the context of plagioclase-melt equilibria for magmas undergoing decompression crystallisation, using two published thermometers. Analysis of decompression experiments conducted at constant temperature show systematic variations in calculated temperature and K_D with varying decompression rate and quench pressure. This indicates that lack of equilibration could result in significant temperature overestimates and potentially spurious results. Analysis of published plagioclase-hosted melt inclusion suites from five subduction zone volcanoes shows a systematic increase in calculated temperature and K_D with decreasing pH_2O. We suggest that such temperatures should be treated with caution unless there is clear evidence of sustained equilibrium between plagioclase and melt during decompression.

The spatial distribution of fractures and extension in oil-mature and immature shales.

Imber, J. & Wille, J.

Academic Staff & L4 Undergraduate 051

The Cleveland Basin, NE England includes a thick (> 100 m) succession of Lower Jurassic black and grey shales. These deposits were buried to the early oil window between (2-4 km depth), prior to inversion and exhumation during the latest Cretaceous to Neogene. Structural analysis of well-exposed coastal sections (Wille, 2015) demonstrates that natural fractures within the Cleveland Ironstone and Whitby Mudstone Formations are characterised by uniform spacings, although fracture densities vary by a factor of 6 depending on the composition of the host shale. In contrast, extension is strongly localised across a few calcite-filled fractures and minor faults (throws < 10 m). The degree of localisation appears to be independent of the magnitude of extension.

Putz-Perrier & Sanderson (2008) studied the spatial distribution of fractures and extension in thin carbonate inter-beds within the shale-dominated Kimmeridge Clay Formation, Dorset. Here, the fractures are also characterised by uniform spacings, but extension is *uniformly* distributed, not localised. Differences in sampling strategy – that is, comparing fractures in carbonate inter-beds in Kimmeridge with

fractures in the shale matrix in NE England – cannot explain this difference in the degree of strain localisation. One potential explanation is that diagenesis and thermal maturation may have altered the mechanical properties of the shale succession in NE England, allowing brittle strain to become localised. By contrast, the immature Kimmeridge Clay Formation appears to have deformed in a more ductile manner.

The morphology of the Tasmantid Seamounts: Interactions between tectonic inheritance and magmatic evolution

Richards, F.D., *Kalnins, L.M.,* Watts, A.B., Cohen, B.E., Beaman, R.J.

Academic Staff 052

The Tasmantid seamounts extend for over 2000 km off the east coast of Australia and constitute one of three contemporaneous, sub-parallel Cenozoic hotspot tracks that traverse the region (the Tasmantid, Lord Howe, and East Australian volcanic chains), locally separated by as little as 500 km. Where dated, the three chains young from north to south, spanning ca. 34–6 Ma. At multiple locations, the Tasmantid chain intersects the extinct Tasman Sea spreading centre, which was active from 84 Ma to 53 Ma, and detailed morphological analysis reveals a strong correlation between tectonic setting, seamount orientation, and volcanic structure. Seamounts at inside corners of the spreading segment-transform intersections are more rugged and constructed via numerous intersecting fissure-fed volcanic ridges, whereas off-axis seamounts tend to be conical with summit craters and isolated dyke-fed flank cones. Such a strong connection between the long-lived mantle upwelling, ridge structure, and subsequent dyke emplacement – despite the ≥20 Ma offset between spreading cessation and initial seamount emplacement – suggests deep faulting of the Tasman Sea oceanic lithosphere in order to channel melts along pre-existing structural trends.

Segmented magmatism in the Mariana Arc.

Macpherson, C.G.

Academic Staff 053

Magmatic arcs, oceanic or continental, reflect the broadly curved nature of convergent plate margins. A common assumption, that arcs are small circles on the Earth's surface, has been used to relate arc volcano locations to their vertical separation from seismicity in the subducted slab and to conclude that the primary control on loci of magmatism lies in the slab or within the mantle wedge. The Mariana Arc is the type example of a small circle arc that has also been studied extensively using many other techniques, making it an important benchmark of volcanic arc geometry and dynamics.

We have applied a visual recognition algorithm, the Hough Transform, to demonstrate that the volcanoes of the Mariana Arc describe great circle segments. Exceptions occur where local tectonic modification of the arc lithosphere stress field is evident as cross-arc volcanic chains. With these exceptions, all active subaerial and submarine vents lie in five, great circle segments, with superior fit than a small circle distribution. Furthermore, the deviation of volcano locations from the best-fit small circle conforms to the expectation of great circle segments. These observations suggest that the transport of magma in the Mariana Arc is controlled in great circle domains that are coherent over 150 – 250km lengths. Any model of magma transport must account for this segmented behaviour.

Slip rate determination in Active Normal faults, central Apennines, Italy.

McCaffrey, K.

Academic Staff 054

High resolution topographic mapping has been used to create an extensive database for normal faults in central Abruzzo, Italy. The 6.3 Mw L'Aquila earthquake was caused by rupture on one of these structures in 2009. By interpreting

profiles across the high resolution topography, slip rates on individual fault structures can be accurately determined. A combination of airborne and terrestrial laser scanning (lidar), and ground penetrating radar also provide constraints for 36Cl cosmogenic sample site integrity and key inputs for the processing and modelling of the results obtained. These data are being used to investigate slip rate variability which seems to be characteristic of fault networks formed in continental crust. The ongoing campaign to map exposed faults in the region provides a baseline database for future large earthquakes in the region.

The nature of the lithosphere-asthenosphere boundary (LAB) beneath ocean basins

Niu, Y.

Academic Staff 055

The oceanic lithosphere begins to form at ocean ridges, thickens with age, reaches its full thickness of ~ 90 km at the age of ~ 70 Ma, and maintains the same thickness independent of its further aging beneath much of the world ocean floor. The relationship, $L \propto t^{0.5}$, between the thickness (L) and age (t) of the lithosphere and the seafloor heat flow data are consistent with conductive heat loss being the primary control. However, conductive heat loss continues, yet the lithosphere does not grow any thicker when $t > 70$ Ma. Many models have been proposed to explain this puzzle, among which small scale convection at the lithosphere-asthenosphere boundary (LAB) is most popular because such convection is thought to supply heat to prevent the lithosphere from thickening. We consider this apparent puzzle may actually be a petrological problem. Petrologists consider the LAB as a solidus, whereas geophysical models treat the LAB as an isotherm (~ 1100°C). For both isotherm (~1100°C) and solidus to "coincide" and to explain $L \propto t^{0.5}$ for $t < 70$ Ma and $L \approx 90$ km for $t > 70$ Ma, the solidus must have a slope $dT/dP \approx 0$ at depths < 90 km, and $dP/dT \approx 0$ at a constant depth of ~ 90 km. All these are wholly consistent with the oceanic lithosphere being defined by the stability of pargasite (amphibole): $P \leq 3$ GPa (~ 90 km) and $T \leq 1100$°C. That is, the LAB is a pargasite dehydration solidus of volatile-bearing mantle peridotite.

Iron stable isotopes, magmatic differentiation and the oxidation state of Mariana Arc magmas.

Williams, H. M.[1], Prytulak, I.[2], Plank, T.[3], Kelley, K. A.[4], Brounce, M. N.[5], Woodhead, J.[6]

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[3]Columbia University

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[5]California Institute of Technology

[6]University of Melbourne

Academic Staff 056

Arc magmas are widely considered to be oxidized relative to mid-ocean ridge lavas. However, it is unclear whether this is a primary feature, inherited from the sub-arc mantle, or the product of magmatic differentiation and/or post eruptive alteration processes.

Iron stable isotopes can be used to trace the distribution of Fe during melting and magmatic differentiation. Here we present Fe isotope data for well-characterized samples from islands of the Central Volcanic Zone (CVZ) of the intra-oceanic Mariana Arc to explore the effect of magmatic differentiation processes on Fe isotope systematics.

The Fe isotope compositions of samples from the CVZ islands range from -0.10 ± 0.04 permil (Anatahan; 3.85 wt% MgO) to 0.29 ± 0.01 permil (Guguan; 3.47 wt% MgO). Lavas from Anatahan have Fe isotope compositions that are displaced to lower overall values than the other CVZ samples and which are positively correlated with SiO_2 and negatively correlated with Ca, Fe_2O_3(t), Cr and V. These correlations are interpreted in terms of clinopyroxene and magnetite fractionation, with magnetite saturation throughout the differentiation sequence. The early saturation of

magnetite in the Anatahan and CVZ lavas is likely to be a function of melt water content and potentially oxidation state. The distinct Fe isotope compositions of lavas and inferred primitive melts from Anatahan and the other islands may reflect derivation from variably oxidised and hydrated sub-arc mantle source regions with distinct Fe isotope signatures.

A 19-year long energy budget of an upland peat bog, northern England

Worrall, F.[1], Clay, G.[2], Moody, C.[1], and Burt, T.[3]
[1]University of Durham, Earth Sciences, Durham
[2]University of Manchester, Geography, Manchester
[3]University of Durham, Geography, Durham

Academic Staff 057

This study has estimated the long term evaporation record for a peat covered catchment in northern England. In this study, 19 years of daily evaporation were estimated for rain-free periods using White's methods. Net radiation was measured over the study period; soil heat flux was calculated from temperature profiles; and sensible heat flux was calculated assuming the energy budget was closed. The calculated time series was compared to available environmental information on the same time step and over the same time period. Over a 19-year period it was possible to calculate 1662 daily evaporation rates (26% of the period). The study showed that the energy flux to net primary productivity was a small, long-term sink of energy but this sink was a virtue of high carbon accumulation in peat catchments: in catchments where there is no long-term dry matter accumulation, net primary productivity must be a small net source of energy. The study showed that evaporation increased over the study period whilst sensible heat flux significantly declined with the ecosystem became a stronger heat sink reflecting an increased use of sensible heat energy to meet evaporative demand. The relatively small change in evaporative flux compared to other energy fluxes suggests that this system is a "near-equilibrium" system and not a "far-from-equilibrium" system.

Understanding multiple element budgets of peatlands – stoichiometry, enthalpy and entropy

Worrall, F.[1], Clay, G.[2], Moody, C.[1], and Burt, T.[3]
[1]University of Durham, Earth Sciences, Durham
[2]University of Manchester, Geography, Manchester
[3]University of Durham, Geography, Durham

Academic Staff 058

A few studies have considered the carbon budget of peatlands; fewer studies have considered the N budget of peat soils. None have considered both together, and furthermore, it is possible to include the oxygen; energy budgets; and even the transfer of entropy. By including the elemental and energy content of a range of organic matter transfers a range of types of flux the study can not only comment on the overall stoichiometry of the ecosystem but also constrain fluxes and predict the likely direction of change in response to ongoing climate change. This study has shown:

1. Over the 13-year study period, the total carbon balance varied between a net sink of -20 to - 91 tonnes C/km^2/yr.
2. Overall, the total N budget of the peat ecosystem varies from -1.0 to +2.5 tonnes N/km^2/yr, i.e. some years the ecosystem is a net source of N:
3. Oxidation state (Cox) decreases through the profile with DOC and POC fluxes acting as additional means of removing oxidised carbon:
4. By combining elemental and energy budgets it is possible to write stoichiometric equations for the ecosystem
5. By understanding the energy content; composition and stoichiometry of components of the organic matter it is possible to constrain processes such as the extent of soil respiration.

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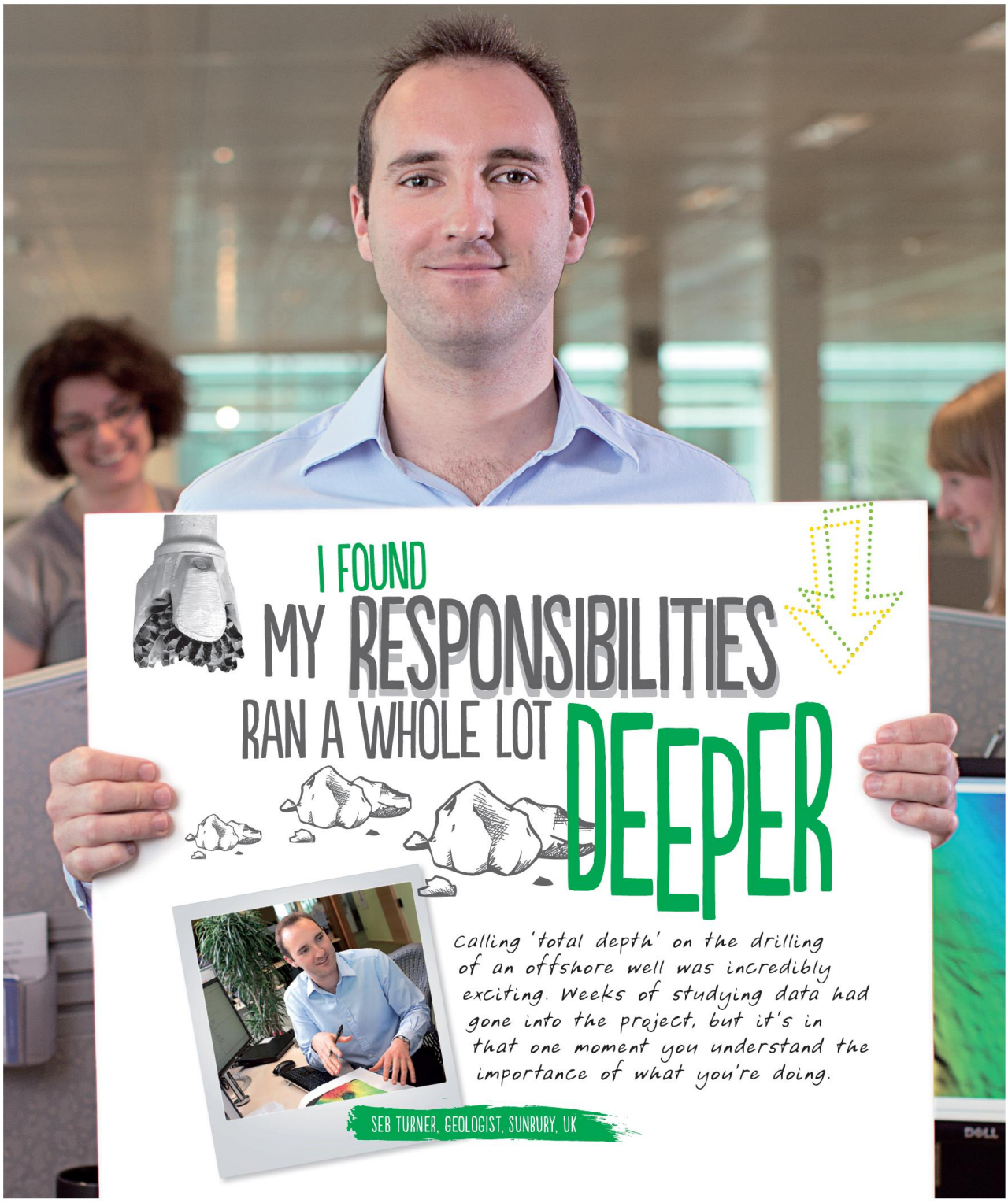

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Posters/Lunch

Environmental

Paleontology

Sedimentary/Hydrocarbons

Structural/Geophysics

Volcanology/ Geochemistry/Petrology

	TR 3	TR 4
09:15-09:30	Kitteringham, J.D.	Bray, P.E.
09:30-09:45	Greener, J.W.	Brett, J.A.N.
09:45-10:00	Barnard, O.M.	Wille, J.E.
10:00-10:15	Whild, H.	Edey, A.J.
10:15-10:30	Pratt, N.	Robson, R.E.M.
10:30-11:00	**Coffee**	**Coffee**
11:00-11:15	Rosin, T.	White, S.
11:15-11:30	Bartholomew, J.	Sanderson, H.C.
11:30-11:45	Taylor, J.	Murray, R.P.
11:45-12:00	Emerson, H.	Stillings, M.D.
12:00-12:15	Landon, E.N.U.	Unwin, R.H.
12:15-12:30	Smith, H.E.	
12:30-14:00	**Poster Session I/Lunch**	**Poster Session I/Lunch**
14:00-14:15	Boughey, S.S.	Cole, R.P.
14:15-14:30	D'Souza, B.	Cromwell, E.J.
14:30-14:45	Gale, W.J.	Dey, S.M.
14:45-15:00	French, G.R.	Haddock, D.G.
15:00-15:15	Santamas, A.A.	Sharp, M.J.
15:15-15:30	Shorey, J.E.	Plumstead, J.
15:30-17:00	**Poster Session II/Drinks**	**Poster Session II/Drinks**

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